BEST PRACTICE APPROACHES TO THE STUDY OF COGNITIVE FUNCTIONING AND PHYSICAL ACTIVITY/SPORTS

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The Development of Motor and Pre-literacy Skills by a Physical Education Program in Preschool Children: A Non-randomized Pilot Trial

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It is known in the literature that fundamental motor skill acquisition is strongly associated with the development of neuromotor, cognitive, social, and emotional aspects in childhood. Unfortunately, in Italy, the physical education teacher is not included in the school's core personnel, and it is very hard to find a specific physical education program (PEP) that could improve preschool children's motor and cognitive status. The aim of this study was to investigate whether the quotient of gross motor development (QGMD) and pre-literacy skills concerning visual analysis and spatial orientation abilities changed after 16 weeks of PEP (2 h/week) in preschool children. We conducted a school-based non-randomized pilot trial. It involved 119 preschool children, clustered in a control group [CG, n = 29, body mass index (BMI): 16.90 ± 3.16 Kg/m^2] and an intervention group (IG, n = 90, BMI: 16.00 ± 1.75 kg/m^2). Participants were assessed for literacy readiness, locomotor and object control skills before and after the experimental period. IG increased the locomotor, object-control skills and QGMD in response to PEP. As concerns the pre-literacy domain, no significant difference was found in visual analysis and spatial orientation skills between IG and CG groups. However, we detected improvements from baseline to post-test in IG children.In conclusion, this study contributes additional evidence suggesting how a PEP could affect not only motor skills, but also cognitive ones. Consistently with the growing research, interventions based on structured ludic-motor activities ensure health benefits for preschool children.

Clinical Trial Registration: www.ClinicalTrials.gov, identifier NCT01274117.

Keywords: physical activity, education, fundamental motor skills, pre-literacy skills, childhood, exercise, health

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INTRODUCTION

Motor skill development influences the entirety of a child's growth (Barnett et al., 2008). Numerous studies have reported that fundamental motor skill acquisition is clearly associated with the development of neuromotor, cognitive, social, and emotional skills in childhood (Gallahue et al., 2003; Lubans et al., 2010; Cameron et al., 2012; Logan et al., 2012; Lloyd et al., 2014; Diamond, 2015;

Oberer et al., 2017; Van Capelle et al., 2017; Taunton et al., 2018). As concern the cognitive domain, recently, positive effects of motor programs on pre-literacy skills have been demonstrated in pre-school age (Diamond, 2015; Callcott et al., 2018). These links among motor and cognitive domains are due to a similar developmental timetable in motor and cognitive development as well as to the fact that motor and cognitive tasks stimulate the co-activation of the prefrontal cortex, cerebellum and basal ganglia (Carson et al., 2015; Diamond, 2015). However, because of the complexity of children's gross motor skills, it is very hard to find specific physical education (PE) programs that could improve a child's motor or cognitive status.

Gross-Motor Development

The combinations of basic movement patterns of two or more body segments may be categorized as stability, manipulative or locomotor skills. Stability motor skills incorporate dodging, dynamic or static balance, and turning; manipulative skills include catching, kicking, striking, and throwing; whilst examples of locomotor skills include sprinting, jumping, and leaping (Donnelly et al., 2009). However, it is known that there is progressive decay along the years in gross motor coordination of children (Roth et al., 2010) following insufficient and unstructured physical activity (PA). Motor development is a critical component of preschool and elementary school PE from ages two through six or seven. Early PA is an encouraging alternative for the improvement of gross motor skills and education for an active lifestyle in preschool children (Lubans et al., 2010). This type of educational area considers the sensory, emotional, motor, social, and cognitive development of children in accordance with a holistic pedagogic approach (Roth et al., 2010). It is, indeed, a very integrative way to support children in their development. Parents and peer support, PA preferences, behavioral intentions and program/facility access can affect participation in the PA. However, adequate motor skill competence in early childhood has been suggested to be a relevant prerequisite for children's involvement in PA later in life (Lloyd et al., 2014; Loprinzi et al., 2015). Several authors showed that regular PE could stimulate the development of self-competence, social aptitude and ability in dealing with materials and contents of everyday life in childhood (Pentimonti et al., 2016). According to several studies, fundamental motor skills such as running, jumping, kicking, throwing and catching, lay the basis for success in cognitive (Vukovic et al., 2010; Diamond and Lee, 2011), physical and sport skills (Battaglia et al., 2014). Fundamental motor skills do not develop automatically. The psychophysical development alone may lead children to acquire basic gross motor skills but PE, encouragement, and instruction by the physical education teacher are needed to mature advanced gross motor skill patterns (Gallahue et al., 2003, 2012). Moreover, several authors found that a structured PE program is more efficient than free play activities (Logan et al., 2012). Unlike other European countries, Italian preschools do not include the PE teacher as part of the school's core staff. This is frequently associated with a lack of opportunities to perform PE by preschool children without the intervention of local institutions such as municipalities, universities or volunteers' associations.

Pre-literacy Development

Recent empirical evidence showed beneficial short- and long-term effects of PA programs not only on motor skill development but also on cognitive growth (Diamond, 2015; Alesi et al., 2016). In their systematic review on PA and cognitive development, Carson et al. (2015) argued that an increase in PA frequency, intensity and duration "…had significant beneficial effects on 67% of the cognitive development outcomes assessed in the executive function (EF) domain and 60% in the language domain" (Carson et al., 2015). This relationship is explained in light of PA effects such as the activation of the prefrontal cortex, the cerebellum and the basal ganglia, the increase in brain-derived neurotrophic factor (BDNF) and the triggering of inhibitor control, planning, and monitoring processes (van der Fels et al., 2015). As a consequence, cognitively engaging motor programs have been planned to improve cognitive development in childhood (Moreau et al., 2017). A range of studies have provided evidence that play-based situations and motor exercise programs improve cognitive development by acting positively on EFs from kindergarten (Lakes et al., 2013; Pesce et al., 2016). EF is defined as higher order cognitive processes, such as inhibition, shifting, updating, fluency, and planning, that are important prerequisites for school readiness. In detail, the ability to control and repress a response in favor of another response or no response, the ability to switch the attention from one task to another, the ability to manipulate mental representations and items stored in working memory, and the ability to plan learning actions, together contribute to enable children to be cognitively competent and able for later literacy and numeracy achievements in primary school (Moffitt et al., 2011; Miyake and Friedman, 2012; Alesi et al., 2018).

Beneficial effects of PA programs on pre-literacy skills have also been demonstrated in kindergarten age (Barnett et al., 2008; Callcott et al., 2018).

Pre-literacy is an umbrella term for a set of predictors of later literacy achievement. These skills are oral language abilities, such as vocabulary, comprehension and listening, alphabetic abilities such as phonological/phonemic awareness and knowledge/understanding about print and its use (Puranik and Lonigan, 2011; Pinto et al., 2016). In particular, phonological awareness and knowledge of the alphabet are two of the strongest predictors of reading and writing acquisition in Italian children because of the transparent nature of their mother language. Phonological awareness refers to the ability to understand that spoken words have a sound structure and involves word, syllable, onset/rhyme and phonemic awareness. As a consequence, the phonological awareness enables preschool children to identify, analyze, and manipulate the word and its sub-components (Gibbs, 2004). Alphabet knowledge refers to the ability for letter-naming and letter-sound knowledge. Letter-name knowledge enables pre-school children to reach letter-sound knowledge and, consequently, grapheme-phoneme conversion (Duncan and Seymour, 2000; Gallagher et al., 2000). Another important pre-literacy set involves visual and visuo-spatial skills, such as the ability for visual analysis and discrimination, spatial orientation and sequential eye movements. Rapid visual processing makes grapheme and phoneme identification easier, with positive consequences on later reading and writing acquisition (Cornoldi et al., 1994).

Recently, preschool-based programs including PA activities and aiming to improve pre-literacy skills have been developed. For example, Bedard et al. (2017) implemented a movement and pre-literacy program of 60 min per week over 10 weeks. This involved pre-school age children and consisted of fundamental movement skills tasks, free-play activities with balls, steps, bricks or puzzles, and a storybook reading activity shared among children and their parents. The authors found that this parent-oriented movement and pre-literacy program was able to improve motor proficiency as well as literacy skills concerning print-concept and alphabet knowledge (Bedard et al., 2017).

Kirk and Kirk (2016) developed a PA program to be carried out by classroom teachers to preschool children over 8 months. This comprised 60 min of moderate PA units (two times per day) combining motor and early literacy tasks aimed at training oral language, vocabulary and phonological awareness. For example, dedicated motor activities such as acting words, jumping, running, moving on lines, and marching were used to improve rhyming, alliteration and picture naming (Kirk and Kirk, 2016). However, in our knowledge, many studies lack of a structured and reproducible *Physical Education Program* (PEP) that includes specific activities, timing and duration. Based on these issues, the aim of this study was to explore the effects of a specific 16-week-long PEP on the development of gross motor and pre-literacy skills concerning visual analysis and spatial orientation skills in preschool children with a psychomotor, fun and enjoyable approach.

MATERIALS AND METHODS

Participants

In agreement with McGee et al. (2016) a school-based non-randomized trial was conducted to evaluate the effect of a pilot PEP on preschool children's gross motor skills (Gallahue et al., 2003, 2012; McGee et al., 2016). This study has been recently developed within the Training-to-Health Project financed by Municipality of Palermo. Due to funding requirements, PEP was carried out in several pilot preschools within the Palermo City Council administrative boundaries. A preschool with demographic characteristics (age, sex, socioeconomic characteristics) similar to the enrolled playschools was recruited in Palermo and used as the control. In particular, the catchment areas of these schools were predominately of middle socioeconomic status as judged by employment and education.

Insufficient funding or perceived benefits associated with participation in the study by children and parents at the control site made the number of control preschoolers very small. However, we used them as the control group because they showed similar demographic characteristics to the children enrolled in the intervention. Need for educational support or disability was considered an exclusion criterion. Once preschools had given written informed consent to participate in the study, all Year 3.5 preschool children were invited to take part in the experiment and were tested before and after the experimental period.

This study involved 119 children who were clustered in a control group [CG, n = 29, age: 52.1 ± 8.65 months; height: 1.10 ± 0.07 m, body weight: 19.20 ± 5.55 kg, body mass index (BMI): 16.90 ± 3.16] and an intervention group (IG, n = 90, age: 57.4 ± 9.42 months; height: 1.10 ± 0.06 m, body weight: 19.30 ± 3.65 kg, BMI: 16.00 ± 1.75). Moreover, 62.10% males and 37.90% females composed the CG. Similarly, 55.60% males and 44.40% females composed the IG. The study was approved by the Ethical Board of the University of Palermo (N. 2/2018) and conformed to criteria for the use of persons in research as defined in the Declaration of Helsinki (Trial Registration: NCT03454061 retrospectively registered 2 March 2018). Given that the participants were minors, parents or legal guardians provided their written informed consent to participate in this research. All children participated voluntarily and could withdraw from the study at any time.

Anthropometric Measurements

Height and body weight were measured according to standard procedures (Lohman et al., 1988) using a stadiometer (maximum height recordable, 220 cm; resolution, 1 mm) and a Seca electronic scale (maximum weight recordable, 300 kg; resolution, 100 g; Seca Deutschland, Hamburg, Germany). Body mass index was calculated using the formula: weight in kilograms (kg) divided by height in squared meters (m^2).

The Physical Education Program

The PEP, based on the psychomotor approach, was done in a group setting and based on useful, goal-directed training, practicing activities of relevance for a preschool child. The program lasted 16 weeks and was applied twice a week by a physical education specialist (PES), who also had experience with preschool children. Teachers were involved in the goal-setting process and cooperated with PES to carry over the activities safely. Before intervention, PES and teachers have followed a training course concerning the aims, methodology and evaluation of PEP in order to make the intervention uniform for all children.

PEP included activities with specific aims developing body awareness, fundamental motor and perceptual-sensory skills of preschool children (see **Figure 1**). Each lesson (see **Table 1**) lasted about 60 min and included the following parts: a warm-up and social interaction phase (about 5 min), enhancing children's fitness level and their motivation to participate; a central phase (about 50 min), including the scheduled activities; and a cool-down and feedback phase (about 5 min), to relax the children and explore their satisfaction levels. In the central phase the number of sets, repetitions and complexity of schedule-related exercises were gradually increased when children were able to perform them easily. Each lesson was structured in the form of scheduled play that emphasizes enjoyment and participation in several play

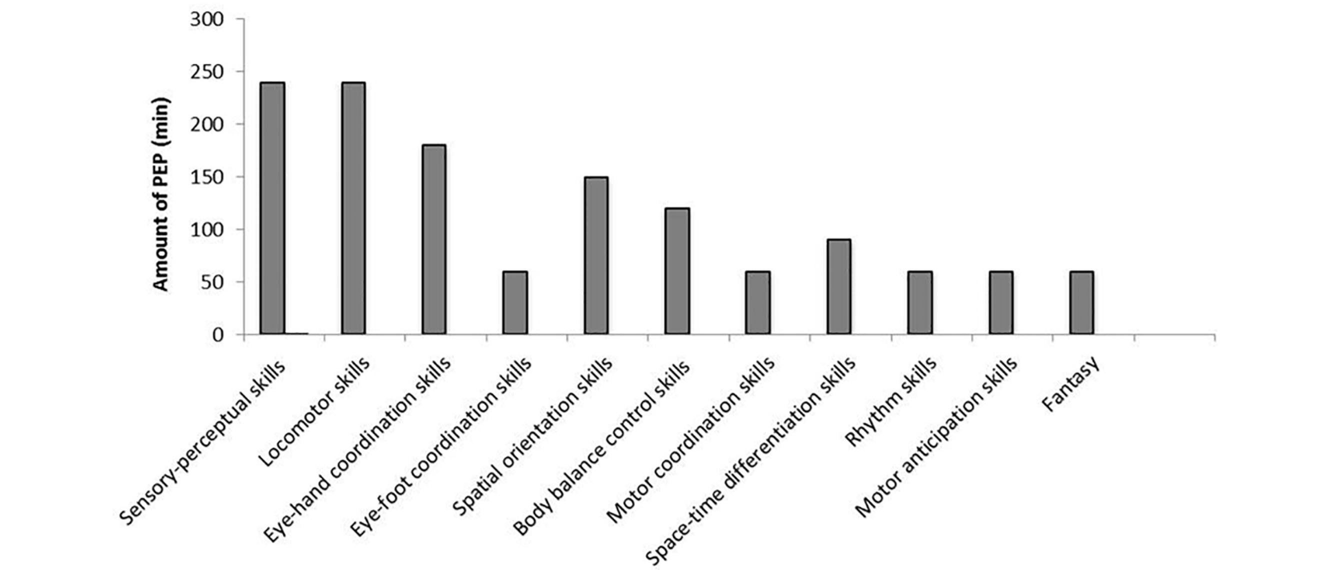

FIGURE 1 | Description of Battaglia's physical education program.

TABLE 1 | Brief description of a week of Battaglia's Physical Education Program.

	Phase	Aims	~Min	Example of activity
1st	Warm-up and social interaction phase	Enhancing children's fitness level and their motivation to participate	5–10	Circle time: after a greeting, children sitting take turns must wave their hand and add a movement like wiggling their nose.
		Sensory-perceptual skills	10	Improvisation with body shapes
		Locomotor skills	10	Running, jumping, and galloping activities.
		Eye–hand coordination skills	5	Catch a ball and throw a ball with the hand
		Eye–foot coordination skills	5	Kick a soft ball running
		Spatial orientation skills	5	Team games with various tempos
		Motor coordination skills	5	Change locomotor skills or space elements according to the different stimuli.
		Rhythm skills	5	Running according to several rhythm
	Cool-down and feedback phase	To relax the children and explore their satisfaction levels	5	Circle time: Calming Breathing activities
2nd	Warm-up and social interaction phase	Enhancing children's fitness level and their motivation to participate	5–10	Circle time: Children's names with clapping.
		Sensory-perceptual skills	10	Reactions to simple rhythmic motives produced by the PES
		Locomotor skills	10	Walking and running, individually or in pairs
		Eye–hand coordination skills	5	Catch and throw a different balls (weight, dimensions, materials)
		Spatial orientation skills	5	Movement change in each stimulus change
		Body balance control skills	5	Walking over unstable surfaces (e.g., pillows on the floor) that make the trunk work hard to maintain an upright position.
		Space-time differentiation skills	5	Use of different space levels according to different intensity.
		Motor anticipation skills	5	Movement responses to different temporal Stimuli
	Cool-down and feedback phase	To relax the children and explore their satisfaction levels	5	Circle time: Calming Breathing activities

PES, physical education specialist.

actions (Pesce et al., 2016). Gross motor skill acquisition was focused by means of developmentally appropriate tasks (Giblin et al., 2014) in order to promote transfer effects between PA and spontaneous play. PES used hands-on discovery and problem-solving heuristic learning modalities in order to strengthen the effectiveness of such a program targeted on the preparation and the scheduled play. The CG participated in classroom activities for the same amount of time as the IG with teachers. Both groups performed the activities during the school period in a multi-activity area.

Evaluation of Gross Motor Development

Participants were assessed for object control and locomotor skills by the Italian version of gross motor development test (Ulrich, 2003). This test examines two different sides of gross motor development, i.e., object control (bounce the ball, catch the ball, catch a ball with a tennis racket, and running while kicking a ball and throwing a ball) and locomotion (requiring subjects to run as fast as possible for 15 m, jump forward, gallop for 10 m, hop on one leg for 5 m, do a long jump, and take little jumps forward and laterally). Scores of two subtests were summed and converted to a combined quotient of gross motor development (QGMD). Children were tested individually and encouraged to produce their maximum effort (e.g., jump far). A digital video camera videotaped all their performances. Before observations, two observers were previously trained on videotapes of children in order to analyze movement sequences and to assign scores. To obtain a higher validity, according to the handbook, each child performed three trials of each skill and acquired a "1" mark, when a criterion performance was executed two out of three times, or a "0" grade, when a criterion was not observed or was used inappropriately two out of three times. The sum of the scores found for each item (maximum total score 48) was converted into standard scores according to the age level of the child. We assessed the gross motor development level based on QGMD scores suggested by the manual, i.e., 131–165 (very high motor ability, VH-MA), 121–130 (high motor ability, H-MA), 111–120 (over average motor ability, OA-MA), 90–110 (average motor ability, A-MA), 80–89 (below average motor ability, UA-MA), 70–79 (low motor ability, L-MA), and 35–69 (very low motor ability, VL-MA).

Evaluation of Pre-literacy Skills

Pre-literacy skills were measured through the PRCR-2/2009 (Cornoldi et al., 2009). This is an Italian battery of standardized tasks aimed at measuring general and specific prerequisites to later reading and writing abilities in preschool children. Four tasks were derived from the PRCR-2/2009 Battery and used in the present study: (1) Printed letters identification; (2) object naming; (3) partially hidden object naming; and (4) pointed object naming. We selected only measures concerning visual analysis and spatial orientation skills because they were considered more closely related to movement activities included in PEP.

The printed letters identification task measured visual analysis ability and spatial orientation. It was composed of a sheet with 12 target letters printed on the left and four letters for each target (the target and three distractor letters) printed on the right. A child was required to identify and cross the target letter. The number of errors for the task was recorded. The final score was obtained by adding together the number of errors.

The object naming task measured linguistic proficiency, visual attention and the sequentiality of eye movements. It was composed of 30 objects in five sequences of six objects for each. The objects were for example animals (mouse, cat, chick), flowers, ice-cream, the sun, stars, etc. The partially hidden object naming task measured linguistic proficiency, visual attention and discrimination, and the sequentiality of eye movements. It was composed of the three sequences of objects that appeared in the objects naming task, but the objects were overlapping and smaller. The pointed object naming task measured the visuo-perceptual ability to identify a figure from the background, linguistic proficiency, visual attention and discrimination, and the sequentiality of eye movements. It was composed of the two sequences of overlapping objects that appeared in the partially hidden object naming task with four objects for each sequence marked by a dot at 15 mm. For measures relating to the last three tasks, a child was required to rapidly name the marked objects from left to right and from the top to bottom. The number of errors for the task was recorded. The final score was obtained by adding together the number of errors.

Data Analysis

Means and standard deviations (SD) were calculated to describe the sample characteristics. Analysis of *gain scores*, also called *change scores* or *difference scores*, was used to test for the effect of treatment; unpaired Student's t-tests were used to compare the post- and pre-test difference in scores between the control and intervention groups (Allison, 1990; Ragosa, 1995; Oakes and Feldman, 2001). Since baseline differences between groups existed at pre-test, analysis of covariance (ANCOVA) was applied as an alternative to analyze the scores. We used the post-test gross motor and pre-literacy scores as the dependent variable, the control/intervention group as independent variable and the pre-test score as covariate. ANCOVA focuses on differences between the groups at post-test while holding constant pre-test differences. In all the analyses, the level of significance was set at $p < 0.05$. Statistics were performed by using STATA/MP 12.1.

RESULTS

At baseline, CG and IG did not show any significant differences ($p > 0.05$) in terms of sex, chronological age, weight, height, BMI and gross motor profile, as shown in **Table 2**.

After the experimental period, CG did not exhibit any significant difference in locomotor, object-control skills or QGMD scores. In contrast, the intervention group showed significant differences ($p < 0.001$) from baseline to post-test in

TABLE 2 | Characteristics of preschool children.

	Control group				Intervention group			
	Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (mo)	52.1	8.65	56.1	8.6	57.4	9.42	61.2	9.5
Height (m)	1.1	0.07	1.1	0.07	1.1	0.06	1.1	0.07
Weight (kg)	19.2	5.55	20.63	5.78	19.3	3.65	19.5	3.75
BMI (kg/m^2)	16.9	3.16	17.50	3.04	16.0	1.75	15.5	3.49

mo, moths; BMI, body mass index.

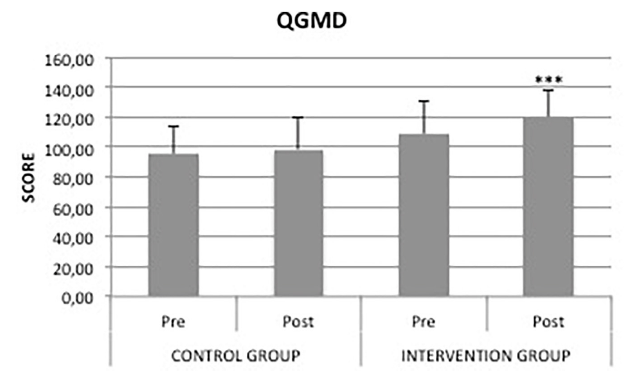

FIGURE 2 | Score of gross motor development quotient in control and intervention group. ***$p < 0.01$, compared with pre-test.

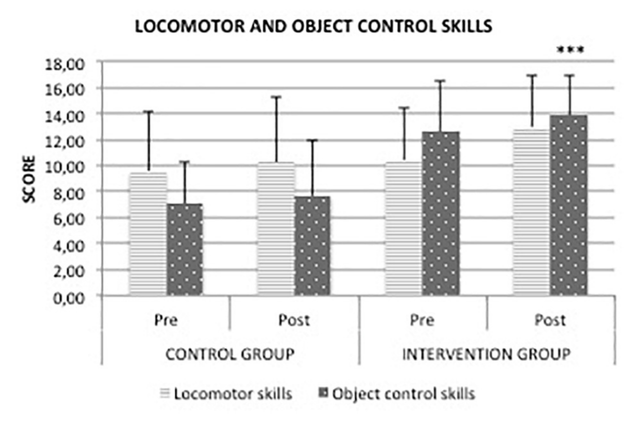

FIGURE 3 | Score of locomotor and object control skills after 16 weeks of physical education program. ***$p < 0.01$, compared with pre-test.

gross motor skills. As shown in **Figures 2**, **3**, locomotor, object-control skills and QGMD increased by 24.4%, 9.7%, and 10.4%, respectively, in IG. Moreover, the mean difference of QGMD between pre- and post-intervention in IG was significantly higher than that in CG (11.3 vs. 3.2, $p = 0.0082$). These results confirmed preliminary results previously reported (Battaglia et al., 2018). The same result occurred for the locomotor skills, showing a significant mean difference of 2.5 in IG compared to the 0.7 in CG ($p = 0.0050$). The analysis of covariance confirmed the positive effect of the intervention in the improvement of children's gross motor skills, starting even from different pre-test scores.

Table 3 displays that specific items of locomotor and object control skills did not increase in the control group after the experimental period, while a highly significant increase was observed in all the items in IG in response to PEP.

All pre-literacy skills significantly improved in IG after the intervention period, while in CG only the number of errors on the naming of objects significantly decreased (see **Table 4**). However, the analyses of gain scores and ANCOVA did not show any significant effect from the intervention between CG and IG.

DISCUSSION

This study investigated the effects of a specific PEP on the outcomes of fundamental motor and pre-literacy skills concerning visual analysis and spatial orientation abilities in a sample of preschool children from Palermo. Gross motor development was expressed as a composite score of a set of fundamental motor skills across the two gross motor skill domains. We observed a positive effect of PEP on gross motor development in the studied population. In particular, IG showed a significant increase in both locomotor ($p < 0.001$) and object control skills ($p < 0.001$) compared with CG after PEP. These findings are consistent with those of previous studies that investigated the effect of PE on preschoolers' gross motor skills (Derri et al., 2001; Alesi et al., 2014; Hestbaek et al., 2017). For instance, Derri et al. (2001) concluded that preschool children who performed PEP with rhythmic accompaniment enhanced significantly their motor performance. Analysis of the covariance and *gain scores* confirmed the positive effect of our intervention in the rise of children's gross motor skills, even starting from different pre-test scores. The use of gain scores or ANCOVA has been largely debated in the past in the analysis of pre-test/post-test designs. While the ANCOVA is suitable only for randomized controlled trials and can bias results in non-equivalent groups or observational designs, the analysis of *gain scores* provides for appropriate, unbiased tests for most research designs (Ragosa, 1995). In the absence of randomization, when baseline differences between groups exist, change-score models yield less biased estimates (Allison, 1990). Based on QGMD scores suggested by the manual's instructions, we found that IG increased the gross motor abilities from average to above average compared with CG, which did not show any relevant change. In addition, the organization of a single lesson in several sub-phases (social-warm up, central, cool-down-feedback phase) was a suitable way to improve children's participation. By control of class log, we found that children attended at least 80% of the PEP. In agreement with several studies in the literature, the difference in the ability levels between locomotor and object control skills might be associated with the maturation of the nervous system and sensory-perceptual and motor experiences of children (Ragosa, 1995). In particular, it is well known that there are critical time courses for rapid development of learning early in a child's life. Vasudevan et al. (2011) showed that the development of temporal and spatial motor adaptation respects different periods, with spatial adaptation maturing through childhood (up to age 12 years), whereas temporal adaptation matured by the age of 3 (Vasudevan et al., 2011). Moreover, according to a holistic pedagogic approach, gross motor skills develop within an all-inclusive system that is affected by relations among the learner, task and environment. PES used hands-on discovery and problem-solving heuristic learning modalities in order to amplify the effectiveness of the described PEP centered on deliberate play and preparation. According to Pesce et al. (2016), the promotion of the spontaneous play by means of these modes of learning is essential in physical and functional contexts, such as in school and on the playground (Pesce et al.,

TABLE 3 | Evaluation of locomotor and object control skills after the physical education program.

	Control group					Intervention group				
	Pre		Post			Pre		Post		
	Mean	SD	Mean	SD	*p*-Value	Mean	SD	Mean	SD	*p*-Value
Locomotor skills	**9.52**	**4.69**	**10.24**	**5.08**	***0.2058***	**10.42**	**4.06**	**12.96**	**3.91**	***0.0000***
Running	2.00	1.34	2.41	1.24	*0.0695*	2.90	1.06	3.51	0.71	*0.0000*
Galloping	1.59	1.15	1.55	1.35	*0.8728*	2.18	1.33	3.02	1.14	*0.0000*
Hopping	0.90	1.05	1.07	1.16	*0.2584*	2.00	1.34	2.63	1.34	*0.0000*
Leaping	1.00	0.93	0.90	0.94	*0.1843*	1.41	1.03	1.86	1.02	*0.0000*
Horizontal jumping	1.52	1.09	1.34	1.26	*0.2584*	2.48	1.12	3.02	1.04	*0.0000*
Skipping	0.76	0.69	1.07	1.00	*0.0475*	1.51	1.05	1.97	1.05	*0.0000*
Sliding	1.76	0.91	1.90	1.17	*0.4238*	2.67	1.03	3.2	0.93	*0.0000*
Object control skills	**7.07**	**3.19**	**7.66**	**4.23**	***0.3326***	**12.61**	**3.84**	**13.83**	**3.14**	***0.0002***
Two-hand striking	1.59	1.30	1.55	1.52	*0.8564*	1.52	1.27	2.28	1.34	*0.0000*
Stationary bouncing	1.03	0.73	0.90	0.86	*0.3548*	1.06	0.98	1.69	1.07	*0.0000*
Catching	1.59	0.98	1.83	1.04	*0.2568*	2.43	1.15	3.1	1.07	*0.0000*
Kicking	1.21	0.56	1.55	1.02	*0.0961*	2.17	1.32	2.8	1.29	*0.0000*
Overhand throwing	1.66	1.14	1.83	1.17	*0.3053*	2.26	1.17	2.72	1.20	*0.0002*

TABLE 4 | Evaluation of pre-literacy skills after the physical education program.

	Control group				Intervention group			
	Pre		Post		Pre		Post	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Printed letters identification (number of errors)	3,7	2,50	3,6	2,73	3,3	2,76	2,6*	2,83
Objects naming (time)	79,9	37,01	76,4	32,29	69,9	23,93	61,8***	24,27
Objects naming (number of errors)	2,2	1,61	1,2***	1,20	1,5	1,56	1,0***	1,40
Partially hidden objects naming (time)	120,7	47,96	109,7	35,34	121,1	58,64	92,0***	28,00
Partially hidden objects naming (number of errors)	5,3	4,13	4,2	3,71	4,2	3,39	2,6***	2,29
Pointed objects naming (number of errors)	2,6	2,18	2,0	1,72	2,0	1,65	1,4***	1,50

**Asterisk indicates significant difference between pre- and post-test in CG and IG (evaluated by paired Student's t-test), *p < 0.05, ***p < 0.001.*

2016). Our PEP positively affected preschoolers' health status indicators. From baseline to post-test we found a relevant QGMD increment in IG compared to CG. This result is consistent with growing research demonstrating how interventions based on scheduled physical exercise are key elements to ensure health benefits for preschool children. As can be seen in **Figure 1** and **Table 1**, we included several specific activities in order to increase gross motor skills in IG. In particular, PEP was made up of 70% of activities improving fundamental motors skills. Scheduled activities never consisted of simply imitating physical movements but always prompted the children to adapt creatively. Furthermore, children were invited to find their own solutions for the tasks they were encountered. High levels of fundamental motor skills are very important to promote children's participation in several types of sports and physical activities, and childhood is a delicate learning period for gross motor development (Gallahue et al., 2003; Pesce et al., 2016). To the best of our knowledge, no studies have addressed this question with preschool children.

As concerns the pre-literacy domain, no significant difference was found on visual analysis and spatial orientation skills (printed letter identification; object naming; partially hidden object naming; pointed object naming) between IG and CG groups. However, we detected improvements from baseline to post-test in IG children. In this group, the significant decrease of errors or times of execution on all pre-literacy tasks revealed significant improvements on the abilities of visual analysis, visual attention, visual discrimination, spatial orientation and linguistic proficiency. Meanwhile, in CG children only the number of errors on the objects naming task decreased in a significant way showing an improvement from baseline to post-test. This is probably due to growth and maturation processes, which are very quick at this age. All together these findings corroborate the hypothesis that PEP would positively influence the abilities belonging to the cognitive domain by training visuo-spatial abilities. This is a result that has been well-documented in previous research reporting how PA effects memory, perceptual performances and learning outcomes in preschool children (Zeng et al., 2017). In their systematic review on PA and cognitive development during early childhood, Carson et al. (2015) argued that an increase on PA frequency, intensity and duration had significant beneficial effects on EF and language domain

(Carson et al., 2015). The lack of significant differences between the IG and CG would be due to a limited number of exercises specifically targeting pre-literacy skills. This interpretation suggests the need to revise PEP by enlarging the number of pre-literacy activities. A further revision could include ludic-motor activities enriched by neuropsychological EF tasks (i.e., Animal Stroop test, fruit Stroop test, body WM, fluency with ballgames . . .) to improve EFs such as inhibitory control, updating, cognitive fluency and planning. Moreover, it would be advisable to add ludic-motor activities to stimulate and enhance linguistic pre-literacy skills. Nevertheless, a methodological shortcoming of the current study is that it administered only visual analysis and spatial orientation measures. The method needs to be enlarged by using larger measures for literacy readiness, such as phonological awareness and alphabet knowledge.

There are several challenges in developing evidence-based motor education guidelines for preschoolers that can promote physical well-being in childhood age. However, several gaps are present in the literature about structured PEPs for preschool children. The present pilot study explored the effects of a specific PEP on the development of locomotor and object control and pre-literacy skills in preschool children. This represents a point of strength for the study. However, the non-randomized design and the relatively small number of children in the CG limited the study. We used a school-based non-randomized trial in agreement with McGee et al. (2016) because the study was carried out within the Train-to-Health Project financed by Municipality of Palermo (McGee et al., 2016). The small number of control preschoolers resulted from insufficient incentives or perceived benefits associated with participation in the study by children and parents at the control site. However, we used them as the control group because they showed similar demographic characteristics to the enrolled IG children. Another limit of the study was that neither the participants nor the research team could be blinded to the intervention because of the practical nature of the school-based non-randomized trial. In several countries, researchers have recently developed PE guidelines for children in preschool years, but there are notable contradictions in the typology and amount of PA. Moreover, the rationale for using a PEP with the sole purpose of seeing its effects on cognitive performance requires more explanation.

CONCLUSION

The results indicated that a PE intervention conducted by PE specialists was effective in significantly raising the levels of gross-motor development in IG compared to CG children and pre-literacy skills only in the IG. This pilot study contributes additional evidence suggesting how a PE program could affect not only motor skills, but also cognitive ones. This is intriguing because it underlines a generalized effect of motor improvement on other developmental areas.

As it concerns the educational implications, the implementation of a ludic-motor program as a part of the school lessons is an issue to be explored. In Italy, PE teachers are not included in the school's core staff at preschools. There is an urgent need for evidence-based studies to suggest guidelines and develop community-targeted programs to ensure healthy levels of PA in order to improve motor and cognitive skills in childhood age. The results from this school-based non-randomized trial are directly transferable to school administrators who wish to increase physical education participation.

As it concerns the research implications, the future goal of our research will be to scale up the study, both in terms of sample size, randomization and tested skills, investigating the effects of our PEP on lifestyle, and cognitive functions.

AUTHOR CONTRIBUTIONS

GB and MA conceived the study, participated in its design and coordination, performed aspects of the measurement and of the PEP, participated in the interpretation of the data, and drafted much of the manuscript. GT conducted the statistical analyses and participated in interpretation of the data. AP participated in the interpretation of the data and guided the study. MB participated in the design and coordination of the study and participated in the interpretation of the data. All authors read and approved the final manuscript.

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Football Players Do Not Show "Neural Efficiency" in Cortical Activity Related to Visuospatial Information Processing During Football Scenes: An EEG Mapping Study

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This study tested the hypothesis of cortical neural efficiency (i.e., reduced brain activation in experts) in the visuospatial information processing related to football (soccer) scenes in football players. Electroencephalographic data were recorded from 56 scalp electrodes in 13 football players and eight matched non-players during the observation of 70 videos with football actions lasting 2.5 s each. During these videos, the central fixation target changed color from red to blue or vice versa. The videos were watched two times. One time, the subjects were asked to estimate the distance between players during each action (FOOTBALL condition, visuospatial). Another time, they had to estimate if the fixation target was colored for a longer time in red or blue color (CONTROL condition, non-visuospatial). The order of the two conditions was pseudo-randomized across the subjects. Cortical activity was estimated as the percent reduction in power of scalp alpha rhythms (about 8–12 Hz) during the videos compared with a pre-video baseline (event-related desynchronization, ERD). In the FOOTBALL condition, a prominent and bilateral parietal alpha ERD (i.e., cortical activation) was greater in the football players than non-players ($p < 0.05$) in contrast with the neural efficiency hypothesis. In the CONTROL condition, no significant alpha ERD difference was observed. No difference in behavioral response time and accuracy was found between the two groups in any condition. In conclusion, a prominent parietal cortical activity related to visuospatial processes during football scenes was greater in the football players over controls in contrast with the neural efficiency hypothesis.

Keywords: football (soccer) players, electroencephalography, alpha rhythms, visuospatial information processing, parietal cortex, neural efficiency, situational awareness

INTRODUCTION

Previous neuroimaging studies using positron emission tomography (PET), single-photon emission computed tomography (SPECT), and functional magnetic resonance imaging (fMRI) have mapped the cortical activation during cognitive-motor tasks in humans in relation to intelligent quotient (IQ). Compared with subjects having a low IQ, high-IQ people showed weaker cortical frontoparietal activations during the performance of cognitive tasks (Haier et al., 1988, 1992, 2004; Parks et al., 1988; Rypma and D'Esposito, 1999; Rypma et al., 2002, 2005; Ruff et al., 2003). These results support the concept that the most brilliant individuals are characterized by a reduced and circumscribed activation of the cerebral cortex during cognitive tasks, possibly due to the efficiency of neural populations involved in the related information processing. However, this neural efficiency hypothesis does not explain all experimental data, especially when cognitive tasks are challenging. Other neuroimaging evidence pointed to a greater task-related cortical frontoparietal activation in individuals exhibiting a high cognitive performance than those manifesting a low cognitive performance (Gray et al., 2003; Newman et al., 2003).

Single-photon emission computed tomography, PET, and fMRI allow mapping fine topographical details of the cortical neural efficiency in experts, but they could not explore underlying neurophysiological oscillatory mechanisms. These mechanisms can be probed by the analysis of electroencephalographic (EEG) activity. EEG alpha (about 8–12 Hz) rhythms are typically reduced in amplitude, as a sign of cortical activation, during sensory, motor, and cognitive information processing (alpha event-related desynchronization, ERD; Pfurtscheller and Lopes da Silva, 1999; Klimesch, 2012). As a manifestation of cortical neural efficiency, the alpha ERD is less prominent in people with high IQ during several cognitive and working memory tasks (Neubauer et al., 1995, 1999, 2004; Grabner et al., 2004, 2006). Cortical neural efficiency was also evaluated in élite athletes, considered as high-performing people, with puzzling results. Some EEG studies on alpha rhythms have exhibited findings in agreement with the neural efficiency hypothesis. As a matter of fact, the frontoparietal alpha ERD was lower in karate athletes and gymnasts over controls while watching and judging videos reproducing sporting performances (Babiloni et al., 2009, 2010a). Furthermore, the alpha ERD was lower in gun shooters over controls during shooting preparation (Haufler et al., 2000; Janelle et al., 2000; Loze et al., 2001; Del Percio et al., 2009a). Compare to controls, élite karate athletes also exhibited lower alpha ERD during the opening of eyes in the resting state condition (Del Percio et al., 2011), difficult upright standing with eyes closed (Del Percio et al., 2010), simple voluntary hand movements (Del Percio et al., 2010), and a mental arithmetic subtraction task (Duru and Assem, 2018). Furthermore, cyclists with high maximal aerobic power showed lower alpha ERD during cycling compared with control subjects (Ludyga et al., 2016). Finally, tennis table experts over novices presented a lower frontoparietal alpha ERD during the imagery of the response to services represented in videos (Wolf et al., 2014).

Other EEG studies on alpha rhythms have exhibited findings in contrast with the neural efficiency hypothesis. Tennis table experts over novices showed a greater frontal alpha ERD during the imagery of the response to services represented in videos (Wolf et al., 2014). Furthermore, golf experts displayed greater frontal alpha ERD few seconds before successful than unsuccessful putts (Babiloni et al., 2008; Cooke et al., 2014). They also exhibited greater frontal alpha ERD compared with novices (Cooke et al., 2014). In the same line, the frontal alpha ERD was greater after the unsuccessful putts in the golf experts over the novices, as expected when substantial cognitive sources are allocated for correcting performance parameters in experts (Cooke et al., 2015). Finally, frontal alpha ERD was greater in karate and fencing athletes over controls who were maintaining the equilibrium using visual information about the surrounding environment (Del Percio et al., 2007).

The present study tested the hypothesis of experts' cortical neural efficiency in the visuospatial information processing during the observation of football (soccer) scenes. For this purpose, the cortical activation was indexed by the alpha ERD computed in football (soccer) players and control subjects during videos of football actions requiring visuospatial demands. The same videos were used for a control condition focused on visual non-spatial demands.

MATERIALS AND METHODS

Participants

Thirteen non-professional male football (soccer) players and eight age- and sex-matched control non-players were enrolled in this experiment. All subjects were right-handed as measured by the Edinburgh Inventory (players: mean of 0.4; non-players: 0.6) and gave their written and informed consent under the World Medical Association's Declaration of Helsinki. They were free to withdraw from the study at any time they wanted. The present study and protocol were reviewed and approved by the Ethics Committee of the Department of Physiology and Pharmacology "Vittorio Erspamer", Sapienza University of Rome.

The football players have been practicing football at the agonistic level (i.e., regular annual tournament at regional or national level) for at least 10 years (mean of 12.7 years $\pm$ 0.3 standard error, SE) and a minimum of 4 times a week during regular sporting seasons except for the event of sporadic sport accidents or diseases. The players' average age was of 25.1 years ($\pm$0.3 standard error, SE).

In the preliminary interviews, the control subjects reported that they had neither practiced football at the agonistic level nor had participated at official amateur football tournaments. They have been occasionally playing football (i.e., on average, once a month) with relatives and friends, especially at the time of high school. The average age of the control subjects was of 25.6 years ($\pm$0.2 SE).

Experimental Procedure

Electroencephalography data were recorded during the observation of 70 videos of football actions lasting 2.5 s each. The videos were presented on a computer monitor placed about 1 m in front of the subject receiving the EEG recording.

The subject kept the left index (non-dominant hand) on a key placed at the left-down angle of the computer keyboard (e.g., Ctrl) while the right index (dominant hand) was on a key placed at its right-down angle (e.g., enter key).

Each video (**Figure 1**) represented a paradigmatic football action planned by a professional football coach. In each video, two forwards were running on the goal (one on the left and the other on the right of a fixation cross at the center of the monitor). Meanwhile, two defenders were running near them to control their movements. During the videos, a central fixation cross changed color either from red to blue or from blue to red. The respective permanence time of the red and blue colors in the cross changed video-by-video in a pseudorandom and matched order. No video showed red and blue colors in the cross for an equal time. At the end of the video, the subject had to press one of the two mentioned keys of the keyboard within a maximum response time of 5 s.

During the EEG recordings, the 70 videos were watched two times. One time, the subject was asked to estimate the distance between the players during the action (FOOTBALL condition). Another time, they were asked to estimate if the central fixation cross was colored for a longer time in red or blue (CONTROL condition). The order of the two conditions was pseudo-randomized across subjects.

In the FOOTBALL condition, the subject had to press the mentioned left key if he thought that there was globally more distance between the forward and the defender at the left side of the monitor compared with the distance between the forward and the defender at the right side. He was instructed to estimate mentally the average distance between the two couples of players (i.e., one forward and one defender) across the whole action of 2.5 s. Vice versa, the subject had to press the right key if he perceived more distance between the forward and the defender at the right side of the monitor compared with the distance between the forward and the defender at the right side.

In the CONTROL condition, the subject had to press the mentioned left key if he thought that there was globally a longer permanence of the red over blue in the central fixation cross. Vice versa, he had to press the right key for a longer permanence of the blue over red in the central fixation cross.

Settings of the EEG Recordings

The EEG data were recorded continuously from 56 monopolar exploring electrodes (bandpass: 0.01–100 Hz; sampling rate: 512 Hz; EB Neuro-Be-plus©, Florence, Italy) positioned on the scalp according to the 10–10 system. The electrical reference was located between the AFz and Fz electrodes and the ground was placed between the Pz and Oz electrodes. The impedance of all exploring electrodes was kept below 5 kΩ. Simultaneously, vertical and horizontal electro-oculographic (EOG) data were registered to monitor blinks and saccadic eye movements (bandpass: 0.1–100 Hz; sampling rate: 512 Hz).

Preliminary Data Analysis

The EEG data related to the 70 videos were divided into 70 epochs having a duration of 8 s each. Any epoch spanned from -4 to $+4$ s with reference to the beginning of the video as a zero time. The EEG epochs were controlled for instrumental, blinking, ocular, and muscle artifacts. A home-made software implementing an auto-regressive procedure (Moretti et al., 2003) corrected blinking and ocular artifacts. Two EEG experts (CDP and AJDM) controlled and confirmed manually the automatic selection and correction of the procedure for all EEG epochs, with special attention to the residual contamination of the EEG signal due to head displacements, facial and neck muscle tension, blinks, and saccadic eye movements. Artifact-free EEG epochs were considered for the following analysis.

Analysis of EEG Alpha Rhythms

Spectral analysis of the artifact-free EEG epochs was based on the computation of Fast Fourier Transform (FFT) approach using the Welch technique and the Hanning function (frequency of 1 Hz resolution). The outcome was the estimation of the EEG power density at any frequency from 1 to 45 Hz.

According to a previous study of our group (Moretti et al., 2004), the frequency bands of interest in the alpha range were individually identified based on the individual alpha frequency peak (IAF). In the EEG power density spectrum, the IAF was defined as the maximum power density peak between 6 and 14 Hz. These frequency landmarks were previously well described by Klimesch (1999, 1996) and Klimesch et al. (1998).

The IAF was individually computed for each subject involved in the study. Based on the IAF, we estimated the low-frequency alpha band from IAF-2 Hz to IAF while the high-frequency alpha band ranged from IAF to IAF+2 Hz. On average, we found that IAF was 10.6 Hz ($\pm$0.3 SE) in the football players and 9.8 Hz ($\pm$0.4 SE) in the control non-players. There was no statistically significant difference between the two groups in the IAF as assessed by a t-test ($p > 0.05$).

Computation of Alpha Event-Related Desynchronization/Synchronization (ERD/ERS)

The alpha ERD/ERS was defined as the decrease/increase in the percentage of the alpha power density during the video compared with a period lasting 1 s immediately preceding its beginning, from –1 s to the zerotime (i.e., the beginning of the video). Specifically, two periods of the video were of interest: T1 from $+0.5$ to $+1.5$ s and T2 from $+1.5$ to $+2.5$ s. Practically, the ERD% was calculated by the following formula: (video – pre-video)/pre-video $\times$ 100 (Pfurtscheller and Lopes da Silva, 1999). As the outcome of the formula, negative percentage values represented the alpha ERD as a sign of cortical activation while the positive percentage values represented the alpha ERS as a sign of cortical deactivation. In this formula, the "video" indicates the alpha power density at T1 or T2 and the "pre-video" denotes the alpha power density during the period lasting 1 s immediately preceding the video beginning. Of note, the alpha ERD calculation was performed for both alpha sub-bands, namely the low- and high-frequency alpha sub-bands.

Topographic Mapping of the Alpha ERD/ERS

A spline interpolating function (Babiloni et al., 1996) was used to compute topographic maps (256 hues) of alpha ERD/ERS values at 56 electrode sites of augmented 10–20 system. This procedure has been successfully used to compute topographic maps of alpha ERD/ERS in our previous studies in élite fencing and karate athletes (Del Percio et al., 2007, 2008, 2009a, 2010). Noteworthy, the present procedure has some important advantages and a minor disadvantage. It interpolates alpha ERD/ERS values exactly at the same scalp sites in all experimental subjects, thus overcoming the spatial errors due to the individual shift of the positioning of the electrode cap across subjects. In this procedure, interpolated alpha ERD/ERS values were projected over a 3-D "quasi-realistic" template model of cerebral cortex. This template model was constructed based on the magnetic resonance data of 152 subjects, digitized at Brain Imaging Center of the Montreal Neurological Institute (SPM96)[1]. It is commonly considered as an acceptable template for the rendering of group neuroimaging data. As a disadvantage of the present approach, spline functions might introduce some minor estimation errors at the border electrodes of the montage. For this reason, we did not consider alpha ERD/ERS solutions in the border regions of the electrode montage.

FIGURE 1 | Electroencephalography (EEG) data were recorded during the observation of 70 videos of football actions lasting 2.5 s each on a computer monitor placed in front of the subject receiving the EEG recording. The subject kept the left index (non-dominant hand) on a key placed at the left-down angle of the computer keyboard (e.g., Ctrl) while the right index (dominant hand) was on a key placed at its right-down angle (e.g., enter key). In each video, two forwards were running on the goal (one on the left and the other on the right of a fixation cross at the center of the monitor). Meanwhile, two defenders were running near them to control their movements. During the videos, a central fixation cross changed color either from red to blue or from blue to red. At the end of the video, the subject had to press one of the two mentioned keys of the keyboard within a maximum response time of 5 s. For a description of the cognitive task planned in the EEG experiment, please see Section "Materials and Methods".

Statistical Analysis

Statistical comparisons were performed by the analysis of variance (ANOVA). With the ANOVA analysis, the Mauchly test evaluated the sphericity assumption, when necessary. Correction of the degrees of freedom was made by the Greenhouse–Geisser procedure, while the Duncan test was used for the *post hoc* analysis ($p < 0.05$).

In the first statistical session (behavioral data), we tested the hypothesis of higher accuracy (i.e., percentage of correct responses) and shorter reaction time in behavioral responses of the football players compared with the control non-players in the FOOTBALL but not the CONTROL condition ($p < 0.05$). This hypothesis was evaluated by an ANOVA having the response accuracy as a dependent variable and Group (football players, non-players; independent variable) and Condition (football, control) as factors. Similarly, another ANOVA used the reaction time as a dependent variable and Group (football players, non-players; independent variable) and Condition (football, control) as factors.

In the second statistical session (EEG data), we tested the hypothesis of mean differences in the alpha ERD between the groups of football players and control non-players in the FOOTBALL but not the CONTROL condition ($p < 0.05$). This hypothesis was evaluated by two ANOVAs, one for the low-frequency alpha band and the other for the high-frequency alpha band. These ANOVAs had the alpha ERD as a dependent variable and Group (football players, non-players; independent variable), Electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, O2), and Condition (football, control) as factors. The results of this statistical analysis were controlled by the Grubbs test ($p < 0.001$) for the presence of outliers.

RESULTS

Behavioral Data

In the football players, the mean accuracy of behavioral responses was of 95% (±1.9 SE) in the FOOTBALL condition and 94% (±1.8 SE) in the CONTROL condition. Similarly, high levels of the mean accuracy were observed in the control non-players. Their mean accuracy was of 94% (±1.9 SE) in the FOOTBALL condition and 96% (±0.9 SE) in the CONTROL condition. **Figure 2** plots these values for illustrative purposes. The ANOVA showed no statistically significant differences between the two groups or between the conditions ($p > 0.05$).

In the football players, the mean reaction time of behavioral responses was of 496 ms (±33 SE) in the FOOTBALL condition and 441 ms (±32 SE) in the CONTROL condition. In the control non-players, the mean reaction time was of 594 ms (±90 SE) in the FOOTBALL condition and 505 ms (±88 SE) in the CONTROL condition. **Figure 3** plots these values for illustrative purposes. The ANOVA showed no statistically significant effect ($p > 0.05$), despite some differences in the mean reaction time between the two groups.

EEG Data: Alpha ERD/ERS

For illustrative purposes, **Figures 4**, **5** plot the topographic maps of the alpha ERD/ERS in the football players and control non-players for the FOOTBALL and the CONTROL condition. Quite similar ERD spatial distributions for low- and

[1] www.mni.mcgill.ca

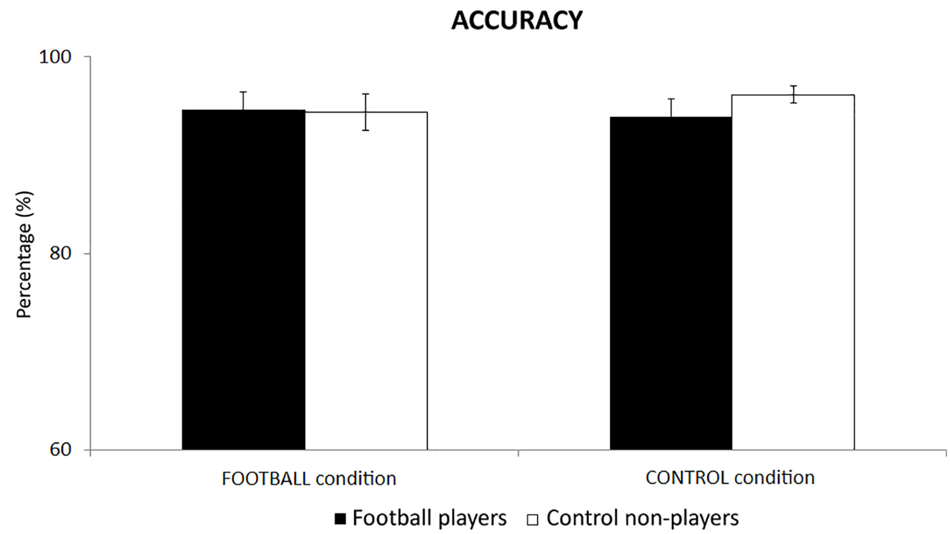

FIGURE 2 | The mean accuracy of behavioral responses in the football players and control non-players in the two cognitive tasks of the present experiments, namely the FOOTBALL and the CONTROL condition.

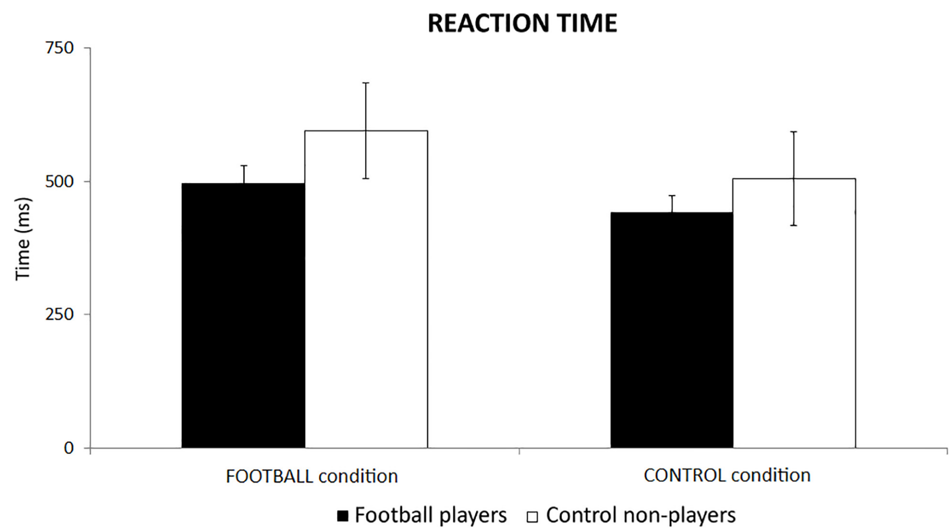

FIGURE 3 | The mean reaction time of behavioral responses in the football players and control non-players in the two cognitive tasks of the present experiments, namely the FOOTBALL and the CONTROL condition.

high-frequency alpha sub-bands were observed, so a general description valid for both alpha sub-bands follows. In the FOOTBALL condition, the topographic maps in both football players and control non-players were characterized by alpha ERD values prominent in bilateral parietal areas during the two periods of interest (i.e., T1 and T2), in line with the visuospatial nature of the task. Compared with the control non-players, the football players showed greater alpha ERD values. Of note, the CONTROL condition did not present the above differences between the two groups. Furthermore, there was no remarkable prominence of the alpha ERD in parietal areas, compatible with the non-spatial nature of the task. Finally, the control non-players exhibited a diffuse and slightly greater alpha ERD compared with the football players.

For the low-frequency alpha sub-band, the ANOVA showed a statistical interaction ($F = 3.1$; $p < 0.001$) among the factors Group (football players, control non-players; independent variable), Condition (FOOTBALL, CONTROL), and Electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, O2; **Figure 6**). The Duncan *post hoc* test unveiled that compared with the control non-players, the football players showed a greater alpha ERD at P4 ($p = 0.01$) electrode in the FOOTBALL condition, in contrast with the neural efficiency hypothesis. In the CONTROL condition, no difference in the alpha ERD was observed between the two groups ($p > 0.05$), despite some differences in the mean values.

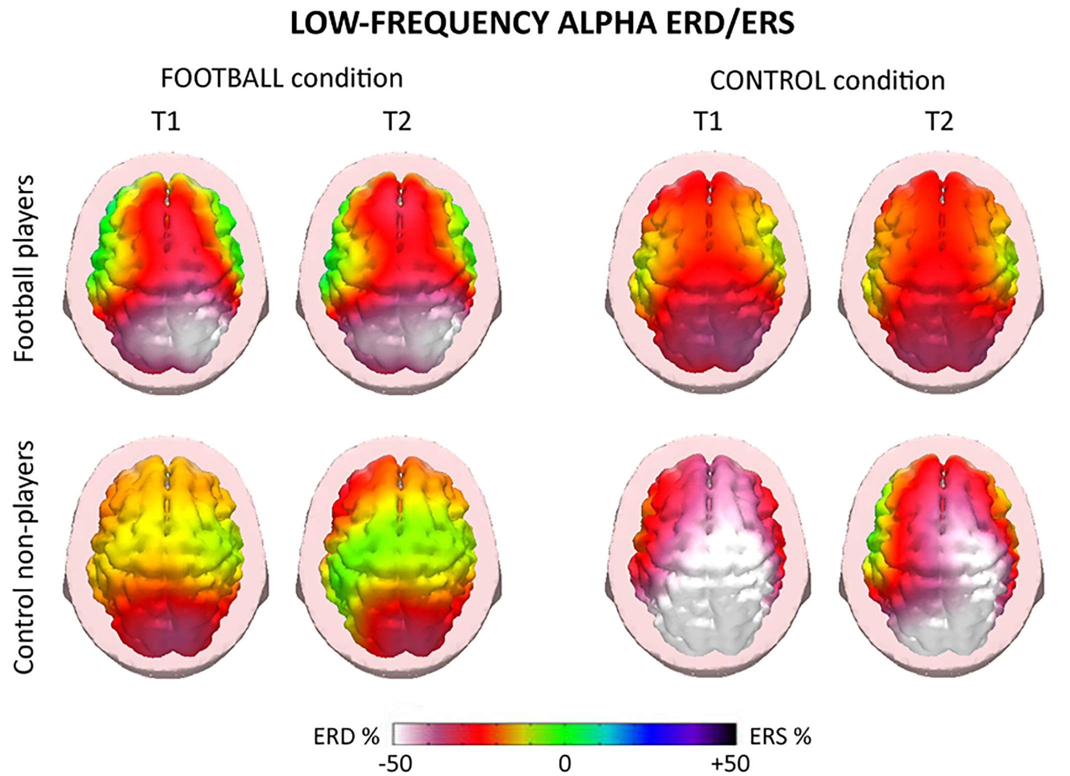

FIGURE 4 | Topographic maps of the alpha event-related desynchronization/synchronization (ERD/ERS) in the football players and control non-players for the "FOOTBALL" and the "CONTROL" condition of the present EEG experiments. These maps refer to low-frequency alpha rhythms (about 8–10 Hz) measured during the videos of 2.5 s showing football actions. Two periods of the videos were of interest, namely T1 and T2. T1 corresponded to the period from +0.5 to +1.5 s, while T2 corresponded to the period from +1.5 to +2.5 s, using the starting of the video as a zerotime. The alpha ERD/ERS during the T1 and T2 periods were computed with reference to a pre-video period from –1.0 s to the zerotime. Color scale: maximum percentage values of the ERD (i.e., cortical activation) and ERS (i.e., cortical deactivation) are represented in white and purple, respectively. The color palette reports the reference ERD/ERS percentage values.

The high-frequency alpha sub-band presented similar ANOVA results reported for the low-frequency alpha sub-band. Specifically, the ANOVA showed a statistical interaction ($F = 4.6$, $p < 0.0001$) among the factors Group (football players, control non-players; independent variable), Condition (FOOTBALL, CONTROL), and Electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, O2; **Figure 7**). Furthermore, the Duncan *post hoc* test showed that compared with the control non-players, the football players showed a greater alpha ERD at C4 ($p = 0.01$), P3 ($p = 0.04$), and P4 ($p = 0.002$) electrodes in the FOOTBALL condition ($p > 0.05$).

Of note, the above findings were not due to outliers from those individual low- and high-frequency alpha ERD/ERS values, as shown by Grubbs' test with an arbitrary threshold of $p < 0.001$.

Control Analysis

A control correlation analysis was performed to evaluate the relationships between the behavioral performance and the alpha ERD (cortical activation) related to visuospatial processes during the FOOTBALL condition. To address this issue, Pearson test ($p < 0.05$) computed the linear correlation between the accuracy and reaction time of behavioral responses vs. the alpha ERD during that condition. For this purpose, we only considered the low- and high-frequency alpha ERD solutions showing statistically significant differences ($p < 0.05$) between football players and control subjects in the FOOTBALL condition (i.e., low-frequency alpha ERD at P4 electrode and high-frequency alpha ERD at C4, P3, and P4 electrodes). Specifically, the correlation analysis was performed in two sessions. In the first session, football players and control non-players were considered as whole a group. In the second session, any single group was considered separately. No statistically significant effect was observed ($p > 0.05$).

DISCUSSION

In the present study, we probed the hypothesis of cortical neural efficiency in football (soccer) players involved in the processing of visuospatial information during videos with football actions. In the FOOTBALL condition, the task required the analysis of the relative distance between forwards and defenders during attacks on goal. The alpha ERD was used as an index of the cortical neural efficiency.

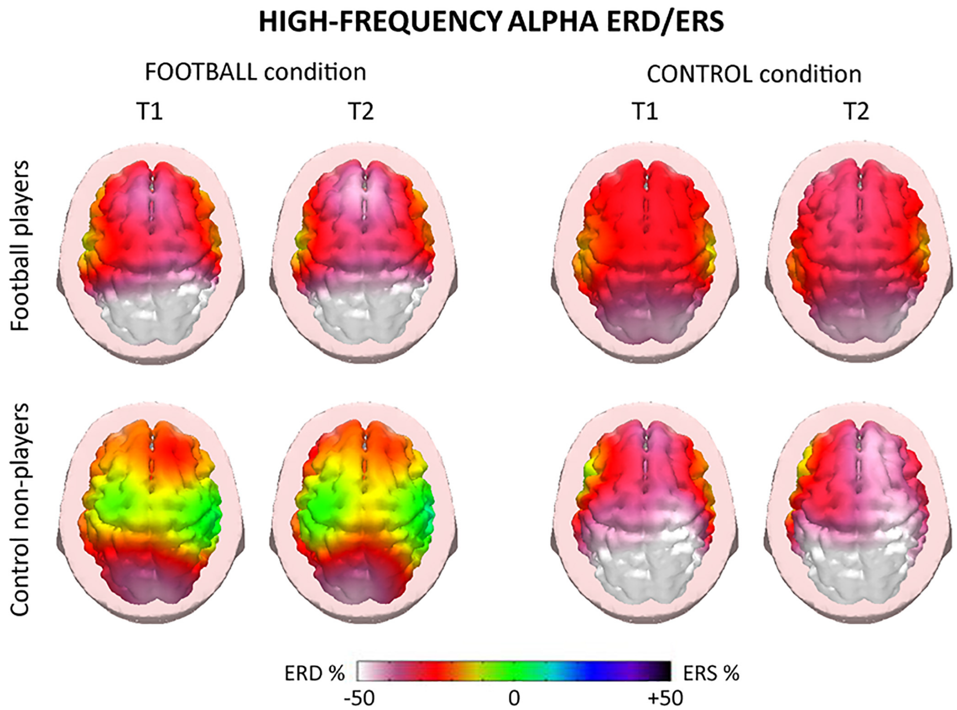

FIGURE 5 | Topographic maps of the high-frequency (about 10–12 Hz) alpha ERD/ERS in the football players and control non-players for the "FOOTBALL" and the "CONTROL" condition. These maps refer to the two periods of the videos considered, namely T1 and T2. Color scale: maximum percentage values of the ERD (i.e., cortical activation) and ERS (i.e., cortical deactivation) are represented in white and purple, respectively. The color palette reports the reference ERD/ERS percentage values.

Cortical Activity of Football Players Does Not Fit Neural Efficiency Mode in Visuospatial Information Processing During Football Scenes

The main results showed that a large-band alpha ERD (about 8–12 Hz) was prominent in bilateral parietal areas in the football players over control non-players during the FOOTBALL condition, in contrast with the cortical neural efficiency hypothesis. Of note, compared with the control non-players, the football players showed a reduced reaction time (<100 ms) in the FOOTBALL condition, but this difference was not statistically significant ($p > 0.05$). In the preliminary interviews, the control non-players reported that they have been occasionally playing football (i.e., about once a month), so they are not "naïve" about the game (In Italy, it is rare to find young adults who do not play this sport at all). However, we think that the mentioned lack of differences in behavioral performances was not mainly due to such minor practice of football in the control non-players. Rather, it may be due to a "floor" effect of the task, due to the lack of specific psychomotor demands trained in football players. In other words, the present computerized visuospatial task of the FOOTBALL condition did not require the combination of visuospatial and psychomotor skills typically trained in football practice. Furthermore, the lack of differences in behavioral performances in the mentioned cognitive task may be considered as an advantage for the evaluation of the neural efficiency hypothesis. Indeed, this hypothesis stands on the principle that compared with learners' brain, that of experts is trained to reach the required level of performance with a selective cerebral activation and the inhibition of irrelevant neural circuits. In this line, the comparison of brain activity can successfully test the neural efficiency hypothesis even better when task performance is paired in learners and experts, as eventual performance differences between groups may be considered as a confounding variable in the analysis of alpha ERD/ERS. In previous studies carried out in élite karate and fencing athletes, no behavioral difference was found between groups of athletes and controls in an equilibrium task (Del Percio et al., 2007, 2009b). That finding allowed us to interpret differences in EEG alpha rhythms as a possible effect of the neural efficiency (Del Percio et al., 2007, 2009b).

The main EEG results of the present study may not be explained by parallel visual non-spatial and short-term memory processes. Indeed, the CONTROL condition used the same videos with a different request to the subjects. They had to estimate the temporal permanence of the red and blue colors in the central fixation cross of the videos. In that CONTROL condition, no substantial difference in the alpha ERD was observed between the two groups.

The EEG results of the present study complement and extend previous evidence challenging the hypothesis of a cortical neural efficiency in athletes engaged in visuospatial tasks. Indeed, a previous fMRI study has shown that the

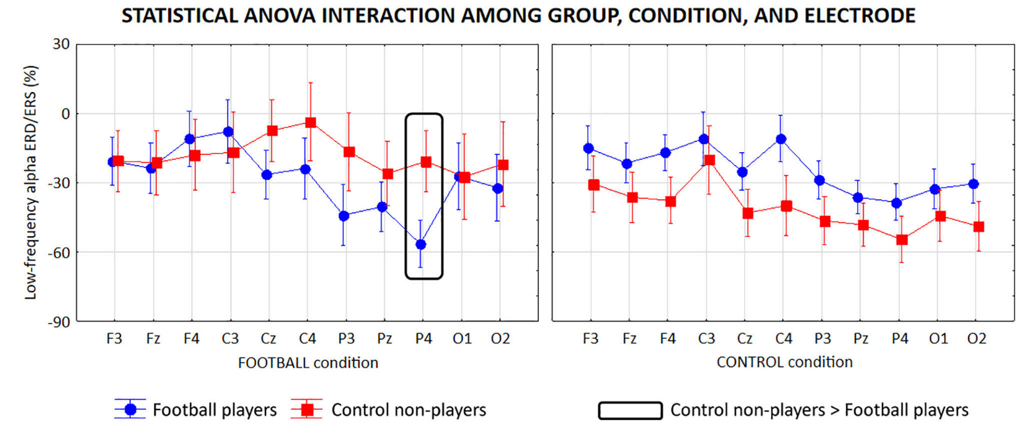

FIGURE 6 | Mean values (±SE) of the low-frequency (about 8–10 Hz) alpha ERD/ERS relative to a statistical ANOVA interaction among the factors Group (football players, control non-players; independent variable), Condition (FOOTBALL, CONTROL), and Electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, O2). Legend: the rectangles indicate the electrodes in which the low-frequency alpha ERD/ERS values showed statistically significant differences between the two groups in the FOOTBALL condition (Duncan *post hoc* test, $p < 0.05$).

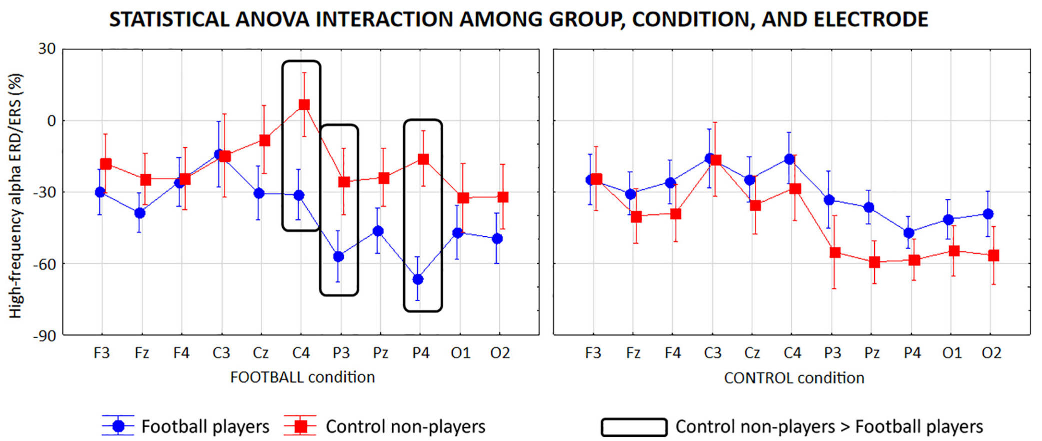

FIGURE 7 | Mean values (±SE) of the high-frequency (about 8–10 Hz) alpha ERD/ERS relative to a statistical ANOVA interaction among the factors Group (football players, control non-players; independent variable), Condition (FOOTBALL, CONTROL), and Electrode (F3, Fz, F4, C3, Cz, C4, P3, Pz, P4, O1, O2). Legend: the rectangles indicate the electrodes in which the high-frequency alpha ERD/ERS values showed statistically significant differences between the two groups in the FOOTBALL condition (Duncan *post hoc* test, $p < 0.05$).

parietal-occipital activation was greater in professional rugby players over beginners engaged in a task of mental spatial rotation of complex objects (Sekiguchi et al., 2011). In another study, the parietal alpha ERD (i.e., cortical activation) was greater in élite karate and fencing athletes over non-athletes during the upright balance grounded on the environmental visuospatial information (Del Percio et al., 2007). Furthermore, the frontal alpha ERD in élite golf athletes was greater in successful than unsuccessful putts, namely a performance implying a complex integration of visuospatial information and multi-joint body movements (Babiloni et al., 2008). On the other hand, the present results are at odds with previous alpha ERD studies leading support to the hypothesis of a cortical neural efficiency in athletes. In those studies, the frontoparietal alpha ERD was lower in elite karate and fencing athletes over control subjects during the observation and global judgment of athletes' performances in videos (Babiloni et al., 2009, 2010b). Furthermore, the alpha ERD was lower in gun shooters over control subjects during actual pistol shooting performances, a task implying a visuospatial information processing in conjunction with a static control of the posture (Haufler et al., 2000; Janelle et al., 2000; Loze et al., 2001; Del Percio et al., 2009b).

Neurophysiological Oscillatory Mechanisms Underpinning Visuospatial Information Processing in Football Players

The present alpha ERD results may be explained by neurophysiological oscillatory mechanisms underpinning visuospatial information processing in parietal areas. In wakefulness, cortical pyramidal neurons in parietal areas may generate ample posterior alpha rhythms due to synchronizing oscillatory signals (8–12 Hz) within a feedback loop spanning cortical, basal ganglia, and thalamic neurons (Pfurtscheller and Lopes da Silva, 1999; Hughes et al., 2008; Lörincz et al., 2008; Klimesch, 2012). That synchronizing mechanism may inhibit visuospatial and sensorimotor information flows toward and from the parietal cerebral cortex, while the opposite desynchronizing mechanism may dis-inhibit that information flow (Pfurtscheller and Lopes da Silva, 1999; Lörincz et al., 2008; Klimesch, 2012). In the present FOOTBALL condition, visuospatial stimuli (i.e., changing trajectories and relative distances between forwards and defenders) may trigger a mechanism of desynchronization of those neurons generating the observed parietal alpha ERD. Overall, this neurophysiological mechanism may release the mentioned background inhibition in the transmission and retrieval of relevant sensorimotor and visuospatial representations in parietal neural networks (Steriade and Llinas, 1988; Brunia, 1999; Pfurtscheller and Lopes da Silva, 1999; Deeny et al., 2003; Hughes et al., 2008; Lörincz et al., 2008; Klimesch, 2012).

Why did previous EEG studies in experts report contrasting results about the cortical neural efficiency in visuospatial tasks? How can or cannot the neural efficiency mode take place in experts? Here we can speculate about these issues. Cortical neural efficiency in experts might result from a long training with repeated episodes and associations among relevant stimuli, behavioral responses, and rewards. Those associations may consolidate synaptic connections into selective brain neural networks impinging on the cerebral cortex. During new episodes, neurophysiological oscillatory mechanisms (e.g., alpha ERD, and gamma ERS > 30 Hz) may selectively re-activate relevant synapses/networks and inhibit the irrelevant ones, thus establishing a cortical neural efficiency (Babiloni et al., 2004, 2006; Murakami et al., 2008). In experts, the neural efficiency mode may be formed by relatively few variants of those associations across episodes and may sub-serve relatively simple and automatic visuospatial information processes as those related to static pistol shooting performances and a global judgment of sporting actions (Haufler et al., 2000; Janelle et al., 2000; Loze et al., 2001; Babiloni et al., 2009, 2010a; Del Percio et al., 2009b).

Keeping in mind the above considerations, it can be speculated that football actions may be intrinsically too unpredictable and variable to be associated with encoding, retrieval, and automatic response processes encrypted within very circumscribed brain neural networks in experts. As a result, the representation of those processes in extended brain networks may make their visuospatial information processing not in line with a neural efficiency mode. Furthermore, those extended brain networks may make visuospatial "situational awareness," decision-making processes, and responses more flexible (Gabbett et al., 2008; Roca et al., 2013; Di Tore et al., 2018). This speculative model may explain what happens in athletes when brain information processing of sporting scenes is challenging, requiring intense involvement of cognitive representations in associative temporal, parietal, and occipital neural networks. This intense involvement may be required for visuospatial information processing and decision-making in some situational sports such as football (soccer), tennis, rugby, basket, handball volleyball, and hockey (Williams et al., 1994; Williams and Davids, 1998; Williams, 2000). In those sports, teammates and opponents may emit partially unpredictable behaviors, cause unexpected ball trajectories, and require quick decisions and adaptive behavioral responses.

CONCLUSION

This study tested the hypothesis of athletes' cortical neural efficiency in the visuospatial information processing related to the observation of football scenes. In the FOOTBALL (visuospatial) condition, prominent and bilateral parietal alpha ERD (i.e., cortical activation) was significantly greater in the football players than non-players. In contrast, no significant ERD differences were observed in the CONTROL (non-visuospatial) condition. These results suggest that the parietal cortical activity of football players did not show a neural efficiency functioning during the complex visuospatial information processing related to football attacks on goal. Future studies will have to test the hypothesis of greater parietal alpha ERD and more accurate behavioral responses in football players over non-players with highly challenging football attacks on goal. Furthermore, future studies will have to measure "situational awareness" with psychometric tests and enrich the neurophysiological model with the analysis of alpha functional connectivity (i.e., coherence), which was proved to be a very fruitful approach to unveil informative neural correlates of mental processes in athletes during sporting performances (Zhu et al., 2011; Gallicchio et al., 2016).

ETHICS STATEMENT

All subjects gave their written and informed consent under the World Medical Association's Declaration of Helsinki. They were free to withdraw from the study at any time they wanted. The present study and protocol were reviewed and approved by the Ethics Committee of the Department of Physiology and Pharmacology "Vittorio Erspamer", Sapienza University of Rome.

AUTHOR CONTRIBUTIONS

CDP and CB involved substantial contributions to the design of the project idea and wrote the article. MF contributed to the project idea and subjects selection. ADM contributed to the subjects selection and handling. GN, RL, and SL performed EEG data recording and analyses, and wrote the article. AS, RF, FS, and CL involved critical revision for important intellectual content. MP, MR, and AT performed data analyses.

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Corrigendum: Football Players Do Not Show "Neural Efficiency" in Cortical Activity Related to Visuospatial Information Processing During Football Scenes: An EEG Mapping Study

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In the published article, there were errors regarding the affiliations for Dr. Roberta Lizio and Prof. Cristina Limatola. The correct affiliation for Dr. Roberta Lizio is [2]IRCCS SDN, Naples, Italy. Furthermore, as well as having affiliation [1]Department of Physiology and Pharmacology "Vittorio Erspamer", Sapienza University of Rome, Rome, Italy, Prof. Cristina Limatola should also have [7]IRCCS Neuromed, Pozzilli, Italy.

The authors apologize for these errors and state that these do not change the scientific conclusions of the article in any way. The original article has been updated.

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The Positive Effect of Moderate-Intensity Exercise on the Mirror Neuron System: An fNIRS Study

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A growing number of studies have reported the beneficial effect of exercise on human social behavior. The mirror neuron system (MNS) plays a critical role in a variety of social behaviors from imitation to empathy. However, neuroimaging investigations into the effects of exercise on the MNS remain unexplored. To address this question, our study determined the effect of moderate-intensity exercise on the MNS using functional near-infrared spectroscopy (fNIRS). Specifically, 23 right-handed young individuals were asked to perform a table-setting task that included action execution and action observation before and after a 25-min exercise session on a cycle ergometer at moderate intensity (65% VO_{2peak}). The control condition was the same task performed without exercise. Cortical hemodynamic changes in the four primary brain regions of the MNS were monitored with fNIRS, using a modified probe configuration that covered all four MNS regions in the left hemisphere. We used a region of interest (ROI)-based group analysis to determine which regions were activated during action execution and action observation. Following a session of moderate-intensity exercise, we found a significant increase in activation in all four MNS regions, namely the inferior frontal gyrus (IFG), premotor cortex (PMC), superior parietal lobule (SPL), and rostral inferior parietal lobule (IPL). This result indicated a positive effect of exercise on the MNS, specifically that moderate-intensity exercise could activate the MNS.

Keywords: mirror neuron system, social interaction, motor cognition, moderate-intensity exercise, fNIRS

INTRODUCTION

In the past decade, there have been many studies investigating the effect of exercise on the brain. There is increasing evidence showing that exercise is beneficial for cognitive performance (Hillman et al., 2003; Yanagisawa et al., 2010), improves memory acquisition (Winter et al., 2007), prevents cognitive dysfunction in Parkinson's disease (David et al., 2015), and improves social behavior in adolescents with Attention-Deficit/Hyperactivity Disorder (ADHD) (Kamp et al., 2014) and in children with autism (Pan, 2010). Social cognition is a complex process, and understanding its neural basis to improve its performance is essential for our survival. Human social behaviors in the brain are mainly controlled by the amygdala, orbitofrontal cortex (OFC), and the mirror neuron system (MNS) regions (Rizzolatti et al., 2001; Adolphs, 2003). Van Rensburg et al. (2009) proposed that exercise can have a positive effect on the OFC. However, the effect of exercise on the MNS remains in question.

Rizzolatti et al. (1996) were first to discover the MNS; it fired when a macaque monkey grasped food (action execution) as well as when the monkey observed the experimenter grasping food (action observation). The MNS responsible for these behaviors was discovered in area F5 and in area PF and PFG of the rostral inferior parietal lobule (IPL) in non-human primates (Rizzolatti et al., 1996; Rizzolatti and Craighero, 2004; Fogassi et al., 2005). Research has also ascertained the brain regions that make up the human MNS; the human homolog of area F5 contains the premotor cortex [PMC; Brodmann area (BA) 6] and the inferior frontal gyrus (IFG; BA44/45), and the most likely homolog for area PF/PFG is located in the rostral part of the human IPL (BA40) and the superior parietal lobule (SPL; BA7) (Buccino et al., 2001; Rizzolatti and Craighero, 2004; Filimon et al., 2007; Kilner et al., 2009; Molenberghs et al., 2010). In terms of human social cognition, the MNS has been reported to control the ability to understand the actions of others (Rizzolatti et al., 2001), to imitate (Iacoboni et al., 1999; Rizzolatti and Craighero, 2004), to communicate using gestures and speech (Rizzolatti and Arbib, 1998; Rizzolatti and Craighero, 2004) and to act in cooperation with others (Egetemeir et al., 2011). Therefore, the basic functions of the MNS include matching the other person's action in our mind, and when we next observe a similar action, the MNS would be activated again. The MNS represents the neural network that helps people identify their own actions and those of others, in order to understand the purpose of others' actions by observation (Gallese et al., 2004), which we refer to as action understanding. In our study, we used both action observation and action execution to determine whether exercise has a positive effect on the function of the MNS. If we had only used action execution to reflect the activation of MNS, it would have been difficult to parse out whether the MNS activation was caused by action understanding or actual physical movement.

Although many neuroimaging studies have investigated the MNS with fMRI and positron emission tomography (PET) (Grafton et al., 1996; Moriguchi et al., 2009), these techniques are restricted to a constrained measuring environment to avoid off-target brain activation. In contrast, functional near-infrared spectroscopy (fNIRS) is more portable, allowing subjects to perform tasks in a natural and comfortable environment. This eliminates the confounding factor of delay between the variable being studied and brain imaging to assess activation. Sun and the colleagues established fNIRS as a non-invasive technique to detect the activation of MNS brain regions during action execution and observation (Sun et al., 2018). Accordingly, fNIRS has become an ideal tool to explore the MNS.

In this study, we used fNIRS to investigate whether activation of the MNS regions in the human brain changed after exercise. This is the first exploration of the possible effects of moderate-intensity exercise on the four dominant regions of the MNS, namely the IFG (BA44/45), PMC (BA6), rostral IPL (BA40), and SPL (BA7), which together cover almost all the mirror neuron-related regions in the brain.

Abbreviations: BA, Brodmann area; ctrl, Control; exec, Action execution; exp, Experimental; fNIRS, Functional near-infrared spectroscopy; IFL, Inferior frontal gyrus; IPL, Rostral inferior parietal lobule; MNS, Mirror neuron system; obs, Action observation; PMC, Premotor cortex; post, Post; pre, Prior to; SPL, Superior parietal lobule.

MATERIALS AND METHODS

Subjects

We recruited 23 healthy subjects (12 males and 11 females) with a mean age of 20.7 ± 1.6 years (range 18–25) to participate in this study. The average body weight of the study cohort was 65.2 ± 11.7 kg and the average height was 169.5 ± 9.0 cm. All subjects were right-handed according to the Edinburgh Handedness Questionnaire (Oldfield, 1971) and had normal or corrected-to-normal vision. None of the subjects had a history of neurological, major medical, or psychiatric disorders, and none were taking medication at the time of the fNIRS measurement. All subjects participated in three sessions (training, experimental, and control sessions) and were instructed to avoid strenuous exercise 24 h prior to each session. The study was carried out in accordance with the recommendations from the Ethic Committee of Guangzhou Sport University with written informed consent from all participants. All participants gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethic Committee of Guangzhou Sport University.

Experimental Design

During their first visit to our laboratory, subjects underwent a training session where they were familiarized with action execution and action observation until they were familiar with the rules and could adequately complete the entire task. Based on the classification of physical activity intensity of the American College of Sports Medicine (Medicine, 2013), the maximal oxygen uptake (VO_{2peak}) was measured (MasterScreen CPX, CareFusion, Hoechberg, Germany) to determine the appropriate individual intensity for a moderate level of exercise. In the second and third sessions, the experimental (exp) and control (ctrl) protocols were conducted with a counterbalanced design on different days. Under the exp protocol, subjects conducted the action execution and observation components of the task before (pre) and after (post) a moderate-intensity level of exercise on the cycle ergometer. Under the ctrl protocol, subjects conducted the same action execution and observation components but rested instead of performing the exercise (**Figure 1A**).

Table-Setting Task Preparation

We adopted a table-setting task to test action execution and observation. The subject and the experimenter sat face to face at a table. In the center of the table, a placemat was positioned on the right-hand side and a storage box of tableware in front. The tableware consisted of five objects: a plate, a saucer, a pair of chopsticks, a soupspoon, and a rice bowl. For the table-setting task, the subjects had to move the five tableware items from the storage box to the placemat on their right-hand side (and back from the placemat to the box) with their right hand at a normal, natural speed. A monitor was placed at a 45° angle in front of the subject to present visual cues: a cross to denote periods of rest and a picture of cups to denote the start of the task. During these rest periods, the subjects were asked to look at the cross on the monitor and avoid any action.

Table-Setting Task Procedure

In the action execution (exec) component of the experiment, each subject was asked to look at the monitor for the appropriate visual cues. The cross was displayed for 20 s (rest period), followed by the picture of cups to begin the task. The exec component of the experiment was comprised of eight blocks, where block 1 consisted of 15 s to move the five tableware items to the placemat and 20 s to rest. In block 2, each subject returned the tableware items to their original positions in the storage box and then rested again for 20 s (**Figures 1B,C**). Block 3, block 5, and block 7 were the same as block 1; block 4, block 6, and block 8 were the same as block 2. The order of placement was always fixed: plate, saucer, chopsticks, soupspoon, and a rice bowl.

In the action observation (obs) component of the experiment, the monitor was turned toward the experimenter, and the same visual cues were displayed as in the exec component. The obs component also consisted of the same eight blocks. While the experimenter executed the actions, the subjects watched carefully, and when the experimenter stopped, the subjects rested. The subjects were instructed to remain still while carefully watching the actions of the experimenter and focusing on their right hand moving the tableware. The order of the two components of the task (exec and obs) was counterbalanced across subjects. In total, there were 16 blocks in exec and obs components.

An experimenter monitored the action of each subject throughout the experiment (all exec and obs components of the exp and ctrl protocols). All subjects reported that it was very easy to follow the experimenter's actions in the obs component. Only one of the subjects felt slightly uncomfortable during the task, but it did not affect their ability to complete the task.

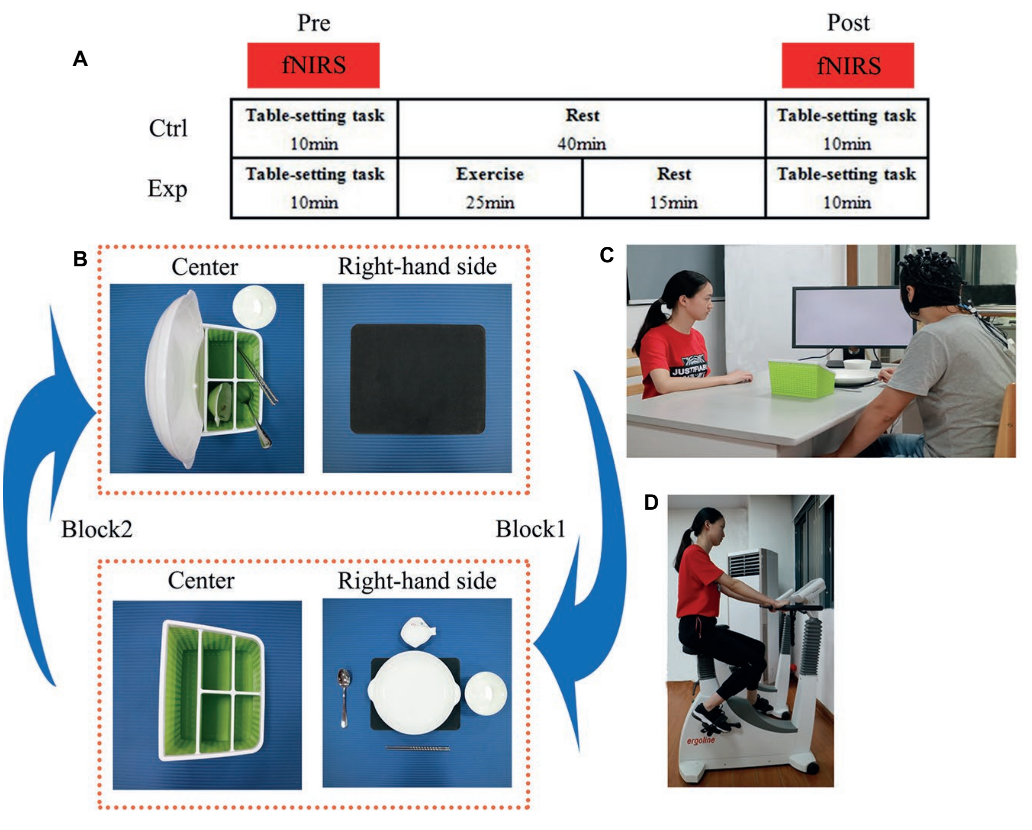

FIGURE 1 | (A) The experimental design showing the experimental (exp) condition with moderate-intensity exercise and the control (ctrl) condition with no exercise (rest). Cortical hemodynamic changes were monitored with functional near-infrared spectroscopy (fNIRS) while subjects performed the table-setting task. The task was performed before (pre) and after (post) exercise or rest. **(B)** Illustration of the block design of the table-setting task. In block 1, the subject (in the action execution component) or the experimenter (in the action observation component) moved the five tableware items from the green storage box in the center to the black placemat on the right-hand side. In block 2, the five tableware items were moved back from the placemat to their original positions in the green storage box. **(C)** Brain activity was measured (black NIRSport cap with probes for fNIRS measurements) while subjects performed the table-setting task (informed written consent was obtained from for the publication of these images). **(D)** The experimenter illustrates the moderate-intensity exercise on the cycle ergometer (informed written consent was obtained from for the publication of these images).

Cardiovascular Exercise Test

As mentioned above, the exec and obs components of the table-setting task were performed during both the exp and ctrl sessions. During the exp session, subjects performed 25 min of exercise on a cycle ergometer (Ergoselect 100, ergoline GmbH, Germany) that consisted of a 5-in warm-up, 15 min of exercise at moderate intensity (65% VO_{2peak}), and a 5 min recovery period (**Figure 1D**). A wireless heart-rate monitor (Acentas pulse meter, BM-CS5EU, Beijing, China) monitored the subject's heart rate (HR) during the entire exercise period. The pedaling rate was maintained at 60 rpm. The resistance workload started out at 30 W and automatically increased in the last 2 min of the warm-up period till the HR monitor reached the target HR at 65% HR_{peak}. Once the subject reached the target HR, the cycle ergometer computer decreased the resistance level to make sure each subject was exercising at moderate intensity for the 15-min exercise period. Finally, the cycle ergometer computer decreased the resistance level back to 30 W to let the subject cool down during the recovery period.

fNIRS Data Acquisition

fNIRS data were collected using the NIRSport mobile fNIRS system (NIRx Medical Technologies, LLC, New York, USA). This continuous-wave fNIRS system consisted of eight light sources and eight detectors, with 3-cm source-detector separations that formed of 14 channels. We recorded hemodynamic responses in the IFG (BA44/45), PMC (BA6), rostral IPL (BA40), and SPL (BA7), which together covered almost all mirror neuron-related regions in the left hemisphere. We placed active probes only in the left hemisphere because the left hemisphere is dominant when subjects perform a right-hand action (**Figure 2,** red dots = sources, blue = detectors; Filimon et al., 2007; Egetemeir et al., 2011). Each LED light source emitted light at two wavelengths (760 and 850 nm), and data were recorded at 7.81 Hz. The cap was positioned on the head by centering the bottom of the probe at the Fpz position (**Figure 2**), according to the international 10/20 positioning system (Zimeo Morais et al., 2018). In addition to the acquisition of hemodynamic response data during the table-setting task (pre/post, ctrl/exp, exec/obs), the baseline data were recorded, while each participant was resting and still for 15 s prior to the start of the table-setting test to avoid irrelevant activation (Fu et al., 2016).

fNIRS Data Preprocessing

The NIRStar acquisition software (NIRx Medical Technologies, LLC, New York, USA) was used to record fNIRS data and to evaluate its signal-to-noise ratio. The nirsLAB data analysis package (NIRx Medical Technologies, LLC, New York, USA) was used for all subsequent calculations. Raw data for all channels were visually inspected, spike artifacts were removed, and faulty channels were removed from subsequent analyses. All channels were band-pass filtered, with a low-cutoff frequency of 0.01 Hz and a high-cutoff frequency of 0.1 Hz to remove baseline drift and physiological noise, respectively (Kirilina et al., 2013). The modified Beer-Lambert law was used to compute estimates of changes in oxygenated hemoglobin (OxyHb), deoxygenated hemoglobin (DeoxyHb), and total hemoglobin (totalHb) levels from the frequency filtered data (Sassaroli and Fantini, 2004).

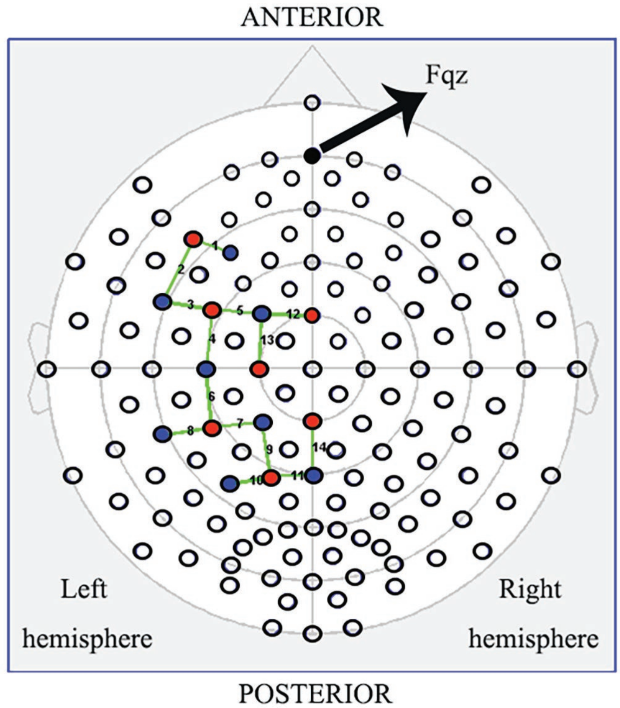

FIGURE 2 | Schematic of the probe setup when positioned on the subject's head. The NIRSport (NIRx Medical Technologies, LLC, Los) is a continuous-wave fNIRS system consisting of seven light sources (red) and eight detectors (blue) with a 3-cm source-detector separation, comprising 14 channels (green) across the IFG (BA44/45), PMC (BA6), rostral IPL (BA40), and SPL (BA7). Active probes were only in the left hemisphere.

Statistical Analyses

The statistical parametric mapping (SPM) utilities incorporated into nirsLAB were used to determine event-related changes in OxyHb, DeoxyHb, and totalHb during executed and observed actions. SPM employed the general linear model (GLM) to identify OxyHb, DeoxyHb, and totalHb hemodynamic brain responses with reference to experimental factors. First-level analyses (SPM 1) assessed differences on a within-session basis, and second-level analyses (SPM 2) assessed differences on a between-session basis. IBM SPSS Statistics 22 was used to analyze the OxyHb beta-value for each subject, condition, and channel obtained in SPM 1.

The traditional channel-based group analysis was used to assess the activation pattern. Two sides, one-sample t-tests were performed based on the individual-level beta-values, to determine if those channels significantly activated during the exec component compared with rest period were also activated in the obs component ($p < 0.05$, FDR-corrected). To achieve better spatial consistency, a region of interest (ROI)-based group analysis was also implemented to assess the activation pattern using two sides, one-sample t-tests.

In order to examine the effect of moderate-intensity exercise on the MNS, we first investigated the four MNS ROIs in response to both action execution and observation during the presessions of both the exp and ctrl conditions, which were free from any effects of exercise or rest periods. Then, each ROI was analyzed using a repeated-measures ANOVA with condition (exp/ctrl) and session (pre/post) as within-subject factors. The exp and ctrl results were compared with a paired *t*-test.

RESULTS

Activation Pattern Assessed Using Channel-Based Group Analysis

First, we analyzed channel-by-channel to explore whether those channels activated during the exec component were also activated in the obs component after exercise. The beta-values of OxyHb for each task were compared to the corresponding baseline (15 s prior to table-setting task onset) OxyHb. When acquiring fNIRS data, changes in OxyHb and DeoxyHb concentration were measured simultaneously. However, there is some scientific disagreement regarding which signal to use to analyze brain activation. In our study, we mainly focused on the OxyHb signal because it was often observed to have higher amplitude than the DeoxyHb signal (Strangman et al., 2002; Yanagisawa et al., 2010). In other words, the signal-to-noise ratio of OxyHb is better, and this signal is more sensitive to task response (Cheng et al., 2015).

The results showed that 11 channels were significantly activated during both exec and obs components ($p < 0.05$, FDR-corrected) in the post-exp condition, which is the exercise-intervention condition. Activated channels were located over all the ROIs, which are IFG (BA44/45), PMC (BA6), rostral IPL (BA40), and SPL (BA7). Moreover, there were five channels strongly activated in the post-exp-obs condition (channel 2, 6, 9, 11, and 13; $p < 0.01$, FDR-corrected), located over the IFG (BA44/45), PMC (BA6), and SPL (BA7).

Next, we compared action execution and observation in the no-exercise condition, which were free from any effect of exercise. Ten channels were activated during both action execution and action observation in the post-ctrl condition (channel 3, 4, 5, 6, 7, 9, 11, 12, 13, and 14; $p < 0.05$, FDR-corrected), which covered all of the brain regions. According to the spatial map of the 23 subjects in the pre-exp condition and pre-ctrl condition, we also found that channels 2, 3, 4, 5, 6, 7, 9, 10, and 13, which mainly belong to IFG (BA44/45), PMC (BA6), and rostral IPL (BA40), were activated during both action execution and observation ($p < 0.05$, FDR-corrected). **Figure 3** illustrates the activated level channel-by-channel in both conditions ($p < 0.05$, uncorrected).

Activation Pattern Assessed Using ROI-Based Group Analysis

Channel-based group analysis of our data showed inconsistent channel activation between the post-ctrl and pre-exp conditions, which despite being two separate groups, still represented the same experimental condition. In order to achieve better spatial consistency, an ROI-based group analysis was implemented (Yanagisawa et al., 2010). Specific regions of interest were selected: the left IFG (channels 1, 2, and 3), the left PMC (channels 4, 5, 12, and 13), the left rostral

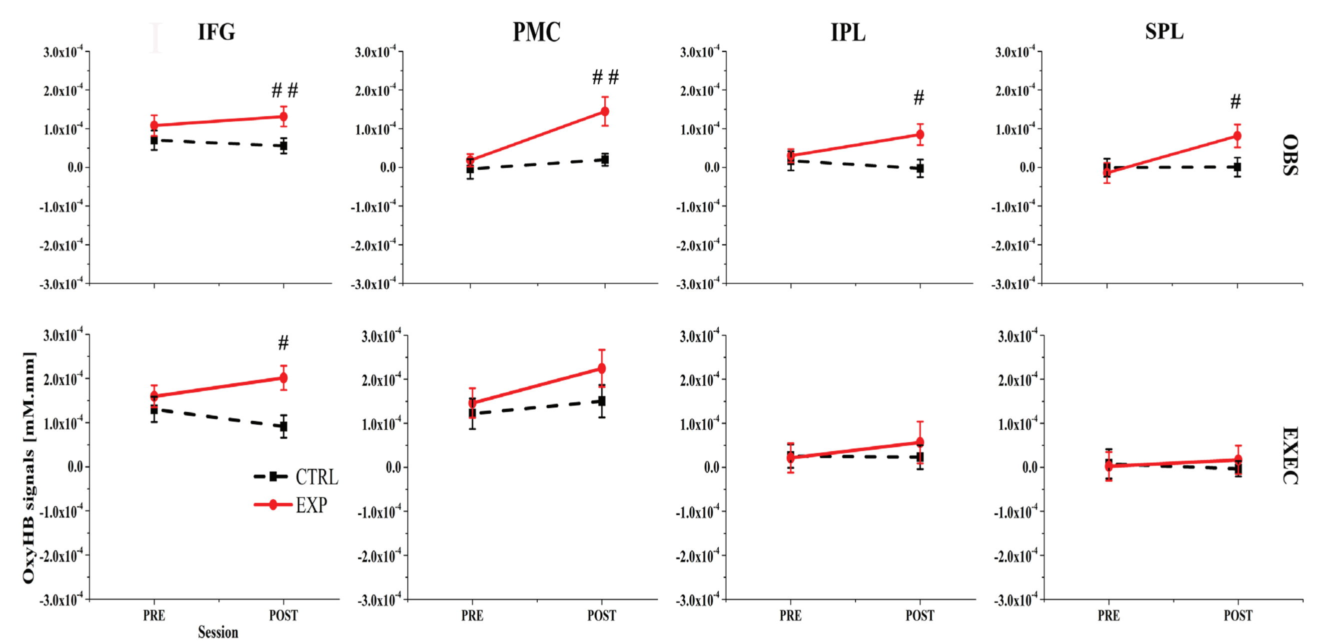

FIGURE 3 | First row lists the action observation (OBS) component and the second row lists the action execution (EXEC) component. IFG, inferior frontal gyrus; PMC, premotor cortex; SPL, superior parietal lobule; IPL, inferior parietal lobule; # represents a significant difference between pre-ctrl and pre-exp condition or post-ctrl and post-exp condition, #$p < 0.05$; ##$p < 0.01$; ###$p < 0.001$.

IPL (channels 6, 7, and 8), and the left SPL (channels 9, 10, 11, and 14). We analyzed them individually to determine which ROIs were activated during action execution and action observation in the exp and ctrl conditions.

We first used ROI-based group analysis to determine which brain area was activated after exercise. We found that four brain regions, namely the IFG (BA44/45), PMC (BA6), SPL (BA7), and the rostral IPL (BA40) were significantly activated during action observation and execution in the post-exp condition ($p < 0.05$, FDR-corrected) except SPL (BA7) during action execution.

The ROI-based analysis results also showed that nearly all of the brain regions, the IFG (BA44/45), PMC (BA6), rostral IPL (BA40), and SPL (BA7) were significantly activated during action observation and execution in all the no-exercise conditions ($p < 0.05$, FDR-corrected), which included the post-ctrl, pre-exp, and pre-ctrl conditions. Only the activation of the SPL (BA7) during action execution in the post-ctrl condition and the rostral IPL (BA40) during action execution in the post-ctrl condition were not significantly activated ($p > 0.05$, uncorrected).

ROI-Based Group Analysis for the Effect of Moderate-Intensity Exercise

We used a paired t-test to statistically compare the cortical activation pattern assessed by ROI-based group analysis in the pre-exp, pre-ctrl, and post-ctrl conditions, which were free from any effects of exercise. As expected, there were no significant differences in any ROIs during action execution or action observation between pre-exp, pre-ctrl, and post-exp conditions ($p > 0.05$, FDR-corrected).

During action observation, the ANOVAs for three of the four ROIs revealed marginally significant interactions between the condition (exp/ctrl) and session (pre/post) factors. Specifically, the ANOVA results were as follows: the IFG (BA44/45) resulted in $F(1, 22) = 2.64$, $p = 0.118$, $\eta^2 = 0.107$; the PMC (BA6) showed $F(1, 22) = 4.73$, $p = 0.041$, $\eta^2 = 0.177$; and the rostral IPL (BA40) was calculated as $F(1, 22) = 3.52$, $p = 0.074$, $\eta^2 = 0.138$. Then we used a paired t-test to statistically compare the cortical activation pattern between presessions (exp/ctrl) or postsessions (exp/ctrl). During the presessions, there were no significant differences between the exp and ctrl conditions ($p > 0.05$, FDR-corrected). However, during the postsessions, there were significant differences between the exp and ctrl conditions in all four ROIs ($p < 0.05$, FDR-corrected).

In contrast, during action execution, only the OxyHb signal in the left IFG (BA44/45) was significantly greater in the post-exp condition compared with the post-ctrl condition ($p < 0.05$, FDR-corrected). These results demonstrated that moderate exercise led to increased Oxy-Hb-related cortical activation in the left IFG (BA44/45), PMC (BA6), rostral IPL (BA40), and SPL (BA7). **Figure 3** presents the OxyHb signal change for both conditions across all ROIs.

In order to intuitively observe the changes in cortical activation by task, we presented **Figure 4,** and the graphs in the lower row show the representative graph of OxyHb change along the experimental timeframe for all the ROIs during action observation in the post-exp condition and post-ctrl condition. In each graph, we can clearly see the increased hemodynamic response in the post-exp condition compared with the post-ctrl condition. The raw data supporting the conclusion of this manuscript are available upon request to authors.

DISCUSSION

Detecting the Activation of the MNS Using fNIRS

Our study adopted a modified task and probe configuration of fNIRS to investigate the effect of moderate-intensity exercise on the MNS. We focused on the four dominant brain regions of the MNS, namely the IFG (BA44/45), PMC (BA6), SPL (BA7), and rostral IPL (BA40), and were able to detect changes in the activity of all four regions when using ROI-based group analysis. These results proved that it is feasible to use fNIRS to investigate MNS activity, a finding corroborated by a previous study (Sun et al., 2018). Sun et al. (2018) also used fNIRS to measure changes in the MNS; however, the fNIRS parameters used in our study were different. Even without their double density probe configuration and a spatial resolution of 3 cm (compared with their spatial resolution of 1.5 cm), we could still detect MNS activity during both action execution and observation before and after moderate-intensity exercise.

MNS Activation Increased After Moderate-Intensity Exercise

There are many studies that have provided evidence of the positive effect of exercise in children and adolescents with autism spectrum disorder (ASD), who have deficits in cognitive processing, impaired social interactions, delayed or limited communication skills, as well as confined activity patterns and interests. Exercise can reduce stereotypic behaviors and improve positive social skills (Magnusson et al., 2012; Olin et al., 2017). Short-duration exercise has been shown to improve performance in cognition tasks; the better the hemodynamic response, the better the cognitive performance (Yanagisawa et al., 2010; Lucas et al., 2012; Byun et al., 2014). Moreover, many studies have indicated that ASD brains have structural abnormalities in the MNS regions (Theoret et al., 2005; Hadjikhani et al., 2006) and that the MNS plays a critical role in social cognition (Gallese et al., 2004). It was reported that the MNS became activated when humans performed tasks related to social behaviors such as imitation, comprehension of intention, and emotional understanding (Iacoboni and Dapretto, 2006). However, there were no reports on whether exercise can have a positive effect on the MNS. We showed that OxyHb in some regions

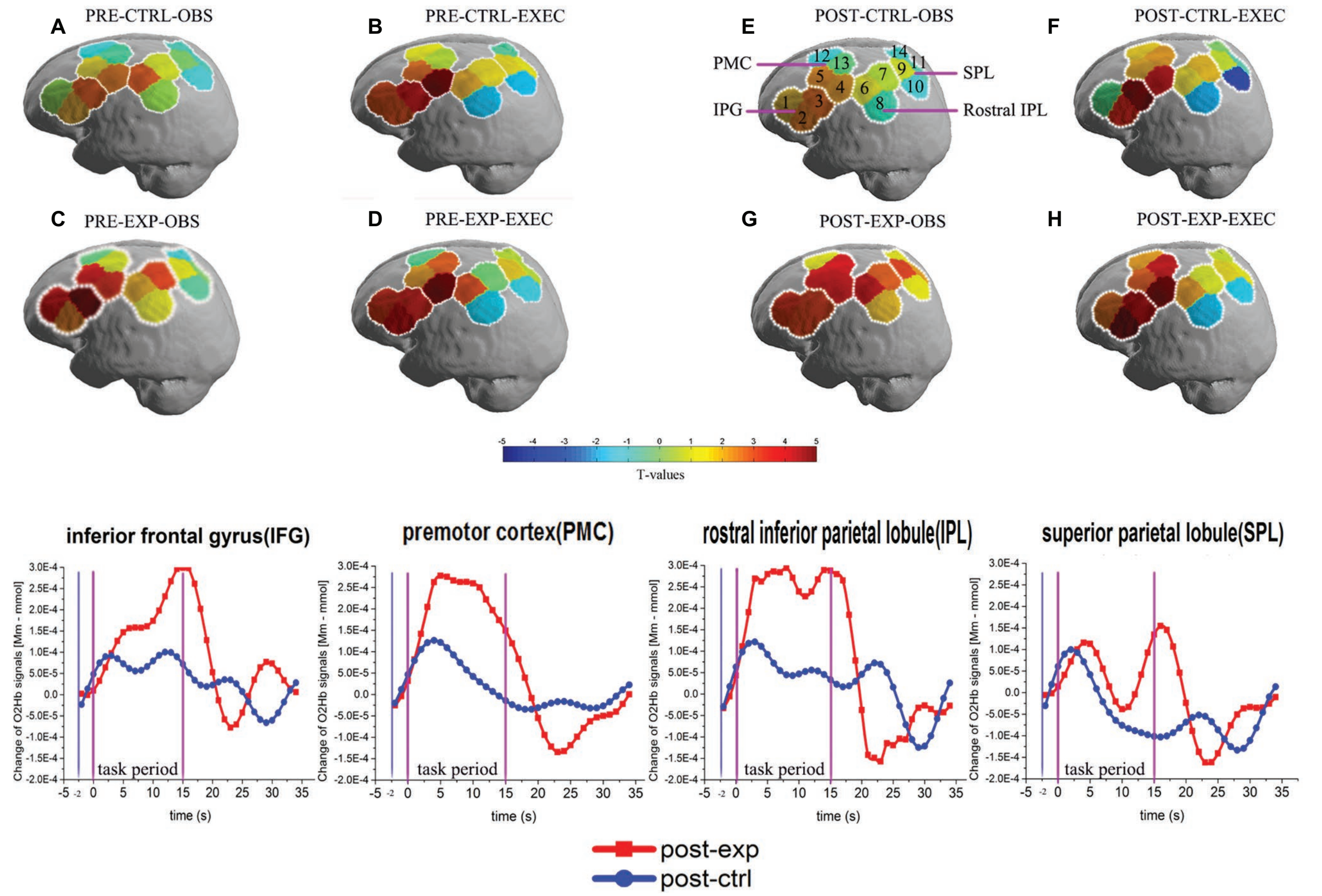

FIGURE 4 | Activation patterns of the MNS after exercise when using the ROI-based group analysis. MNS brain regions activated in the left hemisphere during action observation prior to exercise or rest **(A,C)**, and action execution prior to exercise or rest **(B,D)**, action observation following exercise or rest **(E,G)**, action execution following exercise or rest **(F,H)**. OBS, action observation; EXEC, action execution; EXP, experimental condition/exercise; CTRL, control condition/rest; PRE, prior to EXP/CTRL; POST, following EXP/CTRL. Each small circle in the different colors represents one channel, and the color scale represents the t-values at the group level. Each white circle represents an ROI, namely the IFG (BA44/45), PMC (BA6), rostral IPL (BA40), and SPL (BA7). Representative graphs of the OxyHb signal change over time are shown in the bottom row of the figure, comparing action observation in the post-exp (red line) and post-ctrl (blue line) conditions in the four ROIs. OxyHb signals are shown in arbitrary units (mM mm). Baseline OxyHb level (2 s before task onset, denoted by the first two vertical lines) is also shown.

of the MNS was significantly elevated in subjects during action observation after moderate-intensity exercise. In addition, the social cognition task of table setting expects us to determine a sequence of action, a type of recall that requires activation of the IFG. We found that the activation of the IFG (BA44/45) was significantly increased during action execution after moderate-intensity exercise. Collectively, these results suggest that exercise leads to increased activation of the healthy MNS while performing and observing social cognition-related tasks. Although our study subjects were normal adolescents and young adults between 18 and 25 years of age, the data from our experiments can still contribute to our understanding of MNS dysfunctions in children with ASD or schizophrenia.

Mori and colleagues used fNIRS and proton magnetic resonance spectroscopy (H-MRS) to investigate the MNS, the left amygdala, and the bilateral orbitofrontal cortex (OFC) in children with autism. They found that the concentration of OxyHb in the pars opercularis of the IFG (BA44) in children with autism while they imitated emotional facial expressions was significantly lower than that of normal children. However, concentrations of OxyHb in this same area became significantly elevated in autism after they were trained to imitate emotional facial expressions (Mori et al., 2015). This study suggests that although dysfunction in the MNS may be one critical neurological feature of ASD, mirror neurons can be activated by repeated imitation in children with ASD. Similar to repeated imitation, our study also revealed moderate-intensity exercise to be another method to increase OxyHb in MNS brain regions while observing an action.

Many studies that investigated social behavior have reported a suppression of the MNS in ASD and schizophrenia. The MNS was not as activated in cases with ASD and schizophrenia compared with the healthy group (Iacoboni and Dapretto, 2006; Mier et al., 2010; Derntl and Habel, 2011). EEG data of action observation in ASD showed reduced mu rhythm suppression compared with the healthy group (Oberman et al., 2005). Dapretto and colleagues used fMRI to show that children with ASD exhibited less activation in the IFG compared with controls while observing and imitating emotional expressions (Dapretto et al., 2006). Moreover, transcranial magnetic stimulation (TMS) data showed reduced corticospinal facilitation during action observation in children with autism (Theoret et al., 2005; Habel et al., 2010). Using different paradigms and research techniques, these studies all indicated one common point—individuals with ASD and schizophrenia have impairments in their MNS brain regions. Several intervention studies impressively demonstrated that social cognitive deficits like repetitive behaviors are modifiable through specific sports training programs (Staples et al., 2011; Movahedi et al., 2013). An increasing body of literature supports that appropriate exercise can improve social cognitive deficits in individuals with disorders that include MNS dysfunction such as ASD and schizophrenia. Accordingly, we can assume that physical exercise activates certain brain regions that control social behaviors. Our data revealed a positive effect of moderate-intensity exercise on the MNS of healthy individuals; observing an action increased the hemodynamic activation of the MNS brain regions. This result suggests that the brain regions activated by exercise to improve social behavior in ASD could potentially include the MNS. Therefore, our findings put forward the idea that MNS activation could be a fundamental mechanism underlying the beneficial effects of exercise on social behaviors. In line with this idea, some studies have suggested that MNS activity may serve as a biomarker of psychiatric disorders if future research is able to conclusively associate social cognitive deficits with certain clinical symptoms and syndromes, and if the assessment of MNS dysfunction can be specifically linked to clinical outcome variables (Iacoboni and Dapretto, 2006; Derntl and Habel, 2011). Research specifically testing individuals with ASD and schizophrenia is needed to validate MNS activation as a mechanism linking exercise with improved social cognition and to investigate the potential of MNS activity as a diagnostic marker for such diseases.

Does Exercise Improve Social Cognitive Behaviors by Direct MNS Activation or by Modifying Sensory Perception to Activate the MNS?

Exercise can modify our visual, auditory, and olfactory sensory perception by increasing blood flow or inducing other physical changes in the relevant brain regions (Delp et al., 2001; Krishnamurti and Grandjean, 2003; Davranche et al., 2005; Marioni et al., 2010; Si et al., 2011). Numerous studies have indicated that different exercise patterns have a positive effect on human sensory perception. Sensory perception deficits are some of the core symptoms in children with autism with MNS dysfunction (Robertson and Baron-Cohen, 2017). There are also many studies reporting that different types of exercise can have a positive effect on social cognition in children with autism; for example, aquatic exercises significantly improve the social interactions of children with autism (Yilmaz et al., 2004; Pan, 2010), and walking or jogging can reduce stereotypic behaviors (Prupas and Reid, 2001). From the knowledge gained so far in the field, can we speculate that exercise improves social performance by directly enhancing the function of the MNS? Or does exercise modify sensory perception, which changes our outlook toward the world and activates the MNS, leading to better social behaviors in our daily life? More research is needed to parse out the mechanism by which exercise-induced MNS activation improves social cognitive function.

LIMITATIONS

One limitation of our study was the inconsistent activations we observed following the channel-based group analysis of the same condition (pre-ctrl, pre-exp, and post-ctrl). However, this can be explained by individual differences in brain shape and size. Channel-based group analysis assumes that the probes are positioned in the exact same locations in every subject; however, due to the different shapes of the head across different subjects, channel-based group analysis sometimes generates inconsistent activation results. Another limitation of this study was the weak activation of the rostral IPL (BA40) and SPL (BA7) in action execution and observation. This brain region was the weakest of the four key regions, which are not activated during action execution in the post-ctrl condition. It is possible that the limited number of probes was insufficient to optimally cover the rostral IPL (BA40) and SPL (BA7), preventing the activation of this brain region from being fully detected. A higher sample size and better probe placement could address this issue.

CONCLUSION

Our study demonstrated that an individualized exercise program is an effective method to enhance hemodynamic responses in the MNS of healthy individuals. Our findings could present MNS activation as a potential mechanism for the beneficial effects of exercise on social integration in adolescents with ASD. The benefits of using exercise as an intervention include its cost-effectiveness and potentially preventative nature compared to other behavioral interventions. Thus, our study may also support the use of exercise as an intervention to improve social behavior in autistic and schizophrenic individuals *via* its positive effects on the function of the MNS.

ETHICS STATEMENT

The study was carried out in accordance with the recommendations from the Ethic Committee of Guangzhou Sport University with written informed consent from all participants. All participants gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethic Committee of Guangzhou Sport University.

AUTHOR CONTRIBUTIONS

ZX, MH, X-HH, and M-QX contributed to conception and design of the study. ZX, Z-RW, and JL organized the database. ZX and M-QX analyzed the data. ZX wrote the first draft of the manuscript. MH, X-HH, and M-QX contributed to manuscript revision, and read and approved the submitted version.

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Effect of a Combined Exercise and Dietary Intervention on Self-Control in Obese Adolescents

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Objective: The aim of this study was to determine whether a combined exercise and dietary intervention improved cognitive and physical self-control and whether pre-to-post interventional changes in self-control were mediated by changes in body mass index (BMI) and maximal grip strength (MGS), in a sample of obese adolescents.

Methods: Forty-four obese adolescents were randomly assigned to a combined exercise and dietary program or to a waitlist control group; the data from 36 participants (n = 18 for each group) were analyzed. The combined exercise and dietary program was performed over 6 weeks and was supervised by qualified trainers in a closed boot camp. The exercise consisted primarily of typical aerobic training, sports, outdoor training, yoga, and resistance training. Participants were placed on moderate dietary restriction according to individual target body weight (30 kcal/kg × target weight). The primary outcomes of this study were metrics based on cognitive and physical self-control, assessed by the Stroop task and a handgrip task, respectively. Secondary outcomes included BMI and MGS.

Results: The combined exercise and dietary intervention significantly improved both cognitive and physical self-control. Similar positive effects were also found for reduced BMI and enhanced MGS. Correlation analyses showed that the reduced BMI and enhanced MGS were significantly closely associated with improved cognitive and physical self-control. The mediation analyses revealed that the pre-to-post intervention changes in BMI and MGS significantly mediated physical self-control, but did not mediate cognitive self-control.

Conclusion: Our combined exercise and dietary intervention is an effective approach to improve multiple aspects of self-control, reduce BMI, and strengthen MGS among obese adolescents. These findings also suggest that reduced BMI and enhanced MGS mediate specific aspects of self-control.

Keywords: combined exercise and dietary intervention, obese adolescents, cognitive self-control, physical self-control, body mass index

INTRODUCTION

With the adoption in recent years of high caloric intake and sedentary lifestyles, the prevalence of obesity in childhood and adolescence has steadily increased worldwide, including in China. A study by Zhang et al. (2018) showed that approximately 15.5% of Chinese children and 8.8% of adolescents were overweight or obese; moreover, the prevalence of obesity in adolescents aged 12–18 years has significantly increased between 2011 and 2015. Childhood and adolescence obesity are linked to numerous comorbidities in adulthood, such as diabetes, cardiovascular disease, and metabolic syndrome (Biro and Wien, 2010; Doyon and Schaefer, 2013; Liang et al., 2015).

Adverse obesity-related health consequences have been linked to poor self-control. Self-control involves the capacity to volitionally overcome dominant behaviors or to resist temptation in order to achieve a particular goal, and is integral to the successful navigation of daily life (Baumeister et al., 1998; Englert, 2016). For obese individuals, maintenance of long-term lower weight may require strong self-control in order to consistently reinforce positive health-behavior lifestyles. For example, Bickel et al. (2018) showed that individuals who succeed in maintaining their weight loss exhibited superior self-control compared to those of the control group. However, obesity associated with poorer self-control than in control subjects has been specifically reported across a variety of personality and behavioral measures (Elfhag and Morey, 2008; Chamberlain et al., 2015). A meta-analysis showed significant deficits in inhibitory control in obese participants compared with those in healthy-weight controls [$g = -0.363$, 95% confidence interval (CI): -0.473, -0.252] (Yang et al., 2018a). Importantly, Datar and Chung (2018) found that poor self-control in school-aged children was an important risk factor for an increase in unhealthy body mass index (BMI) during the transition to adolescence over the next 8 years. Therefore, Datar and Chung (2018) suggested that a better understanding of ways to promote self-control may be important for improving the effectiveness of obesity-prevention programs.

According to the strength model of self-control (Baumeister et al., 1998; Muraven et al., 1999), self-control is a domain-general resource. Just as a muscle gets stronger with regular exercise, self-control may be strengthened with repeated regular practice. Several interventions seeking to improve self-control in obese adolescents or adults have shown promise, including self-management training (Vinkers et al., 2014), self-administered internet-based training (Mensorio et al., 2019), executive-function training (Verbeken et al., 2013), and response inhibition to food training (Lawrence et al., 2015; Verbeken et al., 2018).

Among various self-control training protocols, exercise has been regarded as an effective intervention, which has been observed to have benefits for improving the self-control abilities among female college students (Zou et al., 2016), children (Best, 2010), elderly people (Colcombe and Kramer, 2003), and patients with schizophrenia (Li et al., 2014). The benefits of exercise have prompted researchers to adopt exercise training to improve the self-control of overweight or obese individuals. Recently, Liu et al. (2018) demonstrated that coordination-exercise intervention not only improved the physical fitness of obese adolescents and reduced their BMI, but also enhanced their cognitive inhibitory control in the domain of executive function, which was reflected by the results of a normal and food-cue-related Stroop task. Furthermore, a series of randomized controlled trials in overweight children provided evidence of exercise-induced changes in activating their brains, including in the prefrontal cortex and the anterior cingulate cortex (Davis et al., 2011; Chaddock-Heyman et al., 2013; Krafft et al., 2014), which are areas of the brain linked to self-control (Kelley et al., 2015). More importantly, improving self-control may help to enhance health-behavioral options and to overcome unhealthy choices. For example, exercise-induced improvements of cognitive performance, specifically inhibitory control, were recently demonstrated to transfer to self-control in the dietary domain on a following laboratory taste test that included high-energy foods (Lowe et al., 2016). Nonetheless, these previous studies were limited to exercise training alone for improving the self-control of obese individuals and were not combined with dietary intervention. Exercise and diet are well known as the mainstays of obesity treatment, and combined exercise and dietary interventions result in greater weight loss than dietary or exercise interventions alone (Ho et al., 2013; Johns et al., 2014). Clearly, more empirical studies are required to investigate the efficacy of combined exercise and dietary interventions for improving self-control of obese individuals.

Prior studies merely tested the cognitive aspect of self-control in obese individuals, reflected by the Stroop task. However, self-control can be subdivided into other dimensions besides cognitive control, such as physical control. Cognitive self-control refers to an individual's concentration on thinking to complete tasks related to goals, while physical self-control refers to the ability of individuals to overcome potential impulses and to consistently complete motor tasks (Hagger et al., 2010; Berkman et al., 2012). Whether or not these two types of self-control can be improved through combined dietary and exercise interventions for obese individuals remains unknown.

Adolescence is a key transitional stage in terms of physical and mental development, during which personal lifestyle choices and behavioral patterns are established. The purpose of the present study was to assess the effects of combined exercise and dietary intervention on cognitive and physical self-control, as well as BMI and maximal grip strength (MGS), among obese adolescents. An additional purpose of the present study was to assess whether pre-to-post interventional changes in self-control were mediated by changes in BMI and MGS. The primary hypotheses were that a combined exercise and dietary interventional program would improve both cognitive and physical self-control, as well as reduce BMI and strengthen MGS. Secondary hypotheses were that reduced BMI and enhanced MGS would mediate improved cognitive and physical self-control.

MATERIALS AND METHODS

Participants

A sample of 50 obese children was recruited from Shenzhen City in the Guangdong Province of China, from the beginning

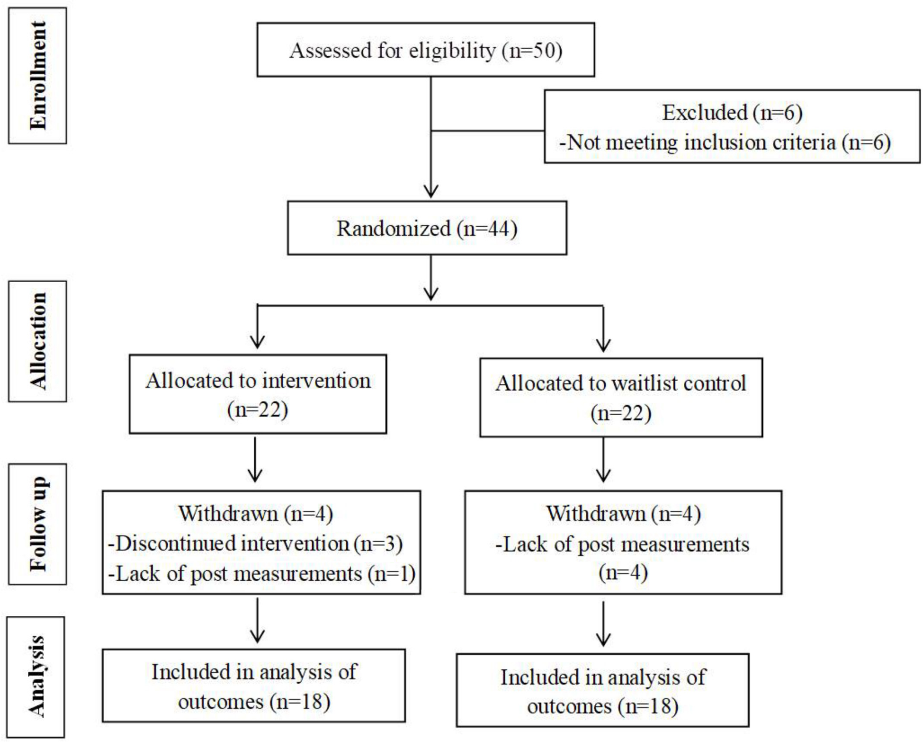

FIGURE 1 | Summary of the participant-flow diagram.

to the end of June 2018. Eligibility criteria included the following: (1) age range from 9 to 16 years; (2) obesity with an age- and sex-specific BMI ≥ 95th percentile (Centers for Disease Control and Prevention, 2019); (3) normal or corrected-to-normal vision without color-blindness; and (4) no self-reported history of severe cardiovascular or psychiatric disorders. According to baseline assessments, 44 qualified participants were allocated randomly—via a computer-generated algorithm—to either a combined exercise and dietary (EXD) group or a waitlist control (CON) group. Prior to the study, the parents or guardians of participants were well informed and their written consents were obtained. Thirty-six participants (n = 18 for each group) completed pre- and post-assessments, which were included in the statistical analysis (see flow diagram, **Figure 1**). In the current study, the sample size was sufficient to reveal at least a medium effect size *via* G*Power analysis (Faul et al., 2007) with the following parameters: effect size: f = 0.25, α = 0.05, $1-\beta$ = 0.80, $r_{\text{repeated measures}}$ = 0.50, ε = 1; exact sample advised: n = 35). This study was approved by the Guangzhou Sport University Human Experimental Ethics Board.

Combined Exercise and Dietary Intervention

The combined exercise and dietary interventional program lasted 6 weeks (from July 2nd to August 12th of 2018) at a closed boot camp in Shenzhen, Sunstarasia.

Dietary Restriction

In the CON group, participants were advised not to change their energy intake. In the EXD group, subjects completed 3-day food records before the intervention. Then, a moderate dietary restriction was provided to each participant based on his or her individual target body weight (30 kcal/kg × target weight). Target body weight of each specific participant was calculated according to his or her target BMI that was based on the BMI data of Chinese children in the 50th percentile from the same age and gender (Yang et al., 2018b). Diet was nutritionally complete (20% protein, 20% fat, and 60% carbohydrate). Calorie intake ranged from 1,300 to 2,000 kcal/day based on body weight. According to an individual's updated weight, the menu and diet were adjusted weekly during the intervention. Energy was distributed as approximately 30% at breakfast, 40% at lunch, and 30% at dinner. Mealtimes were at 7:15–7:45 a.m., 12:00 a.m.–1:00 p.m., and 5:30–6:30 p.m. every day. Registered professional dietitians determined dietary composition using Nutritionist IV software (N-Squared Computing, San Bruno, CA, United States) and prepared and monitored all meals. An example of energy intake over one day for a participant is shown in **Supplementary Table S1**.

Exercise Training

The CON group did not receive any exercise guidance and was instructed to wait until after the study before beginning any new exercise program. In the EXD group, participants performed an exercise training program for 5 h/day, 6 days/week

TABLE 1 | Summary of the 6-week exercise training program.

Classification	Mode of exercise	Intensity	Session duration	Frequency (per week)
Endurance exercise	Rope skipping	60–75% HRmax	60–90 min	1
	Aerobic treadmill	70–90% HRmax	60–90 min	2
	Aerobic dancing	60–75% HRmax	60–90 min	1
	Swimming	60–75% HRmax	90–120 min	1
Ball games	Badminton	60–75% HRmax	90–120 min	1
	Basketball	60–75% HRmax	90–120 min	1
	Football	60–75% HRmax	90–120 min	1
Outdoor training	Hiking or climbing	40–75% HRmax	150–180 min	1
Yoga	Yoga	50–75% HRmax	60–90 min	3
Resistance training	Resistance training	40–50% maximal strength, 3–4 sets of 12–15 repetitions maximum	60–90 min	2

for 6 weeks, which was conducted from 8:00 to 9:30 a.m., from 10:00 to 11:30 a.m., and from 3:00 to 5:00 p.m. every day. The exercise primarily consisted of typical aerobic training (including treadmill, dancing, rope skipping, and swimming), ball games (including basketball, badminton, and football), outdoor training, yoga, and resistance training (for more details, see **Table 1**). An example of a week in the training program is presented in **Supplementary Table S2**. The aerobic exercises included low-intensity (i.e., 2.8–4.5 METs), moderate-intensity (i.e., 4.6–6.3 METs), and high-intensity (i.e., 6.4–8.6 METs) exercise training. The intensity levels were set at approximately 50–63, 64–76, and 77–93% of the heart rate maximum (HRmax), respectively (American College of Sports Medicine, 2010). Heart rates were continuously monitored using Polar heart-rate monitors. Sport games and yoga were accommodated to one's individual skills and rating on the perceived-exertion scale (RPE). Resistance training was performed at 40–50% maximal strength for three to four sets of 12–15 maximal repetitions. The rest period between sets and training was 60–90 s. The energy expenditure was calculated with the following equation: energy expenditure (kcal/min) = 0.0175 × weight (kg) × METs (Pinheiro Volp et al., 2011). Thus, the energy expenditure of participants ranged from 1,500 to 2,500 kcal/day during the exercise program. All the exercise programs were supervised by qualified trainers. As their exercise tolerance improved, the type of exercise program was finely adjusted and the intensity and duration of the exercise program were also progressively increased each week according to individualized data of the participants (Foster et al., 2017).

Testing Procedures

All participants were required to perform measurements with two test sessions (pre- and post-training) including BMI assessment, MGS test, color word Stroop test, handgrip test, physical activity questionnaire, and trait self-control scale. Presentation of the color word Stroop test and handgrip test was counter-balanced between subjects. Each test session was conducted in a specific classroom at a training camp by well-trained graduate students. All outcome measures were performed no more than 1 week before and after the training, respectively.

Outcome Measures

Self-Control Assessment

Two tasks were selected to assess self-control. A modified Stroop task was used to measure cognitive self-control and a handgrip task was used to measure physical self-control.

Stroop task

The modified version of the classic Stroop color–word conflict task is widely utilized to assess cognitive component of self-control (Hagger et al., 2010) and has been demonstrated to exhibit sensitivity to different exercise interventions (Chang et al., 2014; Liu et al., 2018). The stimuli were three color–word names presented in Chinese as 红 (RED), 绿 (GREEN), and 蓝 (BLUE), using E-prime 2.0 software (Psychology Software Tools, Pittsburgh, PA, United States). In the Stroop task, two types of conditions were presented. For congruent conditions, the meaning of the word matched the color ink (e.g., the word RED was presented in red ink). For incongruent conditions, the meaning of the word and color of the ink conflicted (e.g., the word RED was presented in green ink). In both conditions, the participant was instructed to identify the color of the ink. We applied Stroop interference, a specifically defined cognitive process, to elucidate the effect of combined exercise and dietary intervention on cognitive self-control. In this way, the (incongruent − congruent) contrast, which is assumed to represent Stroop interference, was calculated.

The Chinese characters used were 2 cm^2 and each was displayed in the center of a 21-inch screen. The 96 trials in each block (48 congruent trials and 48 incongruent trials) were randomly presented. Each trial was started with the display of a white fixation point in the center of a black monitor for 500 ms, followed by a blank screen for an interval of either 300 or 500 ms (randomly selected) to avoid the participant predicting the timing of the subsequent stimulus word (Chang et al., 2014). The stimulus word was then displayed on the screen for 200 ms, which was followed by a blank screen for 2,300 ms or until the response was given.

A standard computer keyboard with "J," "K," and "L" buttons representing red, green, and blue, respectively, was used as the response panel. The subjects were asked to respond to the color–word by pressing a button that matched the color of ink of the word as quickly as possible with minimal error, and the reaction time and accuracy were recorded by E-prime 2.0 software. The experiment consisted of three blocks of trials, separated by 2 min of rest between each block. Twenty-four practice trials were conducted prior to the beginning of the experiment. The Stroop test lasted approximately 15 min, including practice.

Handgrip task

The handgrip task has been widely applied in self-control studies as a method for measuring physical self-control

(Hagger et al., 2010; Tong et al., 2016). In the present study, handgrip performance was represented by the length of time (seconds) that participants were able to hold 50% of MGS on an isometric handgrip dynamometer (SAEHAN DHD-3, Saehan Corporation, South Korea) that was connected to a graphical computer interface (G-STAR software, Saehan Corporation, South Korea). To compare individual differences in strength, a relative percentage of MGS was used rather than absolute force.

Prior to the endurance trial, participants performed twice on the dynamometer with their dominant hand, with the two trials separated by 1 min of rest. The largest MGS value obtained was then halved to determine the 50% MGS target value for the endurance trials. For the endurance contraction, participants were asked to squeeze the handgrip dynamometer that included concurrent visual feedback in the form of real-time force tracing on a computer monitor. The target force level (50% MGS) was shown as a red static line on the screen. Participants were required to maintain their handgrip squeezing for as long as possible to maintain the force tracing line at, or slightly above, the target line. The trial terminated when the line tracing fell below the target-force value for longer than 2 s or when participants voluntarily gave up gripping the dynamometer. The number of seconds that the participants maintained an isometric handgrip squeeze at ≥ 50% MGS was recorded by G-STAR software and was assessed as the physical self-control performance.

Body Mass Index

Body mass index was carried out according to the standards of the Centers for Disease Control and Prevention (2019) and is a measure that provides BMI and the corresponding BMI-for-age percentile based on the growth charts for children and teens (ages 2–19 years).

Maximal Grip Strength

Maximal grip strength was measured in the dominant hand using an isometric handgrip dynamometer (SAEHAN DHD-3, Saehan Corporation, South Korea). The participants were instructed to squeeze the handle of the dynamometer maximally twice, separated by 1 min of rest. The larger value of the two measurements was recorded for purposes of analysis.

Physical Activity

Physical activity level was evaluated using the short form of the International Physical Activity Questionnaire (IPAQ-SF), which was developed as a global surveillance tool for physical activity (Bauman et al., 2009). Participants reported the frequency and duration of vigorous and moderate physical activities, as well as walking and sedentary activity. For each type of activity, the IPAQ-SF data were converted to a metabolic equivalent (MET min/week). The MET score weights each type of activity by energy expenditure, using 8.0 METs for vigorous activity, 4.0 METs for moderate activity, 3.3 METs for walking, and 1.0 MET for sitting[1]. Our study showed that Cronbach's α for the IPAQ-SF was 0.310, which was similar to that of a prior study (Meeus et al., 2011).

[1]www.ipaq.ki.se

Trait Self-Control

Trait self-control was assessed using the China short form of the trait self-control scale (Tan, 2008), which was developed by Tangney et al. (2004) to measure individual differences in self-control. Our study showed that Cronbach's α for the Chinese version of the trait self-control was 0.79.

Statistical Analysis

Independent t-tests were used for general profile comparisons between the EXD and CON groups in terms of demographic variables, trait self-control, and IPAQ. To evaluate the effects of combined dietary and exercise on self-control, BMI, as well as MGS, we used a mixed-design analysis of variance (ANOVA) between-subjects (group: EXD vs. CON) and within-subjects on a repeated measure (session: pre-test vs. post-test). Independent t-tests were also used to test for differences in pre- to post-interventional changes in self-control, BMI, and MGS between the EXD and CON groups. Bivariate correlations were applied to test the relationships between changes in cognitive self-control, physical self-control, BMI, and MGS. To further explore these relationships, we further performed mediation analyses using PROCESS software for SPSS (Hayes, 2013), based on 5,000 resamples and bias-corrected bootstrapped 95% CI. The separate mediation model postulates that the exercise and dietary intervention (predictor) would predict changed BMI and MGS (mediators), which, in turn, would predict enhanced physical and cognitive self-control (outcomes) (Fairchild and MacKinnon, 2014). The mediation model was significant if the estimated 95% CI for the indirect effect from the bootstrap test did not overlap with zero.

RESULTS

Participant Demographics

Table 2 summarizes the basic descriptive characteristics for the EXD and CON groups. Independent t-tests indicated no significant differences between the two groups for the demographic variables of their age, height, weight, BMI,

TABLE 2 | Baseline demographic characteristics of participants (mean ± SD).

Variables	CON group (n = 18)	EXD group (n = 18)
Age (years)	13.28 ± 0.83	12.50 ± 1.92
Males/females (%)	11/7 (61.11%)	9/9 (50%)
Height (cm)	164.67 ± 7.43	159.72 ± 8.98
Weight (kg)	78.58 ± 8.57	76.42 ± 18.25
BMI (kg/m^2)	29.09 ± 2.66	29.57 ± 4.25
MGS (kg)	27.58 ± 9.21	21.76 ± 6.44*
Trait self-control	3.22 ± 0.45	3.43 ± 0.52
IPAQ (METs min/week)		
Pre-training	4416.48 ± 4471.61	5100.58 ± 3728.50
Post-training	4673.44 ± 4376.30	16,785.78 ± 8680.75***

*BMI, body mass index; CON, control; EXD, combined exercise and dietary; MGS, maximal grip strength; SD, standard deviation. *p < 0.05, ***p < 0.001.*

TABLE 3 | Group differences across time for Stroop task, handgrip task, BMI, and MGS (mean ± SD).

Variable	CON group (n = 18)		EXD group (n = 18)	
	Pre-test	Post-test	Pre-test	Post-test
Stroop task				
Congruent (ms)	450.53 ± 119.48	490.10 ± 91.81	457.78 ± 138.44	460.48 ± 113.23
Incongruent (ms)	574.76 ± 139.78	586.56 ± 105.15	579.94 ± 146.06	507.06 ± 120.89
Stroop interference (ms)	124.23 ± 51.79	96.46 ± 44.21	122.16 ± 83.07	46.58 ± 38.89
Handgrip task				
Endurance contraction (s)	27.46 ± 15.25	28.22 ± 14.50	23.77 ± 14.99	33.43 ± 15.35
BMI (kg/m^2)	29.09 ± 2.66	29.12 ± 2.67	29.57 ± 4.25	25.90 ± 3.79
MGS (kg)	27.58 ± 9.21	27.94 ± 9.25	21.76 ± 6.44	24.13 ± 7.09

BMI, body mass index; MGS, maximal grip strength; SD, standard deviation.

and trait self-control (p = 0.081–0.653). However, there was significant difference between the two groups in their MGS, with participants in the CON group showing greater MGS than those in the EXD group [$t(34) = 2.199$, $p < 0.05$]. According to the IPAQ scores, the two groups did not differ in their pre-training level of physical activity [$t(34) = 0.499$, $p = 0.621$]; however, following the intervention, participants in the EXD group scored much higher than those in the CON group [$t(34) = 5.285$, $p < 0.001$], indicating that the CON group did not take part in as much physical activity as the EXD group during the intervention.

Cognitive Self-Control

Table 3 presents Stroop-task performance differences pre- and post-testing for the EXD and CON groups.

Results of the three-way mixed (group: EXD vs. CON) × (session: pre-test vs. post-test) × 2 (Stroop task: congruent vs. incongruent) ANOVA revealed significant main effects for Stroop condition [$F(1,34) = 143.834$, $p < 0.001$, partial $\eta^2 = 0.809$], indicating that Stroop interference could be generally observed between the congruent and the incongruent tasks. Then, we performed a two-way mixed (group: EXD vs. CON) × (session: pre-test vs. post-test) ANOVA for Stroop interference, which is claimed by many to be one of the indicators of cognitive self-control in healthy children and young adults (Bub et al., 2006). The results showed no significant main effect by group [$F(1,34) = 2.569$, $p = 0.119$, partial $\eta^2 = 0.070$]. There was a significant main effect by session [$F(1,34) = 26.997$, $p < 0.001$, partial $\eta^2 = 0.443$], and the interaction between group and session was also statistically significant [$F(1,34) = 5.777$, $p = 0.022$, partial $\eta^2 = 0.145$]. Simple-effect analyses revealed no statistical significant difference for Stroop interference in the pre-test between the EXD and CON groups [$F(1,34) = 0.008$, $p = 0.929$, partial $\eta^2 = 0.000$]. A significantly reduced Stroop interference was observed in the EXD group [$F(1,34) = 12.917$, $p = 0.001$, partial $\eta^2 = 0.275$], whereas the CON group showed a marginally significant change [$F(1,34) = 3.898$, $p = 0.057$, partial $\eta^2 = 0.103$; **Table 3** and **Figure 2A**]. In addition, the Stroop-interference-change scores were significantly reduced following exercise and dietary intervention, compared with those of control conditions [$t(34) = 2.404$, $p = 0.022$, $d = 0.825$; **Figure 2B**]. Together, these results indicate that exercise and dietary training may have enhanced cognitive self-control.

Physical Self-Control

A two-way mixed (group: EXD vs. CON) × (session: pre-test, post-test) ANOVA was applied to endurance time in the handgrip task. Although no significant main effect was seen by group [$F(1,34) = 0.024$, $p = 0.877$, partial $\eta^2 = 0.001$], a significant main effect by session was revealed [$F(1,34) = 22.363$, $p < 0.001$, partial $\eta^2 = 0.397$], and the interaction between group and session was also statistically significant [$F(1,34) = 16.270$, $p < 0.001$, partial $\eta^2 = 0.324$]. Simple effect analyses revealed significantly improved endurance time under the EXD group [$F(1,34) = 38.391$, $p < 0.001$, partial $\eta^2 = 0.530$], whereas the CON group showed little to no change in endurance [$F(1,34) = 0.2421$, $p = 0.626$, partial $\eta^2 = 0.007$] (**Table 3** and **Figure 2C**). Endurance-time change was significantly greater in the EXD group compared with that of the CON group [$t(34) = 4.034$, $p < 0.001$, $d = 1.384$; **Figure 2D**], indicating that exercise and dietary training may have improved physical self-control.

Body Mass Index

A two-way mixed ANOVA and simple effect analysis revealed that BMI was significantly lower post-test compared with pre-test for the EXD group [$F(1,34) = 203.167$, $p < 0.001$, partial $\eta^2 = 0.857$]; however, no significant decrease in BMI was found in the CON group [$F(1,34) = 0.011$, $p = 0.920$, partial $\eta^2 = 0.001$]. The reduction in BMI was significantly greater in the EXD group compared with that of the CON group [$t(34) = 10.151$, $p < 0.001$, $d = 3.384$], indicating that exercise and dietary training may have reduced BMI.

Maximal Grip Strength

Two-way mixed ANOVA analyses revealed that the interaction between group and session was statistically significant [$F(1,34) = 21.734$, $p < 0.001$, partial $\eta^2 = 0.390$]. Simple-effect analyses revealed a significantly improved MGS performance in the EXD group [$F(1,34) = 60.313$, $p < 0.001$, partial $\eta^2 = 0.639$], whereas the CON group showed little to no change [$F(1,34) = 1.376$, $p = 0.249$, partial $\eta^2 = 0.039$]. The improvement in MGS was significantly greater in the EXD group compared with that in the CON group [$t(34) = 4.898$, $p < 0.001$, $d = 1.68$], suggesting that exercise and dietary training may have enhanced MGS.

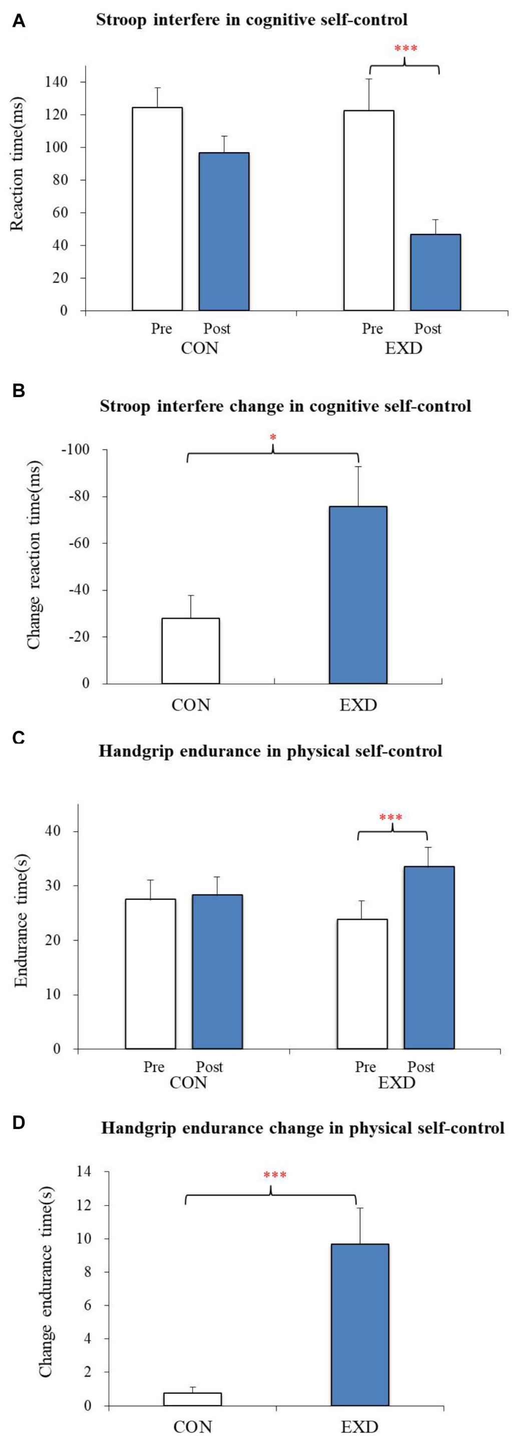

FIGURE 2 | (A) The mean difference in reaction times between incongruent and congruent conditions, indicating Stroop interference [i.e., (incongruent – congruent)] for the waitlist control group (CON) and combined exercise and dietary group (EXD). **(B)** Stroop-interference change [i.e., (post–pre)] in reaction time for Con and EXD groups. **(C)** Mean difference in handgrip-endurance times for CON and EXD groups. **(D)** Change in handgrip-endurance time [i.e., (post–pre)] for CON and EXD groups. All data are presented as the mean ± standard error. $^{*}p < 0.05$, $^{***}p < 0.001$.

Bivariate Correlation

Body mass index reduction was significantly associated with indices of Stroop-interference change ($r = 0.361$, $p < 0.05$) and handgrip-endurance change ($r = 0.659$, $p < 0.01$), with greater pre-to-post decreases in BMI correlating with greater positive change in cognitive and physical self-control performance. MGS enhancement was also significantly linked with indices of Stroop-interference change ($r = 0.340$, $p < 0.05$) and handgrip-endurance change ($r = 0.773$, $p < 0.01$), with greater pre-to-post enhancement in MGS correlating with greater positive change in cognitive and physical self-control performance. Stroop-interference change was not significantly associated with handgrip-endurance change ($r = 0.129$, $p > 0.05$), indicating that change in cognitive self-control was not linked to change in physical self-control (**Table 4**).

Mediation Analyses

The bias-corrected bootstrap method was used to test the mediation model. The results (**Table 5**) showed that the indirect effect of the EXD intervention improving self-control performance through changes in BMI or MGS was significant with respect to physical self-control [$\beta_{BMI} = -0.580$, and 95% CI (−1.057, −0.052), $\beta_{MGS} = 0.447$, and 95% CI (0.224, 0.705), excluding zero] but not significant for cognitive self-control [$\beta_{BMI} = -0.105$, and 95% CI (−0.573, 1.044), $\beta_{MGS} = 0.104$, and 95% CI (−0.269, 0.543), including zero]. These results indicated that BMI and MGS significantly mediated the relationship between exercise and dietary intervention and physical

TABLE 4 | Bivariate-correlation-matrix difference scores for Stroop interference, handgrip endurance, BMI, and MGS.

Variables	1	2	3	4
1 Stroop interference reduced	1			
2 Handgrip endurance improved	0.129	1		
3 BMI reduced	0.361*	0.659**	1	
4 MGS enhanced	0.340*	0.773**	0.713**	1

BMI, body mass index; MGS, maximal grip strength. $^{*}p < 0.05$, $^{**}p < 0.01$.

TABLE 5 | Bootstrapping indirect effect and 95% CI for the mediation model.

Indirect path	β	SE	95% CI	
			Lower	Upper
EXD intervention→BMI→cognitive self-control	−0.105	0.407	−0.573	1.044
EXD intervention→MGS→cognitive self-control	0.104	0.204	−0.269	0.543
EXD intervention→BMI→physical self-control	−0.580[a]	0.247	−1.057	−0.052
EXD intervention→MGS→physical self-control	0.447[a]	0.123	0.224	0.705

Bootstrap sample size = 5000. β, standardized estimate of indirect effect; SE, standard error; CI, confidence interval. [a]95% CI does not overlap with zero.

self-control, but did not mediate the relationship between exercise and dietary intervention and cognitive self-control.

DISCUSSION

In the present study, we tested whether a 6-week combined exercise and dietary intervention improved both cognitive and physical self-control, as well as reduced BMI and enhanced MGS in a sample of obese adolescents. A secondary aim was to determine whether reduced BMI and enhanced MGS outcomes mediated intervention-related improvements in self-control. Compared to the waitlist control group, the combined exercise and dietary interventional program improved both cognitive and physical self-control, reduced BMI, and enhanced MGS. Therefore, the primary hypothesis was supported. However, the pre-to-post interventional changes in BMI and MGS significantly mediated improved physical self-control but not cognitive self-control. The second hypothesis is only partially supported, suggesting that mediational effects of decreased BMI and enhanced MGS depend on the aspect of self-control.

Beneficial Effect of Combined Exercise and Dietary Intervention

The primary findings of our study were that obese adolescents who received a combined exercise and dietary intervention showed a greater improvement in both cognitive and physical self-control compared with that of a control group, suggesting that a general improvement in self-control occurs following a 6-week combined exercise and dietary intervention. The strength model of self-control postulates that all types of self-control share the "domain general" limited resource or strength. Moreover, improvements in self-control gained within one domain may transfer to another domain, and the shared biological substrate of the right inferior frontal gyrus may play a pivotal role in this process (Baumeister et al., 1998; Berkman et al., 2012). Our results supported that improvement gained from a combined exercise and dietary intervention may transfer to improved self-control in cognitive and physical domains. On closer inspection, the effect size of change in cognitive self-control pre-to-post testing (Cohen's $d = 0.825$) between the EXD group and CON group was slightly larger than the effect size of the change in cognitive-function performance (Cohen's $d = 0.56–0.60$) by Liu et al. (2018)—which used coordination exercise intervention for obese adolescents—but was within the range of effect size reported in a meta-analysis by Sibley and Etnier (2003) (Cohen's $d = 0.00–1.49$). The larger improvement of effect size in our present study might be linked to the nature of the intervention. Prior studies involved exercise intervention alone (Liu et al., 2018); however, we combined exercise and dietary intervention in a closed boot camp that was strictly monitored for the duration of the program by nutritionists and exercise trainers. Moreover, the effect size for change in physical self-control was observed to be of greater magnitude than that of the change in cognitive self-control (Cohen's $d = 1.384$ vs. 0.825) in our intervention. To our knowledge, this is the first study in which positive effects of combined exercise and dietary intervention on physical self-control in obese adolescents have been described. One reason why improvement in physical self-control may have been greater is that our exercise approach involved a variety of exercises, such as aerobic training, ball games, outdoor training, yoga, and resistance training, which may have benefited physical self-control more than other types of self-control.

Another finding in the present study was a positive effect from the combined exercise and dietary intervention in reducing BMI, which is similar to a finding from a meta-analysis by Kelley et al. (2014) that examined the effects of exercise (strength, aerobic, or both) on overweight and obese children and adolescents (effect size = 0.47). However, our exercise program involved moderate exercise, high-intensity interval exercise, and resistance training with dietary control, and collectively lead to a large magnitude of BMI reduction (Cohen's $d = 3.29$). Similar beneficial effects were also found for enhancement of MGS (Cohen's $d = 1.68$). These greater changes may be associated with various aspects of the exercise intervention, such as aerobic training, ball games, outdoor training, yoga, and resistance training, which provided obese adolescents with new and stimulating experiences that many may have considered fun and motivating. In addition, given that this was a closed boot camp, many participants may have had higher internal or external motivation to shape and improve physical fitness. Taken together, this combined exercise and dietary intervention may be an effective training program for improvements in self-control and for weight control among obese adolescents.

Mediational Effect of Body Mass Index and Maximal Grip Strength

Based on the observation of a positive effect on cognitive and physical self-control, BMI, and MGS from our combined exercise and dietary intervention, our next step was to search for relationships between reduced BMI, enhanced MGS, and improved self-control. We observed in our study that the reduced BMI was significantly associated with improved cognitive self-control ($r = 0.361$, $p < 0.05$). This finding was consistent with Xu et al. (2017), who found that improved cognitive self-control was positively correlated with weight loss in a sample of obese adolescents and young adults. Similarly, Pauli-Pott et al. (2010) found that cognitive self-control, measured by performance on go/no-go tasks, was also significantly associated with success in weight loss. Differing from previous study findings, our results demonstrated that decreased BMI was also significantly associated with improved physical self-control ($r = 0.659$, $p < 0.01$) as well as cognitive self-control. Importantly, we also observed that enhanced MGS was significantly associated with improved cognitive self-control ($r = 0.340$, $p < 0.05$) and physical self-control ($r = 0.773$, $p < 0.01$). Therefore, our findings more comprehensively revealed the relationships between decreased BMI, enhanced MGS, and the different aspects of improved self-control.

A novelty of our study was our demonstration that reduced BMI and enhanced MGS mediated intervention-related improvements in physical self-control but not cognitive self-control, indicating that the mediational effect of decreased BMI and enhanced MGS depended on the aspect of self-control. Liu et al. (2018) showed that BMI did not significantly mediate improvement of cognitive self-control performance following a 12-week program of coordination-exercise intervention. These findings were in line with our study, and plausible mediators that explain the exercise and cognition self-control relationship may not only include changes in cardiorespiratory fitness and cerebral blood flow, but may also involve brain neurotransmitters and neurotrophic factors implicated in neuronal proliferation and survival (Russo et al., 2017). We demonstrated that decreased BMI and enhanced MGS significantly mediated enhanced physical self-control performance. One reason for this inconsistency in mediational effects may be the existence of different neural mechanisms for improving self-control. Similar brain regions have been demonstrated as potential neural substrates of self-control, including dorsolateral parts of the frontal lobes, the dorsal premotor cortex, medial premotor regions, and parts of the anterior insula/frontal operculum (Langner et al., 2018); however, Kelley et al. (2015) argued that self-control includes several executive functions, each of which may have a neural signature that differs depending on specific task demands, and any one test of self-control may only influence one piece of a larger control system. Based on the results observed in this present study and those from previous neuroscience studies, we speculate that reduced BMI and enhanced MGS are more associated with the physical self-control neural signature to the extent that they mediated performance on the handgrip task. Clearly, more research is necessary to further explore whether changes in key fitness, physiological, or neural variables serve to mediate training-related improvements in self-control.

Strengths and Limitations

There are several notable strengths to our study. First, the combined exercise and dietary intervention was conducted in a closed boot camp that could be well supervised by nutritionists and exercise trainers. Second, because cognitive and physical self-control were both measured in this study, our findings could comprehensively reveal the beneficial effects of combined exercise and dietary intervention on different aspects of self-control. Finally, we tested the mediation effect of BMI and MGS, which could contribute to understanding of how the combined exercise and dietary intervention improves self-control.

At the same time, several limitations of our study should be acknowledged. First, due to the time and resources available to complete the training program, the sample size was small. It is possible that the training was not sufficiently powered for the mediational analyses. Future studies will require sufficient sample sizes and the use of appropriate methods to investigate potential mediators of self-control based on exercise and dietary interventions. Second, our relatively short intervention (6 weeks) did not have multiple measurement points or a follow-up period. This limits the ability to reflect on clinically meaningful changes in self-control, BMI, and MGS, and whether the short-term benefits of our intervention were sustainable is unclear. Finally, we did not directly test the neural mechanisms underlying the effect of exercise and dietary intervention on cognitive and physical self-control. Future research using functional magnetic resonance imaging and/or electroencephalography will be necessary to elucidate any underlying neural mechanisms.

Implications

Our results have several practical implications. For obese adolescents, successful maintenance of long-term lower weight requires strong self-control (Bickel et al., 2018). Although a large number of effective interventions seeking to improve self-control have been demonstrated, exercise and diet are feasible to implement in school practice as the mainstays of obesity treatment. In fact, China's government has enacted a "National Teenagers' Sunny Sports Program" with the goal of having students complete 1 h of exercise every day to promote physical activity (Zhang et al., 2012). In addition, there has been a growing concern about implementation of a school-based nutritional promotional program in China (Wang and Stewart, 2013). We speculate that such programs are not only useful in the field of physical fitness and preventing obesity, but also in improving self-control among obese adolescents. More importantly, improved self-control could benefit obese individuals to become more efficient in daily life when facing self-regulatory struggles such as overcoming impulses, controlling excessive eating, and breaking bad habits. Our study showed that combined exercise and dietary intervention is an effective approach for improving multiple aspects of self-control, reducing BMI, and enhancing MGS among obese adolescents in a closed camp. However, whether this benefit could extend to school-based interventions remains unclear. Thus, future research studies will be needed to explore the effect of school-based exercise and healthy-diet interventions on multiple aspects of self-control among obese adolescents.

CONCLUSION

A combined exercise and dietary intervention program was effective at improving both cognitive and physical self-control, reducing BMI, and enhancing MGS among obese adolescents. The pre-to-post interventional changes in BMI and MGS significantly mediated improved physical self-control but not cognitive self-control, suggesting that the mediational effects of decreased BMI and enhanced MGS depend on the aspect of self-control. The present work extends the pediatric study on obesity, self-control, and combined exercise and dietary intervention, particularly during the critical developmental period of adolescence, and establishes the need for evidence-based public health interventions for overweight and obese adolescents.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the **Supplementary Files**.

ETHICS STATEMENT

The study was carried out in accordance with the recommendations from the Ethic Committee of Guangzhou Sport University with written informed consent from all participants. All participants gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethic Committee of Guangzhou Sport University.

AUTHOR CONTRIBUTIONS

MH, M-QX, J-WL, and J-HH contributed to the conception and design of the study. H-LD, DW, and ZX organized the database. M-QX and ZX analyzed the data. M-QX wrote the first draft of the manuscript. MH, J-WL, and J-HH contributed to the manuscript revision, read, and approved the final version of the manuscript for submission.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01385/full#supplementary-material

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Perceptions of Parenting Practices and Psychological Variables of Elite and Sub-Elite Youth Athletes

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Drawing from the model of parental involvement in sport, the overall purpose was to examine the associations of perceptions of parenting practices (encouragement, reinforcement, instruction, and role modeling) and athletes' psychological variables (self-efficacy, social self-efficacy, self-regulation, and intrinsic motivation) of elite and sub-elite youth athletes. Participants were elite (n = 210) and sub-elite (n = 635) athletes aged between 14 and 18 years (M_{age} = 16.58, SD = 1.33). Structural equation modeling analysis revealed that young elite athletes' perceptions of sport-related parenting practices are associated with their psychological skills and performance level in sport. Specifically, in comparison with their sub-elite peers, perceptions of parental encouragement had a significantly different strong effect on intrinsic motivation. Moreover, perceptions of parental modeling revealed different effects on performance level, as well as on intrinsic motivation, and self-regulation. These perceptions of parenting practices may promote a positive learning environment, resulting in an increased likelihood of achieving a high level of sport performance in comparison with their sub-elite peers.

Keywords: intrinsic motivation, parental roles, self-efficacy, self-regulation, structural equation modeling, youth sport

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INTRODUCTION

Early achievement of elite in sport is influenced by the type of experiences that young athletes have throughout their development, including the psychosocial relationships they establish with their parents (Côté, 1999). Although researchers have tested the influence of parents' behaviors on young athletes' psychological variables in sport (e.g., Babkes and Weiss, 1999; Fredricks and Eccles, 2005), research has generated few empirical data demonstrating how parenting practices influence young athletes' attainment of high levels of performance in sport. In fact, theoretical frameworks that guided research on parents' influences on differential child outcomes in sport and physical activity, such as the Eccles' model of parental influence on children's motivation and achievement (e.g., Fredricks and Eccles, 2004) do not specify the characteristics of parents' involvement and support in competitive sport situations (Holt et al., 2008).

To further understand parental influence in youth sport, Teques and Serpa (2009, 2013) and Teques et al. (2015, 2018) adapted the model of parental involvement in sport, originally developed by Walker et al. (2005). In the present study, we use this model as a framework to specifically examine the associations between parenting practices and psychological skills of elite and sub-elite youth athletes.

Theoretical Model

The model of parental involvement in sport (Teques and Serpa, 2009, 2013; Teques et al., 2015, 2018) was developed to explain why parents get involved in their children's sport, what type of behaviors they display during their involvement, and how their involvement influences young athletes' psychological variables in sport. Recent empirical studies (Teques et al., 2015, 2018) have shown parents' involvement decisions were primarily influenced by (a) a personal construction of a sport specific parental role, (b) the outcomes they expect will follow from their actions to support young athletes development, (c) their perceptions of invitations from the athlete and the coach to be involved, (d) their knowledge and skills about the athlete's sport, (e) and their assessment of time and energy to support the athlete's needs (Teques et al., 2015). During their involvement, parents' reported behaviors (i.e., role modeling, reinforcement, encouragement and technical instruction) are associated with the athletes' psychological variables conducive to achievement in sport (i.e., self-efficacy, social self-efficacy with their coach, self-regulation, intrinsic motivation) via athletes' perceptions of parents' behaviors (Teques et al., 2018). The focus of this study was on how young athletes' perceptions of their parents' behaviors and athletes' psychological variables are associated with their level of performance in sport.

Perceptions of Parents' Behaviors and Elite Performance in Youth Sport

Athletes' perceptions of the dimensions of parental involvement practices have been consistently associated with achieving an elite status in sport (e.g., Wolfenden and Holt, 2005; Clarke et al., 2016; Knight et al., 2016). For example, Holt and Dunn (2004) conducted interviews to explore psychological skills among young elite soccer players. Data analysis showed the importance of parents in providing encouragement to support adolescents cope with stressors associated to elite youth sport.

Parents' modeling behaviors have the potential to influence children's behaviors through observational learning (Bandura, 1997). In talent development studies, children's perceptions of parents as models of hard work who set high standards of performance were reported to influence their achievement in sport. Parents also influence their children's participation in sport through the provision of directive behaviors, such as technical instructions. Specifically, Holt et al. (2008) suggested that parents' instruction behaviors during games accounted for more than one third of the recorded parental comments. In addition, Wuerth et al. (2004) found that athletes who progressed into a higher career stage, reported much more directive behavior from their parents (e.g., showing children how to improve and pushing them to train harder are embedded in praise for trying hard, warmth and understanding) than those athletes who stayed in the same career stage.

Psychological Variables and High Level of Performance in Sport

As several researchers in sport parenting literature have suggested (e.g., Babkes and Weiss, 1999; Woolger and Power, 2000) athletes' development of psychological attributes may mediate the relationship between parents' behaviors and young athletes' experiences in sport. Therefore, the theoretical model of parental involvement in sport (Walker et al., 2005; Teques and Serpa, 2009, 2013; Teques et al., 2015, 2018) identifies four main athletes' psychological attributes related to achievement of high level of performance which can be influenced by parental behaviors. These attributes consist of self-efficacy, social efficacy to relate with the coach, intrinsic motivation, and self-regulatory strategies.

In conceptualizing intrinsic motivation, Ryan and Deci (2006) proposed that people are motivated by innate needs for self-determination. For example, Mallett and Hanrahan (2004) reported that self-determined behaviors of elite athletes comprise enjoyment of sport tasks characterized by an orientation toward mastery, persistence and strong desire to achieve personal goals. The sense of goal accomplishment is associated with self-determined forms of motivation.

According to Bandura (1997), self-efficacy beliefs determine the goals individuals set for themselves, how much effort they exert, and their resilience to failure. Previous studies focusing on the differences of self-efficacy beliefs between elite and non-elite athletes reported conflicting results. For instance, Wilhelm et al. (2013) found that elite handball athletes achieve a higher perceived efficacy in comparison with non-elite athletes, whereas Toering et al. (2009) found no significant differences between groups. It has been suggested that parental encouragement and positive role modeling were related to adolescents' self-efficacy in physical activity (de Farias Júnior et al., 2014).

Another psychological attribute conducive to achievement of a high level of performance is self-regulation. Adolescent elite athletes distinguish themselves from their non-elite and sub-elite peers by their superior self-regulatory skills, underscoring the importance of self-reflection. These findings support the evidence that athletes who reflect upon their actions are likely to know when they make errors, which enables these athletes to learn (Toering et al., 2009).

Finally, although studies on perceptions of parents' social efficacy to relate with the coach were not found, the relevance of such conceptualization is based on studies developed in the academic domain that demonstrate an association between parents' social efficacy to interact with teachers and students' academic performance (Patrick et al., 2007). Similarly, studies in the sport domain support the influence of parents in the relationship between athletes and coaches (Jowett and Timson-Katchis, 2005). For example, Jowett and Timson-Katchis (2005) interviewed coach-athlete-parent links and showed that parents provide a variety of information and emotional support that are susceptible of influencing the value of the relationship between coach and athlete. Also, Averill and Power (1995) found that children who observe their parents' directive behaviors (i.e., they directly interfere with the coach's instructions, undermine the coach's authority, and annoy the coach with concerns for special treatment) showed low levels of cooperation with the coach, suggesting that high levels of parental involvement undermine the coach-athlete relationship. Hence, it is suggested that studies should aim to explain how athletes' perceptions of parents' behaviors interact with the sense of efficacy for relating with their coach.

Aim and Hypothesis

The main purpose of this study was to investigate the associations of perceptions of parenting practices and athletes' psychological attributes in elite and sub-elite participants. In particular, the focus of this study was on the differences between two groups of youth athletes: (a) elite athletes who belong to a national squad (i.e., selection of the best players of that sport who represent the country at international events), and (b) sub-elite athletes who compete at regional level, but they were never selected for national teams. On the basis of the model of parental involvement in sport, as shown in **Figure 1**, this study hypothesizes that perceptions of parenting practices, such as (a) encouragement, (b) reinforcement, (c) role modeling, and (d) technical instruction are directly linked with athletes' playing level (Hypothesis 1). Second, it is hypothesized that perceptions of parents' behaviors concerning (a) encouragement, (b) reinforcement, (c) role modeling, and (d) technical instruction will be significantly associated with young athletes' self-efficacy, social efficacy to relate with the coach, intrinsic motivation, and self-regulatory strategies (Hypothesis 2). Third, this study hypothesizes that young athletes' psychological variables, such as (a) self-efficacy, (b) social efficacy to relate with the coach, (c) intrinsic motivation, and (d) self-regulatory strategies, are associated with athletes' playing level (Hypothesis 3).

MATERIALS AND METHODS

Participants

Eight hundred and eighty-one young athletes (nboys = 689, ngirls = 192) aged between 14 and 18 years participated in the study. The sample comprised participants from the north, center, and south of the littoral regions of Portugal. Participants played a variety of team sports: soccer (44.6%), basketball (21.9%), handball (26.5%), and volleyball (7.0%). Because of the goal of the present study, only participants who identified the father and/or the mother as the person in their family who accompany them in their sport activities were eligible. Thus, data from 36 participants (nboys = 28, ngirls = 8) were withdrawn and the analyses were based on the remaining 845 athletes. The final sample included 210 elite and 635 sub-elite athletes aged between 14 and 18 years (Mage = 16.58, SD = 1.33). **Table 1** presents the participants' demographic information. Elite athletes were classified as those who participated in national teams. Sub-elite athletes competed at regional level. Athletes were representative of four age groups: Under-15 (30.0%), Under-16 (36%), Under-17 (21.3%), and Under-18 (12.7%). On average, participants practiced 5.3 h per week and had 9.2 years of experience in their current sport.

Procedure

This study was approved by the Ethical Committee of the Faculty of Human Kinetics of the University of Lisbon. Club directors and coaches from 23 sporting academies or clubs and four sport Federations authorized the researchers to directly contact athletes for participation. Parental consent forms and information sheets were given to all participants, which were returned when signed by the legal guardians (return rate of 92%). Prior to the administration of the questionnaires, it was made clear to all athletes that completion of the questionnaire was voluntary and that all responses would be kept confidential. Athletes' completed the paper and pencil questionnaires during team training camps, or before regular training sessions. A member of the research team collected the data at each sports club and answered any questions during the data collection. Questionnaires were handed to a research team member immediately upon completion to avoid coaches or other respondents from having the opportunity to examine athletes' questionnaires. Participants took about 15–20 min to complete the questionnaires pack.

Measures

Psychometric scales were used to assess perceptions of parents' behaviors and athletes' psychological variables. All measures employed a four-point Likert-type response scale, ranging from 1 (not at all true) through 4 (very true). All items are presented in the **Table 2**.

Perceptions of Parents' Behaviors

Four types of athletes' perceptions of parental involvement behaviors were examined (Teques et al., 2018): encouragement, reinforcement, instruction, and modeling. In order to assess perceptions of parents' encouragement, parents' explicit support to the young athlete's activities in sport were measured. Items referring to parents' expressed satisfaction when the child improves, learns new skills, and works hard in sport were included to address perceptions of parents' reinforcement behaviors. The instruction scale included items to assess athletes' perceptions of parents' technical instructions before, during and after their sports competitions. The modeling scale was aimed to measure perceptions of parental behaviors as values of hard work that impacts young athletes' sport experiences.

Psychological Variables

This study used four scales to assess athletes' psychological variables in sport: self-efficacy, social efficacy to relate with the coach, intrinsic motivation, and self-regulatory strategies. The sport efficacy scale refers to athletes' judgments of their capability to act in ways that will result in successful performance in their competitive sport. The measure of self-efficacy was adapted from the General Self-Efficacy Scale (Schwarzer and Jerusalem, 1995). The social self-efficacy scale with coach included items to

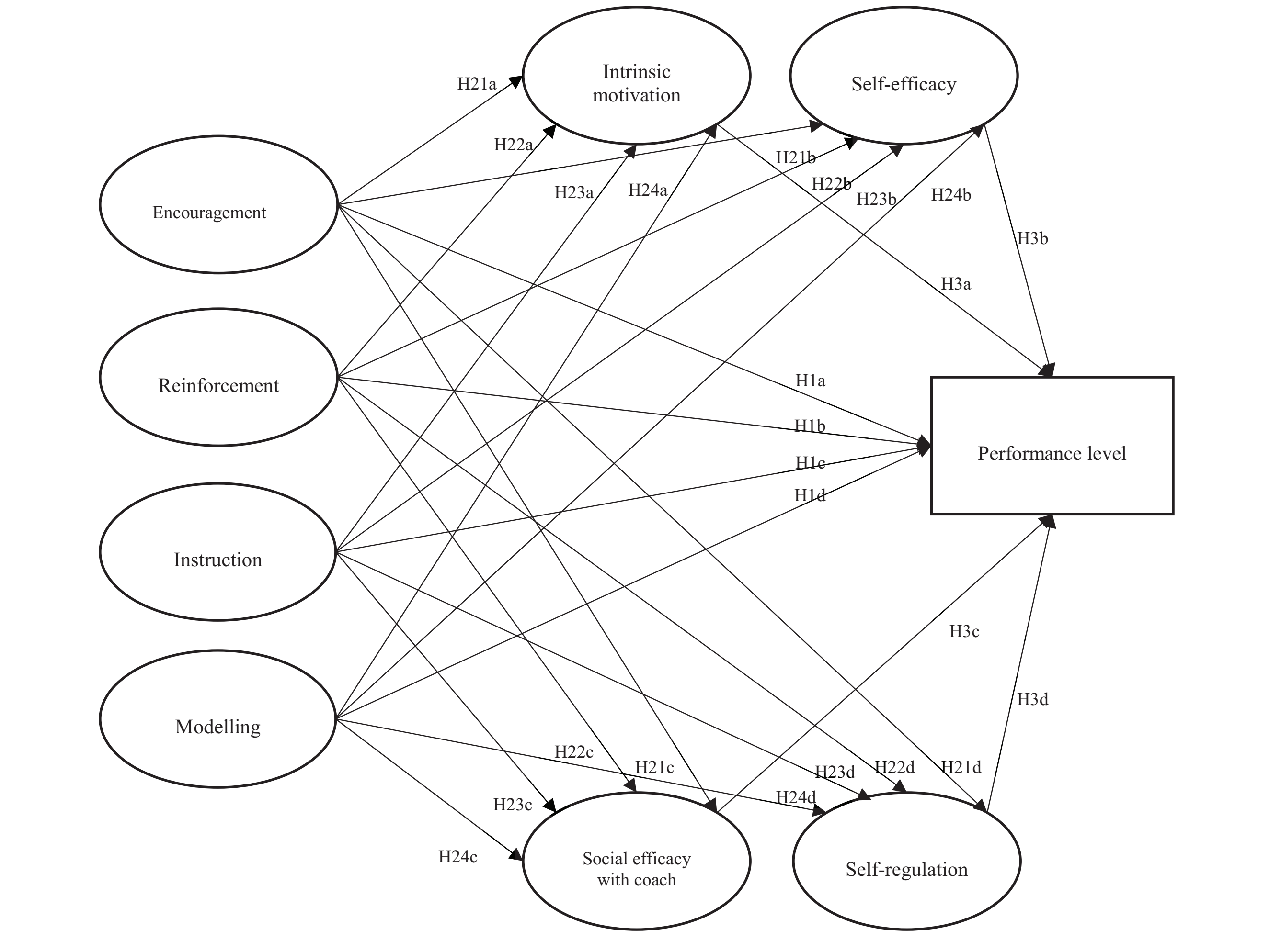

FIGURE 1 | Hypothesized model.

assess athletes' evaluations of their capacity to relate effectively with their coach. Thus, items from the Perceived Social Efficacy with Teacher (Patrick et al., 2007) were adapted to the sport context. The self-regulation strategies scale is based on a wide set of metacognitions and behaviors, such as self-reflection. Athletes self-evaluate the actions employed and the outcome achieved to improve next performance. Four items adopted from the Reflection subscale of the Self-regulation of Learning Self-report Scale (Toering et al., 2012) measured self-regulation. The intrinsic motivation scale focused on athlete's interest in sport practice for the pleasure resultant from trying to exceed oneself or to improve one's skills. Four items of the Intrinsic Motivation to Accomplish subscale of the Sport Motivation Scale were used (Pelletier et al., 1995).

Performance Level

Performance was defined as the level of participation attained by young athletes in their specific sport classified in two types: elite and sub-elite. Elite athletes were those who were selected in the last year for the national teams in their sports and have represented the country at international events. Sub-elite athletes were those who compete only at regional level in their sport and were never selected for national teams. Performance was coded according to youth athletes' playing level in their sport: 0 = sub-elite and 1 = elite.

Data Analysis

A two-step approach to maximum likelihood structural modeling were performed using IBM SPSS AMOS 23 (Analysis of Moment Structures; IBM Corp., Armonk, NY, United States). First, the measurement model was assessed conducting a confirmatory factor analysis (CFA). The internal consistency reliability estimates were evaluated through composite reliability (composite reliability $\geq$0.70; Hair et al., 2014). Convergent and discriminant validity were assessed to test construct validity. The average variance extracted (AVE) was estimated to evaluate convergent validity with values greater than 0.50 indicating convergent validity (Fornell and Larcker, 1981). The criterion to assume discriminant validity was that the AVE for each construct was larger than the inter-construct squared correlation

TABLE 1 | Characteristics of participants.

	Elite (*n* = 210)	Sub-elite (*n* = 635)	Total (*n* = 845)
Age (*M*, *SD*)	(16.77, 1.34)	(16.23, 1.14)	(16.58, 1.33)
Age groups			
Under-15	66	188	254
Under-16	81	223	304
Under-17	45	135	180
Under-18	18	89	107
Gender			
Boys	132	529	661
Girls	78	106	184
Sport			
Basketball	58	127	185
Handball	46	178	224
Soccer	88	289	377
Volleyball	18	41	59
Training (hours p/week)	(7.1, 1.2)	(4.9, 1.8)	(5.3, 2.2)
Years of competitive experience	(9.8, 2.3)	(9.1, 2.7)	(9.2, 2.4)

(Fornell and Larcker, 1981). We followed recommendations from Hair et al. (2014) to assess the adequacy of the model through a variety of fit indices: CFI (comparative fit index) and TLI (Tucker Lewis index) >0.90, RMSEA (root mean square error of approximation) and SRMR (standardized root mean square residual) <0.08.

Subsequently, the structural model was performed to test hypothesis. Also, a multi-group analysis was conducted in order to identify differences on the path coefficients among models for the elite and sub-elite groups. Following Byrne's (2010) suggestions, structural invariance between models was examined with chi-square (χ^2) and CFI difference (ΔCFI) values. The premise of invariance will be accepted if χ^2 is not statistically significant ($p > 0.05$); however, χ^2 is permeable to sample size and consequently changes in the ΔCFI of greater than 0.01 will be considered. The invariance between elite and sub-elite groups was evaluated by sequentially comparing the unconstrained model with the constrained measurement weights model and the constrained structural weights model. The statistical significance of the structural weights was assumed when critical ratios (CR) for differences among parameters produced by AMOS showed values >1.96.

RESULTS

Preliminary Analyses

A preliminary screen to the data was conducted to collect information about outliers, missing values, normality, and collinearity, as suggested by Hair et al. (2014). Missing values comprise 4.2% of cells in the original data, without any missing data patterns. Thus, missing data were imputed using AMOS's regression procedure. Twelve multivariate (Mahalanobis distance = *p1* and *p2* < 0.001) and univariate ($z < 3.00$) outliers emerged (eight cases in the sub-elite and four cases in the elite sample). These cases were removed from subsequent analyzes. Mardia's coefficient (38.74) exceeded minimum values for the multivariate normality. Hence, a Bollen-Stine bootstrap (B-S) on 2000 samples was used for subsequent analysis, as recommended by Nevitt and Hancock (2001). In addition, variance inflation factors were assessed to verify collinearity within all study variables, with values ranging from 1.12 (instruction) to 1.81 (encouragement), showing acceptable conditions to conduct regression analysis (Hair et al., 2014).

Measurement Model

Table 2 shows means, standard deviations and squared correlations among all variables in both subsamples. The mean scores showed that youth elite athletes revealed higher intrinsic motivation to accomplish ($M = 3.49$, $SD = 0.51$) and sub-elite showed lower levels of perceived parental instruction ($M = 2.43$, $SD = 0.86$). All variables are close to or exceeded the level greater than 0.50 of AVE for convergent validity, ranging from 0.49 to 0.65 (elite), and from 0.44 to 0.68 (sub-elite). AVE estimates for each construct were larger than the inter-construct squared correlation, supporting the discriminant validity of all variables. Additionally, the reliability coefficients were greater than 0.70 (Hair et al., 2014) in both models (**Table 3**).

The measurement model for youth elite [$\chi 2(436) = 675.32$, $p < 0.001$, CFI = 0.93, TLI = 0.92, RMSEA = 0.05 (CI = 0.04, 0.06), SRMR = 0.03] and sub-elite athletes [$\chi 2(436) = 974.87$, $p < 0.001$, CFI = 0.94, TLI = 0.94, RMSEA = 0.05 (CI = 0.04, 0.05), SRMR = 0.02] responses, indicated a satisfactory fit to the data (Hair et al., 2014). All items showed moderate to strong factor loadings ranging from 0.626 to 0.871 (elite) and 0.621 to 0.873 (sub-elite) (see **Table 3**).

Structural Model

Overall model fit for structural models was found to be satisfactory for both elite [$\chi 2(470) = 1438.58$, $p < 0.001$, CFI = 0.92, TLI = 0.91, RMSEA = 0.05 (CI = 0.05, 0.06), SRMR = 0.05] and sub-elite [$\chi 2(470) = 1174.87$, $p < 0.001$, CFI = 0.93, TLI = 0.93, RMSEA = 0.06 (CI = 0.05, 0.06), SRMR = 0.04] subsamples.

An examination of the path coefficients for each model in **Table 4**, identified several different relationships between the groups. Athletes' perceptions of parents' encouragement and reinforcement showed significant relationships on athletes' performance level in both models ($p < 0.01$; H1a and H1b), whereas the relationships between parental modeling and performance level were significant for the elite group ($\beta = 0.15$, $p < 0.01$), but not significant for the sub-elite group ($p > 0.05$) – H1d. In contrast, perceptions of parental instruction were not significantly associated with performance for both groups ($p > 0.05$) – H1c. Perceptions of parental encouragement showed a significant positive effect on intrinsic motivation, self-efficacy, and self-regulation for both elite and sub-elite groups ($p < 0.05$) – H21a, H21b, and H21d. The path estimates of perceptions of parents' encouragement and social efficacy with coaches were not significant for both groups ($p < 0.05$) – H21c. Perceptions of parents' reinforcement were significantly associated with intrinsic

TABLE 2 | Factor loadings, composite reliability (C.R.), and average variance extracted (AVE).

	Elite			Sub-elite		
Construct/Items	**Loading**	**C.R.**	**AVE**	**Loading**	**C.R.**	**AVE**
Encouragement: *The person in my family who accompanied me in my sport encourages me…*						
To strive in practices and competitions	0.751	0.84	0.57	0.811	0.84	0.57
To believe that I can do well in (…)	0.826			0.836		
To stick with my problems until I solves it	0.637			0.656		
To believe that I can learn new things (…)	0.793			0.724		
Reinforcement: *The person in my family who accompanied me in my sport shows me that he/she likes it when I…*						
Put maximum effort in practices (…)	0.871	0.88	0.65	0.846	0.88	0.66
Have a good performance	0.870			0.810		
Have a good attitude in practices and competitions	0.759			0.826		
Try hard	0.724			0.771		
Instruction: *The person in my family who accompanied me in my sport tells me…*						
Instructions during competitions	0.768	0.87	0.62	0.783	0.79	0.68
How to do things before the game	0.829			0.851		
How to do to be better	0.809			0.873		
What I did wrong or right after the game	0.759			0.797		
Modeling: *The person in my family who accompanied me in my sport…*						
Does not give up in face of difficulties	0.744	0.77	0.53	0.630	0.71	0.44
Works hard to achieve things	0.626			0.628		
Gives importance to the effort to achieve (…)	0.673			0.621		
gives the best he/she can (...)	0.764			0.740		
Intrinsic motivation						
I feel a lot of personal satisfaction (…)	0.828	0.84	0.57	0.760	0.83	0.56
For the pleasure I feel while improving (…)	0.713			0.791		
For the satisfaction I experience while (…)	0.671			0.680		
For the pleasure that I feel while executing (…)	0.808			0.758		
Social self-efficacy with coach						
I can get along with most of my coaches	0.665	0.86	0.62	0.749	0.85	0.59
I can explain what I think to most of my coaches	0.827			0.743		
I can get my coaches to help me if I have (…)	0.857			0.805		
I can get my coaches to help me develop (…)	0.797			0.790		
Self-efficacy						
I can always manage to solve difficult (…)	0.705	0.79	0.49	0.689	0.80	0.51
I can solve most problems if I invest (…)	0.719			0.687		
I can remain calm wen facing difficulties (…)	0.645			0.717		
I can usually handle whatever comes my way	0.739			0.760		
Self-regulation						
I reappraise my experiences so I can learn (…)	0.608	0.83	0.56	0.721	0.80	0.50
I try to think about my strengths (…)	0.757			0.661		
I think about my actions to see whether I can (…)	0.819			0.695		
I try to think about how I can do things better (…)	0.797			0.757		

motivation, self-efficacy and self-regulation for both groups ($p < 0.05$) – H22a, H22b, and H22d – while not significant with social efficacy with coach for both groups ($p > 0.05$) – H22c. Furthermore, perceptions of parents' instruction were negatively linked with intrinsic motivation and social efficacy with coach for both groups ($p < 0.05$; H23a and H23c). Moreover, perceptions of parents' modeling were related with performance for the elite group ($p < 0.05$). In contrast, perceptions of parents' modeling were significant with self-efficacy ($\beta = 0.09$, $p < 0.01$) and social efficacy ($\beta = 0.12$, $p < 0.01$) for the sub-elite group – H24a, H24b, H24c, and H22d. For the relationships between psychological variables and performance,

TABLE 3 | Means (M), standard deviations (SD), and squared correlations.

Construct	*M*	*SD*	Correlation matrix 1	2	3	4	5	6	7
Elite									
(1) Encouragement	3.29	0.57	1.00						
(2) Reinforcement	3.41	0.59	0.31**	1.00					
(3) Instruction	2.49	0.81	0.04**	0.06**	1.00				
(4) Modeling	3.41	0.51	0.22**	0.18**	0.05**	1.00			
(5) Intrinsic mot.	3.49	0.51	0.21**	0.12**	−0.03*	0.18**	1.00		
(6) Social efficacy	3.30	0.54	0.18**	0.05**	−0.08*	0.08**	0.15**	1.00	
(7) Self-efficacy	3.29	0.50	0.15**	0.18**	−0.02*	0.12**	0.16**	0.20**	1.00
(8) Self-regulation	3.38	0.55	0.15**	0.12**	0.01	0.12**	0.26**	0.18**	0.29**
Sub-elite									
(1) Encouragement	3.29	0.59	1.00						
(2) Reinforcement	3.36	0.61	0.30**	1.00					
(3) Instruction	2.43	0.86	0.02**	0.04**	1.00				
(4) Modeling	3.25	0.55	0.24**	0.23**	0.01*	1.00			
(5) Intrinsic mot.	3.37	0.50	0.13**	0.10**	−0.01*	0.06**	1.00		
(6) Social efficacy	3.34	0.57	0.06**	0.07**	−0.01*	0.07**	0.15**	1.00	
(7) Self-efficacy	3.26	0.51	0.09**	0.11**	−0.00	0.04**	0.11**	0.18**	1.00
(8) Self-regulation	3.25	0.53	0.13**	0.12**	0.00	0.07**	0.19**	0.22**	0.33**

No squared correlations failed the AVE test of discriminant validity. $^{*}p < 0.05$, $^{**}p < 0.01$.

TABLE 4 | Summary results of the structural model for each of the subsamples.

Path		Confirmed?	Elite β	Elite CR	Sub-elite β	Sub-elite CR	Power (1 – β)
H1a	Encouragement → Achievement	Yes	0.48**	15.62	0.36**	13.34	0.93
H1b	Reinforcement → Achievement	Yes	0.22**	8.01	0.24**	8.76	0.14
H1c	Instruction → Achievement	No	−0.02	−1.37	−0.02	−1.31	0.05
H1d	Modeling → Achievement	Partially	0.15**	5.55	0.05	1.86	0.99
H21a	Encouragement → Intrinsic mot.	Yes	0.52**	22.45	0.41**	16.30	0.88
H21b	Encouragement → Self-efficacy	Yes	0.10**	4.26	0.09**	3.66	0.12
H21c	Encouragement → Social efficacy	No	0.02	1.18	0.01	0.98	0.34
H21d	Encouragement → Self-regulation	Yes	0.11**	4.55	0.09**	3.61	0.23
H22a	Reinforcement → Intrinsic mot.	Yes	0.12**	4.91	0.12**	4.90	0.05
H22b	Reinforcement → Self-efficacy	Yes	0.10**	4.13	0.13**	5.04	0.30
H22c	Reinforcement → Social efficacy	No	0.02	1.03	0.01	0.15	0.34
H22d	Reinforcement → Self-regulation	Yes	0.09**	3.61	0.10**	3.23	0.11
H23a	Instruction → Intrinsic mot.	Yes	−0.09**	3.65	−0.14**	5.44	0.61
H23b	Instruction → Self-efficacy	No	−0.01	−1.12	−0.02	−1.34	0.21
H23c	Instruction → Social efficacy	Yes	−0.12**	4.89	−0.06*	1.78	0.86
H23d	Instruction → Self-regulation	No	0.01	1.11	0.02	1.32	0.21
H24a	Modeling → Intrinsic mot.	Partially	0.21**	7.89	0.02	1.30	1.00
H24b	Modeling → Self-efficacy	Yes	0.10**	4.25	0.09**	3.58	0.12
H24c	Modeling → Social efficacy	Yes	0.08**	3.15	0.12**	4.90	0.49
H24d	Modeling → Self-regulation	Partially	0.16**	5.25	0.02	1.29	0.99
H3a	Intrinsic mot. → Achievement	Yes	0.34**	11.14	0.29**	10.05	0.40
H3b	Self-efficacy → Achievement	Yes	0.28**	9.75	0.27**	9.14	0.09
H3c	Social efficacy → Achievement	Yes	0.15**	5.81	0.18**	6.76	0.25
H3d	Self-regulation → Achievement	Yes	0.36**	12.03	0.26**	9.10	0.86

$^{*}p < 0.05$, $^{**}p < 0.01$; *CR = critical ratio.*

results showed significant associations between self-efficacy, self-regulation, social efficacy with coach, and intrinsic motivation with performance for both groups ($p < 0.05$) – H3a, H3b, H3c, and H3d. Together, perceptions of parenting practices and proposed psychological variables explained approximately 28% of the variance for elite ($R^2 = 0.28$) and 20% for the sub-elite group ($R^2 = 0.20$).

Following Byrne's (2010) suggestions, a multigroup CFA was performed to analyze whether the path coefficients differed significantly between elite and sub-elite groups. The fit of the unconstrained model [$\chi 2(940) = 1823.29$, $p < 0.001$, CFI = 0.934, TLI = 0.931, RMSEA = 0.039 (CI = 0.038, 0.042), SRMR = 0.04] was satisfactory. As well as for the constrained measurement weights model [$\chi 2(946) = 1900.81$, $p < 0.001$, CFI = 0.930, TLI = 0.922, RMSEA = 0.040 (CI = 0.037, 0.041), SRMR = 0.05], and constrained structural weights [$\chi 2(952) = 1936.21$, $p < 0.001$, CFI = 0.922, TLI = 0.913, RMSEA = 0.051 (CI = 0.048, 0.055), SRMR = 0.05] models. The χ^2 statistic showed significant differences between unconstrained and constrained measurement weights models [$\Delta\chi 2(44) = 77.52$, $p = 0.001$], and between unconstrained and constrained structural weights models [$\Delta\chi 2(64) = 111.92$, $p = 0.001$].

An inspection to critical ratios (CR) for differences between parameters revealed that six structural paths differ significantly between groups (CR > 1.96, $p < 0.05$). Specifically, the path between perceptions of parental encouragement and intrinsic motivation showed differences among groups (CR = 2.34, $p < 0.05$). Moreover, perceptions of parental modeling revealed a significantly different relationship on performance level (CR = 3.93, $p < 0.05$), on intrinsic motivation (CR = 4.16, $p < 0.05$), and on self-regulation (CR = 2.92, $p < 0.05$). In addition, the relationships among intrinsic motivation (CR = 2.15, $p < 0.05$) and self-regulation (CR = 2.45, $p < 0.05$) with performance were significantly different between elite and sub-elite youth athletes. The path model presented in **Figure 2** shows the summary of differences within the models for both elite and sub-elite groups.

To verify the magnitude of the differences between elite and sub-elite proportions (p1 – p2), a *post hoc* power analysis was completed using GPower 3.1 (Faul et al., 2007). The significance level of $p < 0.05$ was adopted for the suitable level of greater than 0.80. *Post hoc* analyses showed in **Table 4** revealed statistical power for differences between groups.

DISCUSSION

In the present study, we examined the simultaneous associations between athlete's perceptions of parenting practices, self-reported psychological variables, and youth athletes' level of performance in sport. The data supported adequacy of the parental involvement in sport model in explaining how parents' behaviors are associated with their children's achievement of performance via important psychological variables.

Perceptions of Parents' Behaviors and Level of Performance in Sport

According to the model of parental involvement in sport, young athletes' perceptions of parents' behaviors are related to their sport participation (Teques et al., 2018). The findings of this study suggest that perceived encouragement and reinforcement were positively associated with both elite and sub-elite athletes. These

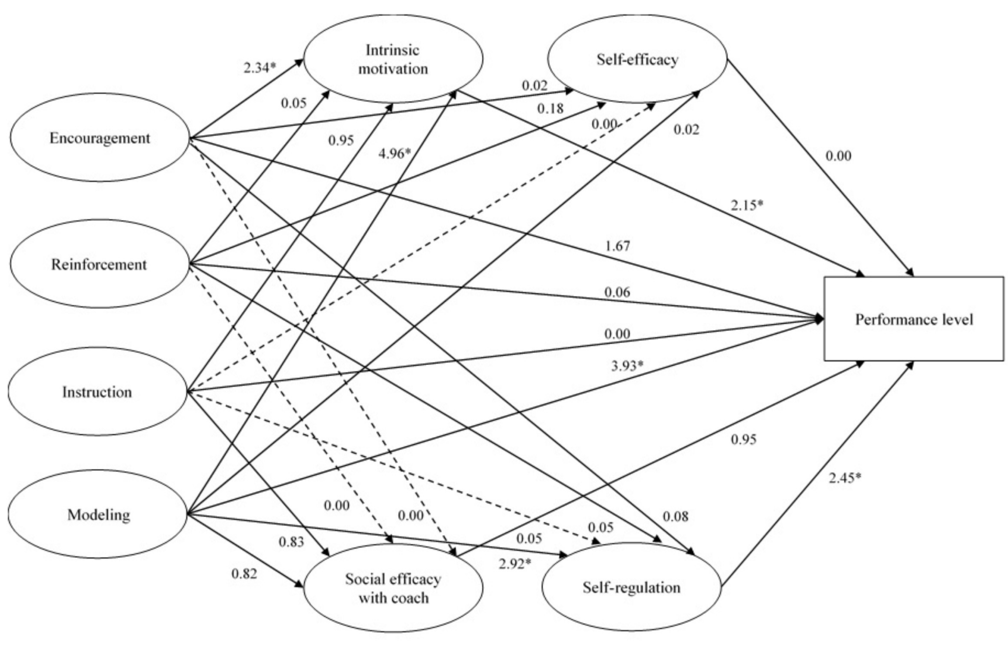

FIGURE 2 | Critical ratios (CR) for differences in structural parameters between both subsamples. *CR > 1.96, $P < 0.05$. The non-significant paths for both subsamples are presented by dashed lines.

results are in accordance with existing literature concerning family influences on children's development in sport (Côté, 1999; Wolfenden and Holt, 2005; Knight et al., 2016). Parents are providers of emotional support through encouragement and reinforcement behaviors and show commitment to doing one's best as values of achievement.

The relationship between parental modeling and performance level was significantly different between groups. Findings of this study showed that modeling as a parental role was only linked to elite athletes. In line with Bloom (1985), parents' commitment to doing one's best is an important value they taught their children; additionally, parental efforts in modeling hard work and setting high standards of performance was recognized by children. Although modeling is often cited conceptually as important for child's values, attitudes and behavior (Bandura, 1997), empirical studies relating parental modeling to achievement of a high standard in sport are rare. The current study examined athletes' perceptions of parental behaviors as values of hard work to impact young athletes' development in sport. Scholars used self-report questionnaires on parents' role modeling designed to assess participants' appraisals of the extent of their parents' involvement in sport and physical activity, revealing inconsistent findings. Babkes and Weiss (1999), for example, found that the perceptions of competence, intrinsic motivation and enjoyment of young soccer players were related with their appraisals of parents' as a positive role model in physical activity. Differing results were found by Fredricks and Eccles (2005) who reported that parents' role modeling, defined as time participation in sport activities, were not a determinant of children's sport participation. Even though modeling likely plays a role in the achievement of a high standard in sport, additional research is needed before its role can be fully understood.

Perceptions of Parents' Behaviors and Athletes' Psychological Variables

A consistent finding across both elite and sub-elite groups was the relationships between perceptions of parents' encouragement and reinforcement, and important psychological variables in sport, such as self-efficacy, self-regulation, and intrinsic motivation. The importance of parental emotional support is consistently evidenced to better understand how athletes achieve elite performance in youth sport (Côté, 1999; Holt and Dunn, 2004; Wolfenden and Holt, 2005). As well as Ward et al. (2007) suggested that elite players mentioned their parents as source of support and encouragement. However, previous research presented parents' behaviors using a descriptive view of emotional support, and the current findings point in evidence the ways in which sport parents shows adequate emotional support and how this optimize their child's psychological variables in sport. Specifically, results of the current study extend previous knowledge suggesting that the linkage between higher amounts of perceived parental encouragement and reinforcement and levels of performance could be explained by stronger beliefs of young athletes in their ability to master their sport activities and higher interest in sport practice for the sense of accomplishment derived from trying to surpass oneself.

The negative association between parental instructional behavior and young athletes' intrinsic motivation to accomplish and social efficacy for relating with the coach may suggest that parental instruction provided to directly command action may undermine athletes' sport experience. As suggested by Holt et al. (2008), this type of parental instruction represents 35% of the recorded comments during games, which means that over one third of the parents' comments may have the potential for undermining athletes' intrinsic motivation. From a self-determination perspective, performance pressure based on excessive instructions or using controlling words such as "should," are particularly insidious to motivation quality (Ryan and Deci, 2006). Furthermore, the negative relationship between perceptions of parent's instructional behaviors and the confidence to be socially related with the coach reinforce the idea that the perceptions of parental instruction by young athletes could undermine the quality of the coach-athlete relationship (Jowett and Timson-Katchis, 2005). In fact, demanding parents displayed behaviors that were generally disliked by the coach and the athlete, such as providing technical and tactical advice (Averill and Power, 1995).

Psychological Variables and Level of Performance in Sport

In line with the model of parental involvement in sport, self-efficacy, social self-efficacy with the coach, intrinsic motivation and strategies for self-regulation are associated with athletes' achievement of elite performance in sport. In this respect, findings of this study revealed a significant linkage between perceptions of parental modeling, self-efficacy and social self-efficacy for relating to coaches, and performance level. Previous research highlighted differences between elite and sub-elite players on self-efficacy beliefs in their sport experiences (Mallett and Hanrahan, 2004). However, the present study extends our understanding by suggesting that the relationship of achievement with perceiving parents as models of hard work could be explained by athletes' stronger beliefs in their ability to master their sport activities. These results reinforce the view that self-perceptions of efficacy operate as cognitive mediators of action (Bandura, 1997). Also, the present results corroborate research in academic context that found that students' efficacy to relate effectively with their teachers and peers is associated with math achievement (Patrick et al., 2007). Further clarification of the relative importance of self-efficacy and social efficacy beliefs in relation to achievement or other motivational outcomes seems merited in sport.

Limitations and Future Directions

Although the current study contributes to a broader understanding of parenting practices in the achievement of elite performance in sport, several limitations are worth mentioning. First, data were cross sectional, which limits causal interpretations of the regression effects. Although the hypothesized associations described in the structural model demonstrate an explanation that fits with the data, longitudinal studies should be developed to assess reciprocal effects to enhance the understanding of how parenting practices, psychological constructs, and elite youth achievement reciprocally impact each other across athletes' developmental stages (Côté, 1999). Second, it seems clear from the levels of variance explained by the model that there are other factors implicated in youth elite achievement in sport. Additional research is warranted to better understand how parenting practices relates to other specific sport performance characteristics. For example, parenting styles seem to indirectly influence on young athlete's behaviors, while parental practices have a direct effect on young athlete's behavior (Holt et al., 2009). Also, various personality characteristics have been associated with talented soccer players, including self-concept, fear of failure, hope for success or self-optimism (Feichtinger and Höner, 2015), and expectancies for success have long been recognized as important variables to explain achievement behaviors, such as task persistence and task choice (Fredricks and Eccles, 2004). Third, it should be recognized that findings of this study might differ depending on adolescent's gender (Fredricks and Eccles, 2005). Future studies are thus needed to further explore the structural mean differences between these two groups. Fourth, the scales used to evaluate psychological constructs (i.e., self-efficacy, social efficacy to relate with the coach, intrinsic motivation, and self-regulatory strategies) were purposely validated for this study. For this reason, we decided to perform a CFA and these scales showed relevant psychometric characteristics, including item individual reliability, scale composite reliability, factorial validity, and convergent and discriminant validity. However, due to the importance shown by these psychological constructs in this study, researchers should validate these instruments in full. Fifth, modeling and self-efficacy demonstrated problems of convergent validity, evidenced by low to moderate correlations between variables. Problems with convergent validity may be due to the fact that the constructs are composed by too few indicators (Kline, 2011). Future studies may explore the functioning of these scales in relation to other psychological constructs. Finally, participants are from a western European country, widely held by young athletes from two-parent families of middle-class status in order to examine parenting practices in youth elite sport. Most of the research on parental involvement has used similar samples. An important area of future research is how parents from different types of families (e.g., single-parent) with fewer resources support children's competitive sport. For example, different relationships between parental practices and youth elite achievement may be obtained with athletes from different cultures and socioeconomic status (cf., Holt and Dunn, 2004; Moraes et al., 2004).

CONCLUSION

In conclusion, the model of parental involvement since its development has contributed to an integrative rationale for research on youth sport, examining the relations between parent-child relationship and child psychological outcomes (Teques et al., 2015, 2018). Based on this line of research, the current study also contributes to expand knowledge about how parents' behaviors are associated with their children's achievement of elite performance in sport via important psychological variables.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available because the datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. Requests to access the datasets should be directed to pteques@ipmaia.pt.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Ethical Committee of the Faculty of Human Kinetics with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Ethical Committee of the Faculty of Human Kinetics.

AUTHOR CONTRIBUTIONS

PT and SS were enrolled in the study design, data collection, and wrote the first draft of the manuscript. PT, AR, and CS participated in the data analysis and wrote the methodology and results. PT, SS, and LC participated in the final revisions of the manuscript. All authors read and approved the final version of the manuscript and agreed with the order of the presentation of the authors.

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Impulsiveness and Cognitive Patterns. Understanding the Perfectionistic Responses in Spanish Competitive Junior Athletes

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Introduction: High performance sport requires that the athletes maintain a constant intensity and control of their personal resources, as well as a balance between self-regulation and performance. Likely, such requirements involve the influence of their beliefs regarding the tasks to be performed to improve the confidence in their own resources to face the competition. Theoretical arguments provide new insights for understanding multidimensional perfectionism and its relationships with other variables such as affective experiences, among others. In this study, perfectionism was conceptualized as a "stable personality disposition," whereas the impulsiveness components were defined as "representing psychological mechanisms (or processes)" underlying the relationships between perfectionism and athletic experiences.

Aim: This study aims to establish and show profiles of perfectionist beliefs and impulsive responses according to sport modality and the relationships between all these variables. Team athletes were expected to show more functional resources than those in combat or endurance sports.

Methods: The psychological responses of 487 athletes (273 boys; 214 girls) practicing high-performance sport were examined. A non-randomized, cross-sectional design was used. Self-reports were used to measure impulsiveness, perfectionism and competence self-perceptions.

Results: Athletes with functional responses of impulsivity and perfectionism showed higher perceived self-competence. Athletes with more reflective thoughts, more careful planning and generally less sensitive to rewards and behaviors were more self-regulated and planned (functional impulsivity) and showed more moderate relationships between the most dysfunctional perfectionist beliefs and self-competence. In addition, perfectionism seems to be useful to the striver athletes that want to be the best, and they are focused on and committed to future goals and performance and self-improvement. It is important for coaches and athletes to understand how the processes of self-regulation (impulsivity) and self-knowledge (perfectionism) could be formed to try to offer better opportunities for building psychological resources that enhance high-performance mental abilities.

Keywords: emotional stability, functional perfectionism, young athletes, sport competition, impulsiveness

INTRODUCTION

The study of impulsiveness, considered the internal force that generates the activation of a person, has traditionally been oriented toward the loss of control and difficulties in managing impulses derived from such activation (Bari and Robbins, 2013). The beliefs and skills related to how to achieve either impulse self-regulation or control, according to what the behavior or performance is, determine the interpretation of these as either a barrier or a reinforcement, with the person being unable to restrain signs of anger, anxiety or fear (in the case of interpretation as a barrier), or attachment or sensation stimulations (in the case of interpretation as a reinforcement) (Corr, 2004; Stoeber and Corr, 2015). In this sense, athletes must be aware of this ambivalence to be able to educate and train themselves and, in this way, to try to manage situations that pose an internal conflict in an assertive way (Laborde et al., 2018).

Cognitively, impulsiveness is characterized by the absence of reflexive control and the anticipation of posterior consequences, which leads to the making of mistakes in performance situations (Dalley et al., 2011; Smith et al., 2016). Emotionally, impulsiveness is characterized by a low tolerance for frustration, inability to delay reinforcements, little resistance to temptation and few control resources for regulating the impulses to quickly respond (Bridgett et al., 2015; Guinote, 2017), which is in opposition to the qualitative reactions of anger, happiness, anxiety, euphoria, or fear (neurotic response) (Cook et al., 2018). Socially, impulsiveness has been linked with socialization difficulties (Van Stekelenburg and Klandermans, 2017), low empathy (Baldner et al., 2015), prosociality (Do et al., 2017), dependence relations (Odacı and Çelik, 2016), aggressiveness (Johnson and Carver, 2016), and manipulation (Salekin, 2016).

In sports, functional impulsiveness requires the presence of high concentration (Kovářová and Kovář, 2010; Gustavson et al., 2014) and adequate self-regulation skills to achieve greater efficiency and speed in decision making or emotional expression (González-Hernández and Garcés de Los Fayos, 2014; Laborde and Allen, 2016; Cook et al., 2018). For example, for a taekwondo fighter to make the final attack to close the fight, for a golfer to decide the most appropriate blow on the next hole, or for a tennis player to deal with a disputed point, they need to maintain a high level of activation, which they have previously developed and processed as automatism in their execution of psychological training.

Perfectionism is considered both a one-dimensional and multi-dimensional trait of our personality, represented by beliefs of a self-demand for excellence and the inclination to set high standards for performance, followed by a hypercritical self-evaluation and high concern focused on errors (to avoid making them) (Frost et al., 1990). In recent years, different authors have defined perfectionism by setting the emphasis on interpersonal facets and social rules (socially prescribed perfectionism) or the internal aspects of individuals oriented toward achieving goals and aims (self-oriented perfectionism) (Flett and Hewitt, 2014; Madigan et al., 2015; Vicent et al., 2016).

By studying perfectionism in the field of sports, it is necessary to discern between perfectionist efforts and perfectionist concerns (Stoeber, 2014). On the one hand, perfectionist efforts (with an adaptive effect) are positively related to competitive self-confidence, positive emotions, hope for success, task orientation, and objectives focused on performance and mastery in both training situations and competition (Jowett et al., 2016). González-Hernández and González Reyes (2017) understand that the construction of perfectionist beliefs allows athletes to adapt to demands, allowing them to have less vulnerability to anxiety (Moshier et al., 2016). In fact, perfectionistic efforts has been negatively related to competitive anxiety and fear of failure. On the other hand, perfectionist concerns are related to emotions that can be considered negative (e.g., cognitive, competitive and pre-competitive anxiety, low self-esteem, fear of failure and avoidance, and practice and mastery of skills) (Koivula et al., 2002; Correia et al., 2015). Correia et al. (2015) consider that perfectionist concerns can have a predictive effect on the fear of failure and, therefore, a dysfunctional effect on the athlete both in competition and in training.

Furthermore, regarding the components of evolutionary and cognitive processes, which are in constant interaction with their contexts, processes such as perfectionism or impulsiveness have been characterized on base of functional or dysfunctional characteristics of humans. Perfectionism is functional when belief schemes have high performance standards in combination with an uncritical evaluation of them (Lo and Abbott, 2013; Mautz et al., 2017). Perfectionism is dysfunctional when high personal standards are associated with an excessively critical self-evaluation (Flett and Hewitt, 2006, González-Hernández et al., 2018). Impulsiveness has been described as functional through self-regulated emotions and behaviors (Boone et al., 2014; Macfarlane et al., 2016). In contrast, dysfunctional impulsiveness processes have been described when there is low emotional quality (De Silva et al., 2016; MacKillop et al., 2016), lack of impulse control (Smillie and Jackson, 2006; Donovan et al., 2014; Harden et al., 2017) and disruptive behavior (Renee-Renda et al., 2018).

Conceptualizations of perfectionism and impulsiveness in sports practice (Stoeber, 2014; Stoeber and Madigan, 2016;

Stoeber and Gaudreau, 2017) are associated with tendencies to excessively assess the level of concern for execution errors (e.g., "*The execution must to be perfect; any small failure is a failure*."), self-evaluation (e.g., "*Have I done it well or have I missed something?*"), feelings of uncertainty (e.g., "*What will happen now?*"), and parental and external expectations, as well as referring to contextual elements that are not very controllable and that do not depend on oneself (e.g., "*What will others think?*") or by giving too much importance to precision, order and organization (e.g., "*This is life for me; here, I cannot fail.*"). In essence, these are perfectionist concerns that are related to, on the one hand, high levels of fear of failure, stress, depression, anxiety and illness and, on the other hand, low levels of confidence in sports performance and satisfaction with tasks. In contrast, and mainly focused on self-security, perfectionism has also been associated with the capacity to make efforts and, at the same time, has been related to indicators of subjective well-being and psychological adjustment (Sirois and Molnar, 2016), greater motivation for participation in training and self-determined behavior in competitions, greater mastery of and orientation in tasks (showing a preference for difficult tasks) (Stoeber and Gaudreau, 2017), high self-confidence, better relationships among peers, and greater self-esteem and better coping strategies in difficult situations (Stoeber and Corr, 2015; González-Hernández and González Reyes, 2017).

The immediacy with which one lives the sport practice, which is excessively related to competition along with the rivalries that are constructed during the competition, and the excess of activation are sources of dysfunctional behaviors (Stoeber et al., 2009; see **Table 1**). Nevertheless, impulsiveness is an important factor in motor performance interference in open-skill sports modalities (e.g., *basketball, hockey, or volleyball*) that experience constant changes in the environment (e.g., *alterations in opponent positioning or changes in partial results*) (Poltavski and Biberdorf, 2015; Ellingson et al., 2019) and where the player is forced to inhibit pre-planned responses, anticipate actions and coordinate corporal segments based on the complex and dynamic flow of sensorial information (Lage et al., 2011).

Finally, considering the variability of such psychological responses as perfectionism and impulsivity and taking into account the characteristics that may be established between their functionality and dysfunctionality, the aims of this study are as follows: (a) to show the indicators of perfectionism and impulsivity in young athletes in the stage of sports technification and belonging to Spanish sports federations; (b) to reflect the linear relationships between them; and (c) to identify the differences in these relationships, according to the sports modality. To do this, a non-random, predictive and cross-sectional study has been designed with the hope of fulfilling the hypothesis that athletes who show a more functional impulsivity are associated with patterns of functional perfectionism and that those who show a more dysfunctional impulsivity are likely to show more patterns of dysfunctionality in terms of perfectionist beliefs. Those who practice more team sports are expected to show more functional responses than those who practice combat or endurance sports.

MATERIALS AND METHODS

Sample

The sample was composed of young Spanish athletes (N = 487), from two technification levels (under 23 years and under 19 years), who resided at the specialized centers of different sports federations and others sport clubs in different parts of Spain. Their age range was between 16 and 23 years old (Mage = 18.76; SD = 3.15). The average competition experience was 7.46 years (SD = 3.62), and the average weekly training session was 15.86 h/week (SD = 3.05). Regarding gender, the sample included 273 boys (50.60%) and 214 girls (43.94%). Sports modalities were grouped into three categories (see **Table 2**): sports combat (taekwondo, judo, karate, and boxing), team sports (soccer, basketball, hockey, volleyball, and handball), and endurance sports (open water swimming, triathlon, and BMX).

Instruments

Perfectionism

The Multidimensional Perfectionism Scale was used (FMPS, Frost et al., 1990, adapted to the Spanish population by Carrasco et al., 2010). This scale is formed by 35 items and consists of four dimensions of the first order (personal norms, organization, concern about mistakes, and doubt related to actions) and two of the second order (functional and dysfunctional). The response options for each of the items cover a range of 5 points on a Likert scale, with 1 meaning "*in total disagreement*" and 5 meaning "*completely agree*." The internal reliability of the questionnaire is high, with $\alpha = 0.87$.

Impulsiveness

The Barrat Impulsiveness Scale for adolescents was applied (BIS-11-A; Spanish adaptation and validation for Martínez-Loredo et al., 2015). This version kept up the 30 items of the original scale, linguistically adapted to adjust for coherence in sport contexts. Participants report, on a Likert scale, the frequency of different behaviors, with 1 being "*rarely or never*," 2 being "*occasionally*," 3 being "*often*," and 4 being "*almost always* or *always*." It is distributed in two subscales: general impulsiveness (e.g., "*I am happy-go-lucky*" or "*I change hobbies and sports*") and non-planned impulsiveness (e.g., "*I plan what I have to do*" or "*I like to think about complex problems*"). The scale is distributed in 30 items, the response range was between 30 and 120, and the internal consistency was $\alpha = 0.86$.

Procedure

First, the research was forwarded to and approved by the Human Research Ethics Committee of the University of Granada. The heads of sports centers (different federations and sports clubs in Spain) were informed about the reasons for and content of the investigation, the guidelines to be followed and requests for the pertinent permits. After consent was given, the protocol was established as follows: (a) there was a meeting with coaches (sometimes, the managers are the coaches), (b) an informed consent document was facilitated through email, in person or by smartphone for each parent/tutor in the case of

TABLE 1 | Functional and Dysfunctional behaviors in athletes.

Functional impulsivity-perfectionism	Dysfunctional impulsivity-perfectionism
Athlete looks for exciting experiences and assumes more risky goals.	Athlete shows a low tolerance for frustration and boredom.
Athlete acts before thinking independently of the situation-problem.	Athlete is disorganized and almost never plans activities.
Athlete is very creative, although many of his proposals are sketches that need to be polished.	Athlete is very forgetful and / or because of lack of foresight.
Athlete is clear about which objectives to direct his efforts.	Athlete changes from one activity to another very frequently.
Athlete is motivated and acts with determination.	Athlete is unable to keep calm to make decisions about their actions.
Athlete improves their efficiency in basic resources for sports performance (concentration, memory, reaction time, decision making, etc.).	Athlete requires a lot of supervision to avoid problems.
Athlete is able to understand when to need the help of others.	Athlete gets angry easily or maintain conflicts with figures in their environment.
Athlete has problems for acting inappropriately.	Athlete demands the help or asks others not to fail.

minors or directly in the case of adults, until the corresponding authorizations were obtained.

Finally, to protect and maintain ethical norms, the researchers explained the confidentiality, anonymity of data management and privacy, according to the American Psychological Association's ethical guidelines (World Medical Association, 2013). A member of the research team was always present to explain, resolve doubts about the answers, and maintain the scientific rigor for the proper application of the instruments.

Data Analysis

Different descriptive analyses (frequencies, central tendency, and dispersion) of socio-sport variables (gender, sport, and sports level) were carried out. Differential analysis was performed for gender (discriminant analysis) and sport modality (ANOVA with an interpretation of Bonferroni test and factor f for effect size), and the Kolgomorov–Smirnov test and Cronbach's alpha were used to assess compliance with the normality and statistical reliability, respectively. The possibility of making type I and type II errors in the hypothesis analysis was considered. Pearson correlation analysis (r) was performed to assess the linear relationship of the dimensions studied, and a radar graphic was created to show the description and differences of the profiles of the associated qualities and attributes, according to the practiced sports modality. The statistical package program IBM SPSS 23.0 was used.

RESULTS

Regarding the aim of showing the differential data about the direct relations between perfectionism beliefs and the impulsiveness response, we computed correlations of the impulsiveness subscales with second-order dimensions of perfectionism (functional and dysfunctional) in each one of the three sports modalities established (**Table 3**). It can be considered that functional perfectionism points to a direct, positive and significant relation with non-planned impulsiveness in all sports modalities studied while maintaining an inverse and significant relation with general impulsiveness, except for team sports, which did not show significant relationships.

Otherwise, dysfunctional perfectionism showed direct, positive and significant relationships with general impulsiveness but maintained inverse and significant relationships with non-planned impulsiveness in all sports modalities studied.

At the same time, "general impulsiveness" indicated positive correlations with concerns about mistakes ($r = 0.47$; $p < 0.03$), doubts related to actions ($r = 0.52$; $p < 0.00$), personal standards ($r = 0.52$; $p < 0.01$), and inverse relationships with the organization ($r = 0.75$; $p < 0.00$). Non-planned impulsiveness was mainly related in a positive way to the organization ($r = 0.60$; $p < 0.00$) and inversely to parental expectations ($r = 0.63$; $p < 0.01$), parental criticism ($r = 0.57$; $p < 0.00$), and doubts related to actions ($r = 0.49$; $p < 0.00$).

Univariate analyses according to gender indicated adequate discriminants ($\lambda = 0.89$; X2 = 33.57; $p < 0.01$), indicating significant functions of maladaptive perfectionism and general impulsivity in favor of boys and significant functions of non-planned impulsivity in favor of girls (78.3%). A comparison of the three sports modalities studied (**Figure 1**) showed that the means are lower for organization in team sports than in both combat sports (ß = 0.16; $p < 0.00$; $f = 0.28$) and endurance sports (ß = 0.19; $p < 0.01$; $f = 0.32$), and the means are higher in concerns about mistakes ($p < 0.00$), general impulsiveness (ß = 0.21; $p < 0.00$; $f = 0.27$) and doubts related to actions (ß = 0.15; $p < 0.01$; $f = 0.34$) with respect to combat sports but not endurance sports. Thus, endurance sports had higher means for general impulsiveness (ß = 0.18; $p < 0.02$; $f = 0.26$) than combat sports but not team sports. Combat sports had higher means for non-planned impulsiveness than both endurance sports (ß = 0.16; $p < 0.00$; $f = 0.25$) and team sports (ß = 0.17; $p < 0.00$; $f = 0.28$) and higher means for organization than both endurance sports (ß = 0.20; $p < 0.01$; $f = 0.33$) and team sports (ß = 0.17; $p < 0.01$; $f = 0.36$). Finally, combat sports showed lower scores in doubts related to actions than team sports (ß = 0.19; $p < 0.02$; $f = 0.24$) and endurance sports (ß = 0.18; $p < 0.02$; $f = 0.30$) and lower scores in concern about mistakes than both team sports (ß = 0.18; $p < 0.00$; $f = 0.28$) and endurance sports (ß = 0.20; $p < 0.00$; $f = 0.24$).

TABLE 2 | Socio-sport, dispersion and descriptors data of participants.

	General		Gender			Sport technification level		
	M_{age} (DE)	As-K	Boys	Girls	As-K	$U19_{years}$	$U23_{years}$	As-K
Combat sports (*n* = 128)	16.73 (4.17)	0.33 (−0.31)	76 (59.37%)	52 (40.63%)	0.42 (−0.23)	74 (57.81%)	54 (42.18%)	0.26 (0.31)
Team sports (*n* = 244)	19.84 (4.82)	0.42 (0.26)	134 (54.92%)	110 (45.08%)	0.34 (0.29)	147 (60.25%)	97 (39.75%)	0.32 (−0.20)
Endurance sports (*n* = 115)	19.23 (3.85)	0.28 (−0.13)	63 (54.78%)	52 (45.22%)	0.33 (−0.27)	43 (37.39%)	62 (53.91%)	0.37 (0.18)

As, Asymmetry; K, Kurtosis. $U19_{years}$, *Under 19 years old (Junior category);* $U23_{years}$, *Under 23 years old (Promises category).*

TABLE 3 | Correlations between perfectionism beliefs and impulsive response in young Spanish athletes.

		Combat sports		Team sports		Endurance sports	
	K-S	GIM	NPIM	GIM	NPIM	GIM	NPIM
Adaptive perfectionism	0.16	−0.59**	0.53*	–	0.34**	−0.62*	−0.35*
Desadaptive perfectionism	0.21	0.24*	−0.52**	0.44*	−0.56**	0.52*	−0.49**

**Significant < 0.05; **Significant < 0.01.*

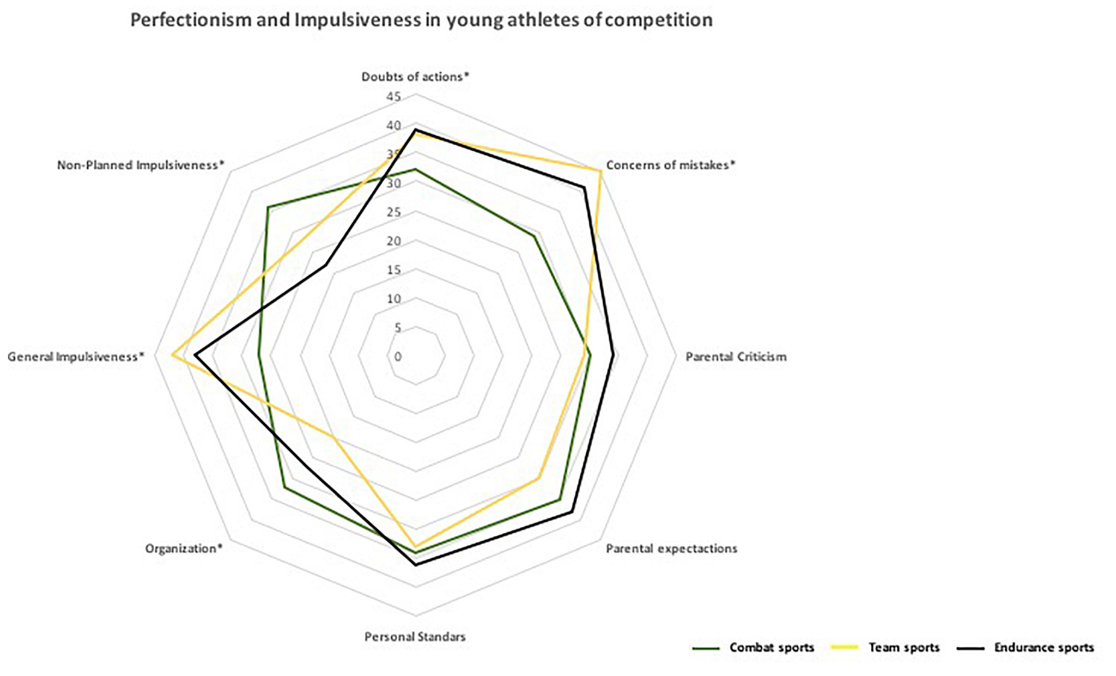

FIGURE 1 | Perfectionism and impulsiveness in young athletes of competition.

There were no significant differences between the three sports modalities in terms of parental criticism and personal standards.

DISCUSSION

For the purpose of analyzing perfectionism and impulsiveness scores in a sample of young athletes in competition, the present work describes how athletes of different sports modalities show different profiles and functional resources related to their psychological response.

First, inverse relationships were shown between functional perfectionism dimensions and general impulsiveness in athletes of combat and endurance sports but not of team sports. However, all modalities showed positive relationships with non-planned impulsiveness, as proposed by the first hypothesis.

These data indicate that athletes build different functional resources (such as perfectionism and impulsivity) based on the needs of each sport modality (e.g., combat sports have a philosophy in which athletes must obtain many self-regulation skills and important technical gestures). All of this makes the athlete work and train to learn how to plan, how to be more self-disciplined, how to focus on the present and how to pay less attention to other distracting stimuli (Williams et al., 2015), so such athletes tend to have high standards and minimal concerns (Suarez-Cadenas et al., 2016).

Although it could be considered that combat can lead to aggressive or impulsive behaviors, athletes of combat sports showed lower scores for general impulsiveness, as similar studies have shown (Parthi, 2013; Gronek et al., 2015). Other studies have indicated that practitioners of endurance sports (e.g., BMX, open water swimming, and triathlon) dispose of higher impulsiveness indicators (Monasterio, 2013; Hřebícková et al., 2014). Moreover, our sample showed inverse correlation scores between functional perfectionism and general impulsiveness. In this way, functional perfectionistic beliefs are considered worthy resources for managing situations in sports or other performance modalities (Stoeber et al., 2009; Gucciardi et al., 2012; Gouttebarge et al., 2015a). It is very likely that ordered thought and self-regulation sensations are the best strategies for psychological responses under pressure (Laborde et al., 2018). In team sports, this relationship has also been found in studies on rugby players (Gherghişan, 2015), volleyball players (Palmateer, 2016), and football players (Gouttebarge et al., 2015b). Thus, dysfunctional perfectionism responses showed positive relationships with dysfunctional impulsiveness and inverse relationships with functional impulsiveness in all sports modalities.

Some studies have also linked impulsiveness to positive outcomes such as lower reaction time (Congdon et al., 2010), high sensation seeking (Corr and Krupić, 2017), creativity (Kipper et al., 2010) and adventure behaviors (Quilty et al., 2014).

With reference to the second hypothesis, there were substantial differences among modalities. Combat sports showed that their athletes develop more functional resources than do those of the other modalities. Team and endurance sports athletes had the highest scores in dysfunctional resources. The literature on sports psychology, focused on disorders or alterations in behaviors, has shown that for training in this kind of sport, it helps to have high scores in perfectionism and low self-regulation (Hřebícková et al., 2014; Gouttebarge et al., 2015b; Nixdorf et al., 2016; Prinz et al., 2016).

In contrast, personal standards and parental criticism did not show differences in any of the sports modalities, which made us think that athletes, independent of their disciplines, understand sports competition in a similar way, with high self-demands to reach their athletic aims independent of the sport and modality (Dunn et al., 2006).

Similarly, although paternal figures influence perfectionistic beliefs by their high criticism and expectations (Appleton et al., 2010; Hill et al., 2014), such criticism did not show significant differences in the present study.

CONCLUSION

By analyzing the interactions between aspects related to sports success, this study will provide valuable information for coaches and athletes to enhance personal resources and psychological skills toward competition, which will allow them to make adjustments during training seasons.

For an athlete, striving to achieve the best result for success, fulfillment and improvement is similar to "his/her law" or his/her faith. However, the disappointment of achieving something less than "the best" often causes the athlete shameful and negative feelings. Researchers have examined the positive and negative sides of this double-edged sword. Perfectionist efforts (also described as "adaptive or functional perfectionism") help athletes to gain pleasure from their efforts. However, they also allow them to accept limitations and setbacks, even criticism. Building such functionally perfectionist beliefs in athletes or coaches directly influences their motivation, emotions, balance, and self-confidence. In fact, perfectionism is often seen as either a reinforcement in sports and performance contexts, (e.g., security in actions).

Athletes who describe striving for the best, focusing on future goals and performances, benefit from their perfectionism and are more likely to set goals. As a consequence, they commit themselves to working hard and self-improvement, generating a "perfect" and focused result in their thoughts, self-regulations and feelings. Self-regulation skills, planning skills, emotional management skills or the definition of expectations should be personal resources in psychological training, from which athletes can train and/or restructure their perfectionist beliefs and impulsive responses. Thus, a better understanding of competitive situations and sports planning (e.g., macro cycles, micro cycles, and competitions), the management of exaggerated pressure maintained over time or communication and empathic skills with their athletes will help coaches build better training environments and connections with their athletes. This will facilitate the mental growth that these athletes need to guide them in their competitive and non-competitive moments.

The findings present a number of limitations focused on the difficulties in data collection and the need to acquire permissions for entry into the changing rooms of clubs and sports institutions. Sports contexts are environments with high possibilities to show the importance of the connections between temperament and character resources under pressure responses in athletes. In this study, only two variables were considered, but we can reflect on more (e.g., narcissism and self-regulation). Therefore, new proposals will consider designs with more variables (e.g., predictive models or models combining three variables at different levels) and longitudinal research designs that can help to show the continuity or changes in the psychological response of athletes in their competition seasons, categories or personal circumstances (e.g., injuries or sport transition).

AUTHOR CONTRIBUTIONS

JG-H developed the methodological proposal and data analysis, realized the literature review, and wrote the part of the theoretical frame. MG-L described the "Conclusion" and "References" sections. CCD collaborated in data analysis and results redaction.

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Body Composition and Cognitive Functioning in a Sample of Active Elders

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The purpose of this paper was to analyze the relationship between body composition and cognitive functioning in an elderly people's sample. A total of 106 older adults between the ages of 60 and 79 were involved in physical activity (M = 67.57; SD = 4.96). About 31.10% were men (n = 33) and 68.90% were women (n = 73). The instruments used to assess cognitive capacity were the Trail Making Test (forms A and B), the Stroop Test, and the Attention Test d2. The body composition of the participants was evaluated by electrical bioimpedance. Correlation analysis, linear regression (successive steps), and cluster analysis were carried out to analyze the relationships between the different measures. The results showed significant relationships between the analyzed variables. In addition, muscle mass predicted the cognitive functioning values. These results suggest that healthy lifestyles, including physical activity, are essential for well-being and quality of life in older people. In addition, it appears from the results found that it would be necessary for these lifestyles to contribute to preserving their level of physical condition, because of the possible impact it would have on their health.

Keywords: physical activity, body composition, elderly, attention, cognitive development

INTRODUCTION

Active aging is associated with positive health effects, improved psychosocial functioning, and lower mortality risk (Haskell et al., 2007; García-Molina et al., 2010; Reigal and Hernández-Mendo, 2014). Specifically, regular physical activity is associated with improvements in the cognitive functioning of older people, as evidenced in research conducted in recent years, in which positive relationships have been found with abilities such as attention, memory or executive functioning (Bherer, 2015; Daly et al., 2015; Iuliano et al., 2015; Sánchez et al., 2018).

Specifically, attentional capacity has been studied from numerous authors (Marshall et al., 2015; Strait et al., 2015). This is a basic cognitive capacity that is related to multiple cognitive processes such as memory, executive control, language or learning, and has a great interest in educational or clinical field (Maureira and Flores, 2017). Dimensions such as selective attention is considered as an indicator of the ability to attend to specific stimuli and ignore others, being a relevant process to successfully perform a broad set of tasks that allow people to adapt correctly to their environment (Estévez-González et al., 1997; Giuliano et al., 2014).

Likewise, executive functioning refers to a set of complex cognitive processes considered relevant to people's functioning (Davis et al., 2011; Kramer and Colcombe, 2018) and is related to the control of thought and behavior (Zelazo and Carlson, 2012). These processes include aspects such as inhibitory control, cognitive flexibility, the organization and planning tasks, the selection of objectives and the establishment of strategies to achieve them, or working memory (Banich, 2009; Barkley, 2012; Diamond, 2013; Karr et al., 2018).

These functions may suffer a natural decline throughout the aging process (Schiebener and Brand, 2017), being the main cause of loss of autonomy in the elderly population (Boucard et al., 2012; Weinstein et al., 2012). Therefore, the main lines of research encourage cognitive assessment in adulthood as an effective predictor of cognitive decline in old age (Ferreira et al., 2015), as well as promoting healthy and active lifestyles (Ballesteros et al., 2013).

Although physical activity has been described as a predictor of cognitive functioning, several studies have highlighted the need to assess the impact it has on physical condition to adequately interpret its incidence on brain development (Reiter et al., 2015). In other words, physical activity must modify physical and physiological parameters to modulate the impact on health. Thus, several studies have revealed that the benefits of physical activity on cognitive functioning in the elderly were preceded by changes in physical condition and brain structure (Guzmán-Cortés et al., 2015; Fernandes et al., 2017; Jonasson et al., 2017).

Cognitive aging, and its relationship to physical condition and body composition, has been the subject of several studies (Cansino et al., 2011; Albinet et al., 2012; Weinstein et al., 2012; Müller et al., 2017). Some studies have shown that cardiovascular fitness, achieved through moderate to vigorous physical activity, has been associated with both relative preservation of inhibitory capacity later in life and general improvements in cognitive functions throughout adulthood (Kamijo et al., 2009; Boucard et al., 2012; Kerr et al., 2013). In addition, it has been shown in several studies that the organic deterioration produced by aging could be cushioned by physical condition and body composition, which are predictors of some health parameters. Thus, a study of 32 Parkinson's patients investigated posture, stability, and body composition as relevant factors from a neurological disease prevention perspective (Wilczyński et al., 2017).

Similarly, at present, there is a special interest in structuring healthy lifestyles and the practice of physical activity in those cases in which it is presented as an alternative to pharmacological interventions, showing potent improvements in executive control processes in women at risk of cognitive impairment (Baker et al., 2010). In response to this demand, new lines of research on the cognitive benefits associated with physical activity place their attention not only in the benefits derived from the practice of aerobic activities by itself but also in programs that also require cognitive execution (Reyna et al., 2013; Diamond, 2015). The results obtained by these studies provide new data on the positive impact of physical activity on the cognitive health of older people and open the door to a new range of work pathways (Reigal and Hernández-Mendo, 2014).

Thus, the existing literature has shown that only practicing physical activity does not ensure improvements in health, but it is necessary to observe the impact it has on the organism. For this reason, to analyze whether there are significant differences between people who carry out physical activity by differentiating two groups in terms of a better body composition condition, the aim of this work was to evaluate the relationships between body composition and cognitive functioning in a sample of active elderly people in the province of Malaga.

MATERIALS AND METHODS

Participants

In total, 106 active older participants (age: $M = 67.57$; SD = 4.96) from the municipalities of Benalmádena ($n = 36$) and Ronda ($n = 70$), both in the province of Málaga (Spain), were evaluated. All engaged in regular physical activity, specifically maintenance activities in organized groups with a frequency of 2 days a week for 60 min. About 31.10% were men ($n = 33$) and 68.90% were women ($n = 73$) and had a highly variable practical experience, ranging from 1 to 46 years ($M = 9.19$; SD = 9.37).

Measurements

Cognitive Flexibility

As a measure of executive function, cognitive flexibility includes the capacity for cognitive control and implies the capacity to inhibit the first response, the automatic response or the most obvious response, flexibly changing the choices to give way to a second response pertinent to the variation of requirements of the task (Buller, 2010). To obtain a measurement of the cognitive flexibility of the participants, the Trail Making Test was used in its forms A and B (Reitan, 1958, 1992; Tombaugh, 2004). The Trail Making Test Form A consists of 25 numbers distributed randomly on a sheet of paper, which must be connected by a line in ascending order by the participants, leaving no unconnected numbers. On the other hand, the Trail Making Test Form B requires the participant to alternate numbers and letters by joining upwards and interspersed 13 numbers with the first 12 letters of the alphabet. Prior to each form of the test, the participant has a detailed example, which allows the researcher to make sure that the participant has understood the instructions correctly. For both form A and form B of the test, the performance of the tests is timed by the assessor.

Inhibitory Control

Measurement of executive function involves the selection of relevant stimuli required for the achievement of the objective, the maintenance of focus on relevant stimuli, and a low level of sensitivity to interference by irrelevant stimuli (Buller, 2010). For the evaluation of inhibitory control, the Stroop Test was used (Stroop, 1935; Golden, 2001). In this test, the participant must do three consecutive parts, having 45 s to accomplish each of them. Thus, the first of the tests presents the words "RED," "GREEN," and "BLUE" distributed along a list of 100 words, asking the participant to name as many as possible in the established time. The second of the tests presents the text "XXXX" written in green, red or blue, configuring in total a new list of 100 elements, in this case, the participant must indicate the color of the ink in which it is written. In the third and last test, 100 words are presented that indicate the colors "RED," "GREEN," and "BLUE" but written in a different one, which generates an interference effect. The participant, as in the second test, is urged to say the color of the ink in which the words are printed, thus inhibiting the direct reading of them.

Attention

For the evaluation of the participants' attention, the Attention Test d2 was used (Brickenkamp and Zillmer, 2002). This test consists of a total of 14 lines, each of which contains the letter d repeatedly, as well as the p interspersed. The task asked the subject to mark each letter d that has two small lines distributed either above the letter, below or in both places, adding in any case a total of two lines around the letter. To do this, the subject has 20 s to make as many marks as possible in each line, once this time has passed, they must continue the task on the next line. The main concepts to be evaluated by the test are those of sustained attention, requiring the participant to maintain continuous attention for approximately 10 min; and selective attention, with the participant having to select only those relevant stimuli from each line, inhibiting the rest of the distracting stimuli.

Anthropometric Measurements and Body Composition

To analyze the height, a tape measure was used and placed on the wall completely straight and glued to prevent displacement during the measurement and a square was placed over the head of the participant, noting the result later. The researchers read about it beforehand so that the measurements would be as realistic as possible with the means available. In addition, a bioimpedanciometer (Tanita® Body Composition model BC-601) was used. The model is a tetra-polar machine, which has electrodes in four points of contact on the sole of the foot, and two on a support that is grasped with the hands, which use a low frequency signal to obtain the measurement to evaluate corporal fat, percentage of muscular mass, and the percentage of bone mass. Prior to obtaining the data, parameters such as age, gender, the person's level of physical activity and height are added.

Procedure

Prior to carrying out the study, directors and monitors of the Benalmádena and Ronda Municipal Sports Center were contacted in order to obtain their consent, subsequently the participants were informed about the study that was going to take place, the aspects relating to their privacy and voluntary nature of their collaboration. In addition, prior authorization was obtained from the Ethics Committee of the University of Malaga (no. 244, CEUMA Registry No.: 19-2015-H). After the first contact, the volunteer participants were summoned individually in offices set up for the interviews and informed consent of each participant was obtained before starting the evaluations. Also, ethical principles of the Declaration of Helsinki were respected (World Medical Association, 2013).

Each evaluation session lasted approximately 30–60 min, although for personal reasons of the participants, with some of them it was necessary to have more than one appointment to perform all the tests. The structure of the sessions was as follows: presentation of the study, obtaining informed consent, brief initial interview to obtain health-related data such as drug consumption, cognitive tests, height measurement, and obtaining anthropometric measurements and body composition by bioimpedance. Most of the measurements were intended to be taken in the morning, without shoes and with comfortable, light clothes. Considering aspects such as not attending after a meal or intense exercise as indicated by the device's instructions, and after a brief period of rest seated before.

Data Analysis

Descriptive and inferential analysis of the data was performed, as well as a study of data normality (Kolmogorov-Smirnov and Shapiro-Wilks). Correlations between physical and cognitive measures were analyzed using Pearson's bivariate coefficient. Previously, a treatment of lost values was carried out. In addition, a k-means cluster analysis was performed and two groups were generated. The U-Mann Whitney test was used to compare scores between groups. The $p < 0.05$ was considered for rejecting null hypothesis. The statistical package used was the SPSS version 20.0.

RESULTS

Descriptive and Correlation Analysis

Table 1 shows the data referring to the descriptive statistics of maximum values, minimum values, mean values, and standard deviation of the variables studied. Normality analysis was performed using the Kolmogorov-Smirnov test, as well as analysis of asymmetry and kurtosis. In the variables where the criterion of normality was not fulfilled, a transformation of the score with $\ln(x)$ was carried out, obtaining proportional distributions that satisfactorily fulfilled this criterion (Commissions-D2: $Z = 1.18$, $p > 0.05$; total effectiveness of the test (TOT)-D2: $Z = 1.35$, $p > 0.05$; Trail Making Test A: $Z = 0.69$, $p > 0.05$).

Table 2 shows the results of Pearson's correlation analysis. This analysis indicated the existence of relationships between body composition and cognitive measures. Specifically, the most

TABLE 1 | Descriptive and normal statistics.

	Mean	SD	Asymmetry	Curtosis	Z
Age	67.57	4.96	0.26	−0.75	0.89
% Fat mass	37.54	6.42	0.12	0.66	0.76
% Muscle mass	59.23	6.65	0.04	1.35	0.93
% Bone mass	3.19	0.33	0.18	1.15	0.88
Physical practice experience (years)	9.19	9.37	1.72	3.04	10.80**
D2-TR	41.15	12.68	0.80	2.71	1.09
D2-TA	38.59	14.31	0.88	2.27	1.34
D2-O	43.45	21.29	0.58	0.15	1.06
D2-C	24.13	16.92	0.87	0.18	1.44*
D2-TOT	36.25	11.63	0.45	0.24	10.81**
D2-CON	31.52	14.45	−0.01	−0.52	1.04
D2-TR+	41.15	11.86	−0.28	0.78	0.68
D2-TR−	48.85	10.42	0.53	−1.04	1.30
D2-VAR	50.94	22.22	0.21	−0.52	0.79
Trail Making Test A	48.31	19.18	1.14	1.86	1.41*
Trail Making Test B	119.85	52.56	0.95	1.05	1.25
Stroop-words	88.81	20.42	0.31	−0.33	0.57
Stroop-colors	60.72	13.17	0.20	−0.11	0.71
Stroop-words/colors	34.81	12.71	0.88	1.01	0.84

*Z = Kolmogorov-Smirnov; D2-TR = total number of attempts; D2-TA = total hits; D2-O = omissions; D2-C = commission; D2-TR+ = line with the highest number of attempted elements; D2-TR− = line with fewer items attempted; D2-TOT = total effectiveness in the test; D2-CON = concentration index; D2-VAR = variation index.*p < 0.05; **p < 0.01.*

TABLE 2 | Correlation level (Pearson).

	D2									Trail Making Test		Stroop		
	TR	TA	O	C	TOT	CON	TR+	TR−	VAR	A	B	W	C	W/C
Age	−0.16	0.6	0.11	−0.04	−0.13	−0.06	−0.21*	−0.05	−0.15	0.34**	0.25*	−0.07	−0.03	0.00
% FM	−0.18	−0.16	−0.2	−0.11	−0.24*	−0.21*	−0.10	−0.22*	0.05	0.28**	0.27**	−0.10	−0.10	−0.14
% MM	0.23*	0.19	0.00	0.09	0.29**	0.25**	0.13	0.23*	−0.04	−0.31**	−0.32***	0.11	0.15	0.21*
% BM	0.20*	0.18	0.01	0.06	0.26**	0.22*	0.13	0.21*	−0.01	−0.28**	−0.27**	0.09	0.12	0.19*
PPE	−0.03	−0.17	−0.14	−0.01	−0.07	−0.09	0.08	−0.16	0.19	−0.10	−0.11	0.15	0.06	0.05

*FM = fat mass; MM = muscle mass; BM = bone mass; PPE = physical practice experience; D2-TR = total number of attempts; D2-TA = total hits; D2-O = omissions; D2-C = commission; D2-TR+ = line with the highest number of attempted elements; D2-TR− = line with fewer items attempted; D2-TOT = total effectiveness in the test; D2-CON = concentration index; D2-VAR = variation index; W = words; C = colors; WC = words/colors.*p < 0.05; **p < 0.01; ***p < 0.001.*

TABLE 3 | Linear regression analysis (successive steps).

Variable criterion	*R*	R^2 corrected	D-W	Predictor variables	Beta	*t*	*T*	FIV
D2-TR	0.27	0.06	2.17	% MM	0.27	2.76**	1.00	1.00
D2-TOT	0.38	0.13	1.86	% MM	0.38	3.24**	1.00	1.00
D2-CON	0.33	0.10	1.60	% MM	0.33	2.72**	1.00	1.00
TMT-A	0.40	0.15	1.89	% MM	−0.40	−4.30***	1.00	1.00
TMT-B	0.37	0.13	1.99	% MM	−0.37	−3.99***	1.00	1.00
Stroop W/C	0.21	0.04	2.03	% MM	0.21	2.23*	1.00	1.00

*D2-TR = line with fewer items attempted; D2-TOT = total effectiveness in the test; D2-CON = concentration index; TMT-A = Trail Making Test A; TMT-B = Trail Making Test B; Stroop-W/C = Stroop words/colors.*p < 0.05; **p < 0.01; ***p < 0.001.*

remarkable relationships occurred with the TOT, CON and TR+ measurements of Test D2, as well as with the TMT measurements (forms A and B). Age was only significantly associated with TR+ (D2) and TMT (forms A and B).

Linear Regression Analysis

Table 3 shows the linear regression analysis performed using the successive steps technique. The predictor variables in each model are visceral fat and muscle mass, and the criterion variables are components of the different cognitive questionnaires. This procedure has been used to check out which aspects of body composition (in this case muscle mass and visceral fat) allow predicting the value of the cognitive questionnaires (D2, Trail Making Test and Stroop). The variables excluded in each case are due to their lack of significance ($p > 0.05$).

Referring to the Durbin-Watson statistic, the values ranged from 1.60 to 2.17. Based on the interpretation of Pardo and Ruiz (2005), when the statistician is between 1.50 and 2.50, it can be assumed that the waste is independent and the assumption of independence of independent variables with respect to the dependent is fulfilled. For their part, collinearity statisticians indicated appropriate variance and tolerance inflation values.

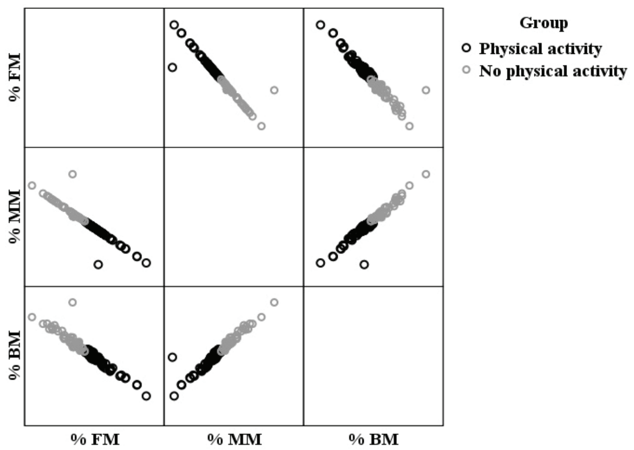

FIGURE 1 | Clusters made from body composition measures. Note. FM = fat mass; MM = muscle mass; BM = bone mass.

As can be seen in **Table 3**, the analysis, using the successive steps method, indicated that the percentage of the muscle mass variable predicted the scores in some measures of the attention test d2, specifically TR (R = 0.27; R^2 *adjusted* = 0.06; F = 7.61; $p < 0.01$), TOT (R = 0.38; R^2 *adjusted* = 0.13; F = 10.51; $p < 0.01$), CON (R = 0.33; R^2 *adjusted* = 0.10; F = 18.98; $p < 0.001$), as well as Form A scores (R = 0.40; R^2 *adjusted* = 0.15; F = 18.56; $p < 0.001$) and B of the Trail Making Test (R = 0.37; R^2 *adjusted* = 0.13; F = 15.91; $p < 0.001$) and Stroop P-C (R = 0.21; R^2 *adjusted* = 0.04; F = 4.97; $p < 0.05$).

K-Means Cluster Analysis

Through cluster analysis (*k*-means), two clusters were generated depending on the variable's fat mass percentage, muscle mass percentage, and bone mass percentage. Each case was well classified, since the maximum distance of each one from the center of its group (14.22) was less than the distance between the centers of the clusters (50.36). Thus, and as can be seen in **Figure 1**, the two groups constituted were characterized by (1) having a higher percentage of bone and muscle mass, as well as lower fat mass (n = 46; 20 men and 26 women; age: M = 66.76; SD = 4.72; practical experience: M = 8.79; SD = 10.55) and (2) have a lower percentage of bone and muscle mass, as well as higher fat mass (n = 60; 13 men and 47 women; age: M = 68.18; SD = 5.09; practical experience: M = 9.39; SD = 8.82). The two groups did not show differences in age ($p < 0.05$) or

TABLE 4 | Descriptive and normal measures of the variables analyzed as a function of physical condition.

	Group 1 (*n* = 46)					Group 2 (*n* = 60)				
	M	**SD**	**A**	**K**	**S-W**	**M**	**SD**	**A**	**K**	**S-W**
Body composition										
Age	66.76	4.72	0.19	−1.10	0.94*	68.18	5.09	0.27	−0.66	0.77
% FM	31.84***	3.81	−1.12	0.87	0.90**	41.91	4.20	1.67	2.73	1.41*
% MM	64.91***	4.43	1.61	3.02	0.84***	54.88	4.41	−1.70	2.63	1.57*
% BM	3.47***	0.23	1.35	2.23	0.88***	2.97	0.21	−1.47	2.51	1.28
PPE	8.79	10.55	2.41	6.44	0.85***	9.39	8.82	1.22	0.62	1.32
Cognitive functioning										
D2-TR	43.92*	13.53	1.20	4.18	0.92**	39.03	11.67	0.26	0.19	0.77
D2-TA	42.56*	15.00	1.35	2.93	0.91**	35.55	13.09	0.32	0.67	1.10
D2-O	44.87	18.21	0.78	0.86	0.95*	42.37	23.47	0.56	−0.15	0.96
D2-C	24.70	18.57	0.77	−0.15	0.90*	23.77	16.00	0.96	0.58	1.14
D2-TOT	39.58*	12.10	0.43	0.70	0.97	33.70	10.68	0.36	−0.47	1.62*
D2-CON	35.15*	13.55	0.03	−0.52	0.97	28.73	14.62	0.05	−0.55	0.83
D2-TR+	46.97	14.27	1.10	1.94	0.92**	40.27	11.13	0.27	0.43	1.20
D2-TR−	46.64*	19.17	0.32	−0.40	0.98	54.23	23.94	0.02	−0.62	0.55
D2-VAR	40.86	15.02	0.15	0.59	0.97	39.85	16.70	0.46	0.01	0.63
TMT-A	46.67	19.38	0.67	−0.30	0.94*	49.57	19.09	1.56	3.63	1.38*
TMT-B	113.83	47.13	0.38	−0.33	0.97	124.47	56.33	1.15	1.23	1.25
Stroop-words	91.52	21.28	−0.05	−0.69	0.98	86.73	19.67	0.62	0.37	0.71
Stroop-colors	61.78	13.72	0.32	0.16	0.98	59.90	12.80	0.06	−0.39	0.58
Stroop-W/C	36.43	14.98	0.86	0.57	0.94*	33.57	10.62	0.54	0.21	0.90

*A = asymmetry; K = Kurtosis; S-W = Shapiro-Wilk test; FM = fat mass; MM = muscle mass; BM = bone mass; PPE = physical practice experience; D2-TR = total number of attempts; D2-TA = total hits; D2-O = omissions; D2-C = commissions; D2-TOT = total effectiveness in the test; D2-CON = concentration index; D2-VAR = variation index; D2-TR+ = line with the highest number of attempted elements; D2-TR− = line with fewer items attempts; TMT-A = Trail Making Test A; TMT-B = Trail Making Test B; Stroop-W/C = Stroop words/colors.*p < 0.05; **p < 0.01; ***p < 0.001.*

physical practice experience ($p < 0.05$), although they did show differences in gender distribution ($\chi^2 = 5.78$; $p < 0.05$).

Table 4 shows the descriptive statistics of the variables analyzed and the normality tests (Kolmogorov-Smirnov and Shapiro-Wilks), for the groups formed from the level of physical condition presented. As it can be seen, group 1 had higher scores on body composition measures ($p < 0.001$), on TR, TA, TR-, TOT, and CON (d2) ($p < 0.05$) than group 2.

DISCUSSION

The aim of this work was to analyze the relationships between body composition and cognitive functioning, specifically executive and attentional functioning variables, in an active older people sample. Specifically, the aim was to explore whether, despite physical activity, there were differences depending on the impact produced on measures of physical condition and body composition. For this study, we have considered the percentage of fat, bone, and muscle masses. In addition, as complementary measures, age and experience of physical practice were valued as measures that could generate biases in the analysis realized.

The correlation and linear regression analysis carried out indicated that there were significant relationships between the body composition measures analyzed and some of the cognitive functioning measures presented in this study. However, the variables age and physical practice experience had little impact on the analysis performed, suggesting that the impact of lifestyle on the body is an essential phenomenon when exploring health relationships in people. This has already been highlighted in previous research and is considered a fundamental line of work when dealing with this object of study (Reiter et al., 2015; Fernandes et al., 2017). Therefore, the relationships between physical activity and health in older people should be analyzed in response to the changes that occur in the organism, as these data will indicate if the health is being truly improved. This matches with previous findings that had observed relationships between increased fat mass and decrement of muscle mass in the cognitive functioning of older people (Papachristou et al., 2015).

These results are interest given that regular physical exercise is one of the main, non-pharmacological strategies, to age healthier and improve quality life of older people (Kamijo et al., 2009; García-Molina et al., 2010). Although direct physical performance level has not been evaluated, muscle mass percentage is shown to be the variable that best predicts cognitive functioning in the participants group from this study. Yoon et al. (2017) had already indicated that improving strength in older people could help preserve their cognitive functioning. In this sense, physical exercise and increased physical performance would be linked to this phenomenon, helping to preserve muscle mass during the aging process. For this reason, the results found would support what was evidenced in previous studies, indicating that active lifestyles and adequate physical condition would help protect cognitive deterioration in elderly people (Baker et al., 2010; Boucard et al., 2012; Ballesteros et al., 2013; Kerr et al., 2013; Bherer, 2015; Müller et al., 2017). In addition, these body-composition indicators contribute to a better follow-up of the results of the health programs applied to older people.

In recent years, there has been a notable increase in neuroimaging studies that have corroborated neurobiological correlates, when positive influences of habitual exercise on cognitive functions have been analyzed. Although more work is still needed to give definitive answers to certain questions such as, the differentiated effects of physical exercise programs, how they interact with other elements of lifestyles like food and rest, or how the type of work done throughout life or other leisure tasks, might also contribute to preserving and improving cognitive functioning in people (Yanagisawa et al., 2010; Bherer et al., 2013). In fact, in recent years, evidence has emerged on the positive effects of physical exercise programs integrated with cognitive involvement tasks, which arise as an appropriate way to enhance the effects of isolated physical exercise on people's cognitive abilities (Rey et al., 2011; Reyna et al., 2013; Reigal and Hernández-Mendo, 2014). Among other reasons, improving cognitive functioning at these ages is important, due to its involvement in social adaptation processes and adjustment to the environment (Kotwal et al., 2016).

For this reason, the present work presents some limitations that could be corrected in future works. On one hand, it would be interesting to extend the study sample in order to carry out more analysis based on variables such as gender or classify according to other variables specific to healthy lifestyles such as diet, type of academic training or usual rest time. On the other hand, it would be appropriate to include some physical performance measure, to have a broader vision of the physical state of those evaluated. Likewise, different programs for physical exercise could be contrasted, to observe if the integration of interaction activities and cognitive implication during the physical work could produce any differences between the participants. In addition, the bioimpedance analysis has a margin for error. Therefore, these measures could be supplemented with others that offered a greater approximation to the real value of body composition.

Despite the study limitations, the data found contribute to the body composition and physical condition research on the cognitive functioning of older people, suggesting that age and practical experience is not as relevant as the impact it has on people's bodies. This suggests that beyond the exercise programs that are carried out, an exhaustive control of the effects on people would be necessary, with the objective of foreseeing with greater adjustment of the implications that it could have on their health. These objectives are of high social relevance, given their impact on public health and on quality life of older people, which could help them to have a more satisfying life (García-Molina et al., 2010; MacAuley et al., 2016).

CONCLUSIONS

Data obtained in this work have pointed to positive relationships between the muscle mass percentage and cognitive functioning measures such as attention and executive functions. Also, older adults with higher muscle percentage and bone mass, as well as lower fat mass, showed better scores in attention measures. Results suggest that developing active lifestyles that promote better fitness could help preserve cognitive decline in this population.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

AH-M, VM-S, RJ, AR, RR, AW-R, and JM-B helped in design of the work and acquisition, analysis, and interpretation of data for the work. MC-J, JD-G, RR, and AH-M helped in acquisition, analysis, and interpretation of data for the work. MC-J and JD-G helped in acquisition and analysis of data for the work. All authors helped in drafting the work or revising, final approval of the version, and agreement to be accountable for all aspects of the work.

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REVIEW
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Effects of Open Versus Closed Skill Exercise on Cognitive Function: A Systematic Review

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Background: Exercise modes can be divided into open skill exercise (OSE) and closed skill exercise (CSE). While research has shown that these two exercise modes may have different effects on cognitive function, this possibility has not been systematically reviewed.

Objective: The purpose of the present review was to objectively evaluate the research literature regarding the effects of OSE versus CSE on cognitive function.

Methods: Six electronic databases (Web of Science, EMBASE, Google Scholar, PubMed, PsycINFO, and SPORTDiscus) were searched from inception dates to December 2018 for studies examining the associations of OSE and CSE with cognitive function. The literature searches were conducted using the combinations of two groups of relevant search items related to exercise modes (i.e., OSE and CSE) and cognitive function. Articles were limited to human studies in all age groups. Both intervention and observational studies with full text published in English-language peer-reviewed journals were considered eligible. The search process, study selection, data extraction, and study quality assessment were carried out independently by two researchers.

Results: A total of 1,573 articles were identified. Fourteen observational and five intervention studies met the inclusion criteria. Twelve of the 14 observational studies found that OSE benefits cognitive function, and seven of these 14 observational studies supported superior effects of OSE compared with CSE for enhancing cognitive function. Three of the five intervention studies found that OSE (versus CSE) led to greater improvements in cognitive function in both children and older adults.

Conclusion: Although the majority of studies in this review were observational cross-sectional designs, the review tends to support that OSE is more effective for improving some aspects of cognitive function compared with CSE. More rigorous randomized control trials with long-term follow-ups are needed in order to confirm these differential cognitive effects of the two exercise modes.

Keywords: motor skill, open skill exercise, closed skill exercise, cognition, executive function

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INTRODUCTION

The beneficial effects of physical activity and exercise on physical health have been well-documented among all age groups (Booth et al., 2012; Hills et al., 2015), and an increasing number of researchers have recently paid great attention to investigating further associations between exercise and cognitive function (Lin et al., 2018; Pedersen, 2019; Stern et al., 2019). Cognitive functions refer to mental processes of obtaining knowledge and understanding through thought, experience, and the senses, including perception, attention, visual and spatial processing, language, memory, executive functions, etc. (Lezak et al., 2012). Executive function, also termed cognitive control, refers to higher-order, self-regulatory cognitive processes that aid in the monitoring and control of thought and action (Carlson, 2005). It encompasses working memory, inhibitory control, cognitive flexibility, reasoning, planning and problem solving, etc. (Diamond, 2013). Executive function plays a crucial role in daily life and it has attracted much attention in current research. Although existing evidence has shown that physical fitness and exercise have important relationships with various aspects of cognitive functions (Kramer and Erickson, 2007; Aberg et al., 2009; Chaddock et al., 2011), studies tend to suggest that the beneficial effects of exercise are larger and more evident for executive function (Kramer and Erickson, 2007; Chaddock et al., 2011). For example, a higher level of physical fitness has been associated with better executive function and academic performance in children and adolescents (Huang et al., 2015; Marques et al., 2018; Westfall et al., 2018). Physical exercise intervention programs can enhance children's executive function performances as measured by inhibition and cognitive flexibility tasks (Hillman et al., 2014). Additionally, people who exercised regularly have demonstrated slower cognitive declines and a lower risk of developing dementia (Middleton et al., 2010; Zotcheva et al., 2018). Well-designed randomized controlled trials have also provided compelling evidence that physical exercise interventions can improve executive function and spatial memory in older adults (Kramer et al., 1999; Erickson et al., 2011). Furthermore, current evidence suggests that different types of physical exercise may exert differential influences on cognitive function and mental health (Tsai et al., 2012; Tsai and Wang, 2015; Chekroud et al., 2018). Yet, there remains some controversy regarding what types of physical exercises may be more effective for improving cognitive function.

Recently, studies have suggested that the extent of improvements in cognitive function through physical exercise may be related to the motor movement characteristics of the activities involved (Guo et al., 2016; Chang et al., 2017; Cho et al., 2017). According to the effects of environment on motor skills, motor skills can be divided into open and closed skills (Knapp, 1967). Open skills are performed in a dynamic and changing environment, while closed skills take place in a predictable and static environment (Galligan, 2000). Accordingly, exercise modes can be classified into open skill exercise (OSE) and closed skill exercise (CSE) (Di Russo et al., 2010; Dai et al., 2013; Tsai and Wang, 2015; Tsai et al., 2016, 2017). OSEs (e.g., table tennis, tennis, squash, basketball, or boxing) involve unpredictable environments, active decision making, and ongoing adaptability in which participants must alter responses to randomly occurring external stimuli (Brady, 1995; Di Russo et al., 2010; Wang et al., 2013a). OSEs are predominantly perceptual and externally paced. In contrast, CSEs (e.g., running, swimming, cycling, golf, or archery) are performed in a relatively stable and predictable environment in which motor movements follow set patterns. CSE skills tend to be self-paced, as there are fewer cognitive demands and decision-making requirements (Brady, 1995; Di Russo et al., 2010; Wang et al., 2013a). In the context of this conceptual framework, researchers have investigated the associations of OSE and CSE with cognitive function among participants in different age groups. Some studies have shown that OSE participants performed better in some aspects of executive function (e.g., inhibitory control and cognitive flexibility) than CSE participants (Giglia et al., 2011; Dai et al., 2013; Wang et al., 2013a). In contrast, some studies reported that the cognitive effects of OSE and CSE did not differ (Chang et al., 2017; Chueh et al., 2017; Becker et al., 2018).

Despite the rapid expansion of interest in this topic, there has been no systematic review of existing literature that has critically evaluated the differential effects of OSE versus CSE on cognitive function across the lifespan. Given a lack of clarity regarding suspected differences in the benefits of these exercise modes for benefiting cognitive function, we undertook the current systematic review of intervention (including acute exercise and chronic exercise) and observational research to date.

MATERIALS AND METHODS

This systematic review was conducted according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). Notably, as demonstrated hereafter, there was considerable heterogeneity across the studies, regarding study design and participant characteristics. As such, a meta-analysis was not conducted with this systematic review.

Literature Searches

We began with a computerized search of six electronic databases (Web of Science, EMBASE, Google Scholar, PubMed, PsycINFO, and SPORTDiscus) for all research in these databases up to December 2018. Articles were limited to human studies in all age groups. There was no restriction on publication year. We used the combinations of the following two groups of retrieval terms: (a) OSE and CSE, feedback exercise and non-feedback exercise, open loop exercise and closed loop exercise, and planned exercise and incidental exercise, and (b) cognition, cognitive function, executive function, working memory, memory, inhibitory control, and cognitive flexibility. Each (a) item was combined with all (b) items during the search process. In order to exclude duplicate or apparently irrelevant studies, the authors next screened all retrieved titles. From this shorter list, two authors (QG and TH) independently reviewed the abstracts of each remaining study. Having further reduced number of the articles in this manner, the two authors (QG and TH) then independently screened the full text of the remaining studies, using predetermined inclusion and exclusion criteria (see below for details). Disagreements were discussed in all cases until a consensus was reached among the authors. The review authors then searched the bibliographies of all included articles in the same fashion as outlined above to further ensure that relevant articles had been captured.

Inclusion/Exclusion Criteria for Study Selection

The identified studies were initially screened by two authors (QG and TH) to determine whether they met our inclusion criteria as follows: (a) intervention [assigned into either an experimental arm (OSE or CSE) or control arm] and observational studies with full text published in English-language peer-reviewed journals; (b) both OSE (a type of exercise is performed in an unpredictable environment, where the exerciser is not the one who decides when the skill and movement need to be executed such as some team-based sports and racket sports) and CSE (a type of exercise is performed in a relatively stable environment, where the exerciser is able to dictate when he or she starts to perform the motor skill) have to be clearly defined and simultaneously examined in the study; (c) study outcomes must include at least one measurement of any aspects of cognitive function (e.g., perception, attention, visual and spatial processing, language, memory, and executive functions). It is worth emphasizing that the participants' ages, gender, race/ethnicity, etc., were not restricted in this systematic review in order to gain a comprehensive understanding of this new topic based on the inclusion of all relevant articles. This review excluded studies which applied other combined interventions such as OSE or CSE plus a nutrition program. The studies were finally included when a consensus was reached by two authors.

Data Collection

Information regarding publication year, participant characteristics, location, intervention program, exercise experience, educational level, outcomes (assessment instruments) and study results were independently extracted by two authors (QG and TH) for later analysis and presentation.

Methodological Quality

Methodological quality was assessed independently by two authors (QG and TH). Any discrepancies in the ratings of the methodological quality were settled by discussion, based on the scoring criteria of the two assessment instruments, among the authors until a consensus was reached. The two authors independently assessed the methodological quality of the intervention studies using the Physiotherapy Evidence Database (PEDro) scale (Elkins et al., 2013). The PEDro scale consists of 11 items, namely eligibility criteria, randomization, allocation concealment, baseline equivalence, blinding of the instructor, blinding of participants, blinding of outcome assessors, retention rate of $\geq$ 85%, intention-to-treat analysis, between-group comparison, and point measures and measures of variability. A maximum of 11 points can be obtained (clear description = 1 and unclear description = 0) (Elkins et al., 2013). The methodological quality of observational studies was assessed using the evaluation tool developed by Fuzeki et al. (2017) and Engeroff et al. (2018). It consists of five components (12 items in total), namely the assessment of study purpose, study design and methods, statistical methods, results, and discussion. The 12 items of the assessment tool are listed in **Supplementary Table 1**. A maximum of 12 points can be obtained. According to Fuzeki et al. (2017), the quality of studies can be divided into three categories ($\geq$10 points as high quality; 6–9 points as moderate quality; and <6 points as low quality).

RESULTS

Study Selection

A flowchart of our study selection process is shown in **Figure 1**. The search strategy first identified 1567 potential articles from the six electronic databases as well as six additional records that were identified through checking the references in the most relevant studies. After removing duplicates and irrelevant articles, 437 articles remained for screening via title and abstract. Of these, 35 were identified as potentially relevant. After independently evaluating the full text of these 35 articles using the predefined inclusion criteria by the two reviewer authors (QG and TH), we excluded 16, leaving 19 studies eligible for this systematic review. Fourteen studies were observational in design (Giglia et al., 2011; Dai et al., 2013; Wang et al., 2013a,b; Huang C.J. et al., 2014; Jacobson and Matthaeus, 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Chang et al., 2017; Chueh et al., 2017; Yu et al., 2017; Becker et al., 2018; Li et al., 2018) and five were intervention studies (Crova et al., 2014; Schmidt et al., 2015; O'Brien et al., 2017; Tsai et al., 2017; Hung et al., 2018). Based on the pretermined inclusion criteria, study selection was independently performed by two raters and the agreement score was 18 out of 19. To resolve this disagreement on this study, a third author was invited to discuss and finally reach a consensus.

Characteristics of Included Studies

As noted above, five of the 19 included studies were intervention studies (including two acute intervention studies) (Crova et al., 2014; Schmidt et al., 2015; O'Brien et al., 2017; Tsai et al., 2017; Hung et al., 2018). These five intervention studies included two involving children (Crova et al., 2014; Schmidt et al., 2015), one involving young adults (aged 18–35 years) (Hung et al., 2018) and two involving older adults (aged older than 55 years) (O'Brien et al., 2017; Tsai et al., 2017). Within the two studies involving children (Crova et al., 2014; Schmidt et al., 2015), OSE intervention programs were administrated through physical education classes. The other three studies (O'Brien et al., 2017; Tsai et al., 2017; Hung et al., 2018) were conducted in laboratory settings and the exercise interventions were supervised.

Among the 14 observational studies (Giglia et al., 2011; Dai et al., 2013; Wang et al., 2013a,b; Huang C.J. et al., 2014; Jacobson and Matthaeus, 2014; Tsai and Wang, 2015; Guo et al., 2016;

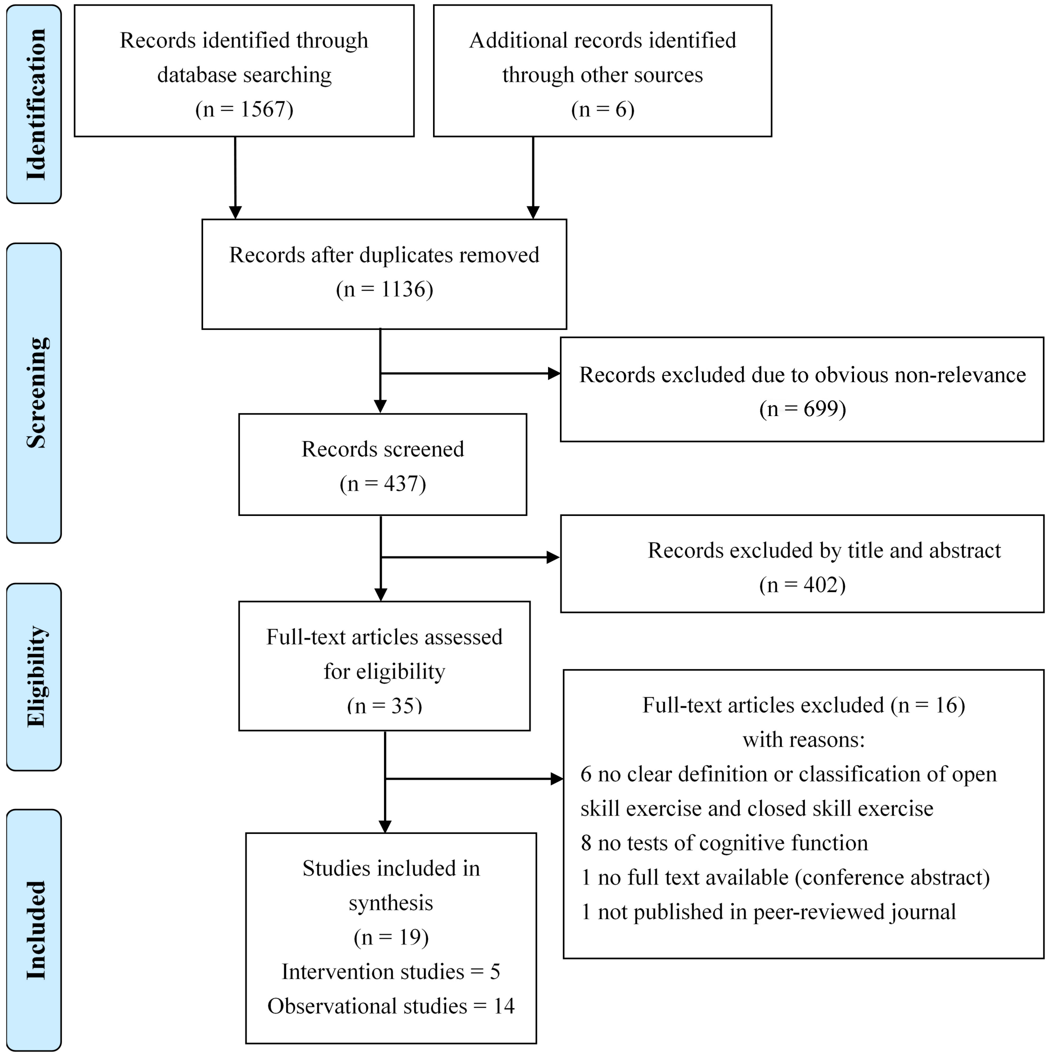

FIGURE 1 | Flow diagram of each stage of the study selection.

Tsai et al., 2016; Chang et al., 2017; Chueh et al., 2017; Yu et al., 2017; Becker et al., 2018; Li et al., 2018), one involved children (Becker et al., 2018), seven involved young adults (Giglia et al., 2011; Wang et al., 2013a,b; Jacobson and Matthaeus, 2014; Chang et al., 2017; Chueh et al., 2017; Yu et al., 2017), and six involved older adults (Dai et al., 2013; Huang C.J. et al., 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Li et al., 2018).

As an indication of how recently this topic has drawn investigator interest, 18 of these 19 articles were published after 2013. Collectively, within these 19 studies, a total of 1,845 participants were included. Study participants sample sizes ranged from 20 to 660, with an average sample size of 97 (*SD* = 140). The mean age of participants ranged from 9.6 to 70.5 years old. Across these 19 studies, a total of 21 cognitive tasks were used, measuring various aspects of cognitive function including inhibitory control, working memory, cognitive flexibility, planning, decision making, problem solving, processing speed, perception, attention, and memory. These characteristics of the intervention and observational studies are summarized in **Tables 1**, **2**, respectively.

Methodological Quality of Included Studies

According to the PEDro scale, the average score of the methodological quality of the five intervention studies (Crova et al., 2014; Schmidt et al., 2015; O'Brien et al., 2017; Tsai et al., 2017; Hung et al., 2018) was 6.6, with scores ranging from 5 to 8 (see **Supplementary Table 2** for details). The rating scores are also presented in **Table 1**.

Based on this 12-item assessment tool (Fuzeki et al., 2017; Engeroff et al., 2018), the average score of the methodological quality of the 14 observational studies was 8.1, with scores ranging from 7 to 10 (see **Supplementary Table 3** for details). Thirteen (Giglia et al., 2011; Dai et al., 2013; Wang et al., 2013a,b;

TABLE 1 | Characteristics of the included intervention studies.

Study (Authors, Publication years, Methodological quality, Location)	N	OSE (1) Gender (2) Age (years) (3) Exercise (4) Education (years)	CSE (1) Gender (2) Age (years) (3) Exercise (4) Education (years)	Control group (1) Gender (2) Age (years) (3) Exercise (4) Education (years)	Intervention duration/ Session length	Cognitive tasks	Cognitive functions	Results
Children and adolescents (6–17 years old)								
Crova et al., 2014 7/11 Italy	70	(1) 20M/37 (2) 9.6 ± 0.5 (3) Enhanced PE (including curricular PE classes and additional skill-based and tennis-specific training)	(1) 15M/33 (2) 9.6 ± 0.5 (3) Curricular PE	None	6 months	RNG task	Inhibitory control; Working memory	OSE led to greater improvements in inhibitory control compared with the CSE.
Schmidt et al., 2015 7/11 Switzerland	181	(1) 26M/69 (2) 11.3 ± 0.6 (3) Team games	(1) 28M/57 (2) 11.3 ± 0.6 (3) Aerobic exercise	(1) 28M/55 (2) 11.4 ± 0.6 (3) PE program with low physical exertion and cognitive engagement	6 weeks	N-back task; Flanker task	Inhibitory control; Cognitive flexibility; Working memory	OSE resulted in improvement on cognitive flexibility. CSE did not change cognitive function.
Young adults (18–35 years old)								
Hung et al., 2018 6/11 China (Taiwan)	20	(1) 20M/20 (2) 23.2 ± 2.5 (3) Badminton	(1) 20M/20 (2) 23.2 ± 2.5 (3) Running	None	40 min: 5 min (warm up) 30 min (exercise) 5 min (cool down)	Task-switching paradigm	Cognitive flexibility	One-bout OSE resulted in significantly higher serum BDNF and near significant smaller global switch costs compared with CSE.
Older adults (≥ 56 years old)								
O'Brien et al., 2017 5/11 Ireland	58	(1) 1M/18 (2) 69.2 ± 5.1 (3) Tennis, aerobics classes or dance classes	(1) 12M/19 (2) 69.2 ± 4.8 (3) Swimming or gym circuits, etc.	(1) 8M/21 (2) 70.5 ± 6.9 (3) Active retired group meeting or card games	OSE group: 80 ± 20 min; CSE group: 70 ± 20 min; Control group: 60 min	SiFI task; Forward Digit Span task	Memory (immediate memory); Multisensory perception	The immediate memory was improved in both exercise groups. Only OSE led to improvement in sensitivity in audio-visual perception.
Tsai et al., 2017 8/11 China (Taiwan)	64	(1) 22M/22 (2) 66.9 ± 4.7 (3) Table tennis (4) 12.5 ± 4.1	(1) 21M/21 (2) 66.2 ± 4.9 (3) Bike riding or brisk walking/jogging (4)12.6 ± 3.0	(1) 21M/21 (2) 65.7 ± 3.5 (3) A balance and stretching program (4) 10.6 ± 3.2	6 months	Task-switching paradigm; N-back task	Cognitive flexibility; Working memory	OSE and CSE differently influenced executive function. OSE led to improvement on cognitive flexibility. CSE led to greater improvement on working memory compared with the OSE.

BDNF, brain-derived neurotrophic factor; CSE, closed skill exercise; M, male; OSE, open skill exercise; PE, physical education; RNG, random number generation; SiFI, sound induced flash illusion.

TABLE 2 | Characteristics of the included observational studies.

Study (Authors, Publication years, Methodological quality, Location)	N	OSE (1) Gender (2) Age (years) (3) Exercise (4) Education (years)	CSE (1) Gender (2) Age (years) (3) Exercise (4) Education (years)	Control group (1) Gender (2) Age (years) (3) Exercise (4) Education (years)	Exercise experience	Cognitive tasks	Cognitive functions	Results
Children and adolescents (6–17 years old)								
Becker et al., 2018 10/12 The United States	660	(1) NA (2) Third grade (3) Baseball/softball; Martial arts; Hockey; Tennis; Football; Soccer; Basketball; Volleyball	(1) NA (2) Third grade (3) Swimming; Cheerleading; Track and field; Golf; Skateboarding; Dance; Skating	None	NA	Tower of Hanoi task	Inhibitory control; Cognitive flexibility; Working memory	There were no significant association of exercise modes (OSE and CSE) with executive function.
Young adults (18–35 years old)								
Chang et al., 2017 8/12 China (Taiwan)	60	(1) 15M/20 (2) 21.2 ± 1.2 (3) Martial arts training (4) 14.7 ± 0.9	(1) 14M/20 (2) 21.2 ± 1.8 (3) Marathon running (4) 15.0 ± 0.0	(1) 13M/20 (2) 21.6 ± 1.4 (3) Infrequent exercise/recreational activity (4) 14.8 ± 0.7	Martial arts: 8.6 ± 2.3 years; Marathon running: 7.8 ± 2.4 years; Control group: 0.9 ± 1.7 years	Stroop task; WCST; Tower of London task	Inhibitory control; Working memory; Cognitive flexibility; Planning	There were no differences in cognitive performance among the OSE, CSE and control group.
Chueh et al., 2017 8/12 China (Taiwan)	48	(1) 9M/16 (2) 20.0 ± 1.2 (3) Badminton or table tennis	(1) 9M/16 (2) 21.1 ± 2.3 (3) Swimming, triathlon, or distance running	(1) 9M/16 (2) 20.7 ± 1.1 (3) Sedentary control	OSE group: 10.8 ± 2.2 years; CSE group: 9.7 ± 3.2 years	Non-delayed and delayed match-to-sample test	Visuospatial attention; Visuospatial memory	The visuospatial attention and memory performance of the OSE and CSE groups were better than control group. There were no differences in cognitive function between OSE and CSE.
Giglia et al., 2011 8/12 Italy	56	(1) 23M/23 (2) NVP: 26.0 ± 4.3; RVP: 25.6 ± 3.4 (3) Volleyball	(1) 10M/10 (2) NR: 19.2 ± 4.0 (3) Rowing	(1) 10M/23 (2) 24.8 ± 2.5 (3) Sedentary control	NVP: 3.4 ± 1.0 hours/day; RVP: 1.1 ± 0.3 hours/day; NR: 3.1 ± 0.5 hours/day	Line-length judgment task	Visuospatial attention	Visuospatial attention was better in OSE group compared with the CSE and control group.
Jacobson and Matthaeus, 2014 7/12 The United States	54	(1) 14M/22 (2) 20.1 ± 1.2 (3) Externally paced exercise	(1) 3M/17 (2) 20.2 ± 1.5 (3) Self-paced exercise	(1) 6M/15 (2) 20.2 ± 1.3 (3) Sedentary control	Exercise group: ≥ 1 times/week	D-KEFS Tower test; D-KEFS Color-Word Interference Test; Coding test	Problem solving; Decision making; Inhibitory control; Processing speed	The problem solving and inhibitory control performance of the OSE and CSE groups were better than control group. The OSE group showed better problem solving compared with CSE group. The CSE group showed better inhibitory control compared with OSE group.

(Continued)

TABLE 2 | Continued

Study (Authors, Publication years, Methodological quality, Location)	N	OSE	CSE	Control group	Exercise experience	Cognitive tasks	Cognitive functions	Results
		(1) Gender (2) Age (years) (3) Exercise (4) Education (years)	**(1) Gender (2) Age (years) (3) Exercise (4) Education (years)**	**(1) Gender (2) Age (years) (3) Exercise (4) Education (years)**				
Wang et al., 2013a 9/12 China (Taiwan)	60	(1) 20M/20 (2) 20.7 ± 2.4 (3) Tennis	(1) 20M/20 (2) 19.3 ± 0.8 (3) Swimming	(1) 20M/20 (2) 20.4 ± 2.1 (3) Sedentary control	Tennis: 5.5 ± 2.8 years; Swimming: 4.9 ± 1.7 years	Stop-signal task	Inhibitory control	The OSE group showed better inhibitory control than the CSE and control group.
Wang et al., 2013b 7/12 China (Taiwan)	42	(1) 14M/14 (2) 20.6 ± 2.8 (3) Tennis	(1) 14M/14 (2) 19.4 ± 0.7 (3) Swimming	(1) 14M/14 (2) 21.2 ± 2.6 (3) Sedentary control	Tennis: 3–11 years; Swimming: 2.5–9 years	Go/No-Go Variable FP Paradigm	Decision making in inhibition	The OSE group showed better temporal preparation compared with control group. There were no differences between the OSE and CSE group.
Yu et al., 2017 9/12 China (Hong Kong)	54	(1) 10M/18 (2) 21.1 ± 2.2 (3) Badminton	(1) 11M/18 (2) 21.1 ± 2.0 (3) Track and field	(1) 9M/18 (2) 21.8 ± 2.1 (3) Sedentary control (no formal exercise training)	Badminton: 11.3 ± 2.7 years; Track and field: 7.9 ± 1.6 years	Task-switching paradigm; Simple reaction task	Cognitive flexibility; Processing speed	The OSE group had a lower switch cost of RT compared with CSE and control group when the task cue was 100% valid, whereas the OSE and CSE group had a lower switch cost of RT compared to the control group when the task cue was 50% valid. There were no differences in processing speed among the three groups.
Older adults (≥ 56 years old)								
Dai et al., 2013 8/12 China (Taiwan)	48	(1) 9M/16 (2) 69.0 ± 3.6 (3) Table tennis or tennis (4) 10.7 ± 2.8	(1) 6M/16 (2) 69.9 ± 3.6 (3) Jogging or swimming (4) 10.8 ± 4.2	(1) 2M/16 (2) 67.3 ± 3.0 (3) Irregular exercise (4) 13.0 ± 3.3	Table tennis/tennis: 13.0 ± 5.7 years; Jogging/swimming: 11.1 ± 4.5 years; Irregular exercise: 0.7 ± 0.6 years	Task-switching paradigm	Cognitive flexibility	The OSE and CSE group showed better cognitive flexibility compared with control group. The OSE group showed better cognitive flexibility compared with the CSE and control group.
Guo et al., 2016 8/12 China	111	(1) 17M/36 (2) 67.6 ± 5.9 (3) Table tennis (4) 12.6 ± 2.7	(1) 15M/38 (2) 66.7 ± 5.8 (3) Jogging or swimming (4) 11.4 ± 2.9	(1) 16M/37 (2) 66.9 ± 5.9 (3) Sedentary control (4) 11.0 ± 2.6	Exercise group: ≥ 30 min/session, ≥ 3 times/week, ≥ 1 year. Sedentary controls: inactivity or low activity level.	VWMT; VSMT; VMTT	Visuospatial working memory	The two exercise groups showed better performances on visuospatial working memory than the control group. The OSE group showed better performance on visuospatial short-term memory task than the control group. There were no differences in visuospatial mental rotation task among the three groups.

(Continued)

TABLE 2 | Continued

Study (Authors, Publication years, Methodological quality, Location)	N	OSE	CSE	Control group	Exercise experience	Cognitive tasks	Cognitive functions	Results
		(1) Gender (2) Age (years) (3) Exercise (4) Education (years)	**(1) Gender (2) Age (years) (3) Exercise (4) Education (years)**	**(1) Gender (2) Age (years) (3) Exercise (4) Education (years)**				
Huang C.J. et al., 2014 8/12 China (Taiwan)	60	(1) 11M/20 (2) 69.4 ± 3.0 (3) Table tennis, tennis, badminton, etc.	(1) 9M/20 (2) 70.6 ± 2.6 (3) Jogging, swimming, etc.	(1) 6M/20 (2) 68.3 ± 2.3 (3) Irregular exercise	OSE group: 7.8 ± 1.1 years; CSE group: 6.7 ± 2.4 years	Eriksen flanker task	Inhibitory control	The OSE and CSE group demonstrated better performance on inhibitory control compared with sedentary control group, whereas the OSE group showed better electrophysiological performance (i.e., event-related potential P300 amplitudes).
Li et al., 2018 8/12 China	75	(1) 15M/25 (2) 69.0 ± 3.4 (3) Table tennis or tennis (4) 10.7 ± 3.6	(1) 8M/25 (2) 69.8 ± 3.1 (3) Jogging or brisk walking (4) 11.2 ± 3.3	(1) 4M/25 (2) 67.8 ± 2.9 (3) Irregular exercise (4) 11.9 ± 3.4	Exercise group: ≥ 30 min/ session, ≥ 3 times/week, ≥ 3 months.	SCWIT; Task-switching paradigm	Inhibitory control; Cognitive flexibility	The OSE and CSE group showed better performance on inhibitory control and cognitive flexibility compared with control group, while the OSE showed better electrophysiological performance (i.e., event-related potential smaller N200 and larger P300a amplitudes).
Tsai and Wang, 2015 8/12 China (Taiwan)	64	(1) 14M/21 (2) 65.4 ± 4.2 (3) Badminton or table tennis (4) 13.7 ± 3.0	(1) 14M/22 (2) 66.0 ± 4.1 (3) Jogging or swimming (4) 13.5 ± 3.5	(1) 13M/21 (2) 63.9 ± 3.4 (3) Sedentary control (4) 12.9 ± 2.0	Exercise group: ≥ 30 min/ session, ≥ 3 times/week, ≥ 2 year.	Task-switching paradigm	Cognitive flexibility	The OSE and CSE group showed better performance on cognitive flexibility than control group. The OSE group showed better cognitive flexibility compared with the CSE and control group.
Tsai et al., 2016 8/12 China (Taiwan)	60	(1) 13M/20 (2) 65.3 ± 4.1 (3) Badminton or table tennis (4) 14.0 ± 2.8	(1) 14M/20 (2) 67.0 ± 4.7 (3) Swimming or jogging (4) 13.3 ± 3.6	(1) 13M/20 (2) 64.3 ± 3.6 (3) Sedentary control (4) 13.2 ± 2.0	Exercise group: ≥ 30 min/ session, ≥ 3 times/week, ≥ 2 year. Sedentary controls: < 30 min/ session, < 2 times/week, ≥ 2 year.	Central cue Posner paradigm	Visuospatial attention	The OSE and CSE group showed better performance on visuospatial attention than control group. The OSE could have more beneficial effects compared with CSE.

CSE, closed skill exercise; D-KEFS, Delis–Kaplan executive function system; FP, foreperiod; M, male; NVP, national-level volleyball player; NR, national-level rowers; NA, not available; OSE, open skill exercise; RT, response time; RVP, regional-level volleyball player; SCWIT, Stroop Color-Word Interference Test; VMTT, visuospatial mental rotation task; VSMT, visuospatial short-term memory task; VWMT, visuospatial working memory task; WCST, Wisconsin card sorting test.

Huang C.J. et al., 2014; Jacobson and Matthaeus, 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Chang et al., 2017; Chueh et al., 2017; Yu et al., 2017; Li et al., 2018) of the 14 observational studies were found to be of "moderate quality" and one study (Becker et al., 2018) was judged to be of "high quality." The rating scores are presented in **Table 2**.

Study Findings

Observational Studies

Of the 14 observational studies, 12 (85.7%) showed that OSE group performed better on several aspects of cognitive function than the control group (Giglia et al., 2011; Dai et al., 2013; Wang et al., 2013a,b; Huang C.J. et al., 2014; Jacobson and Matthaeus, 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Chueh et al., 2017; Yu et al., 2017; Li et al., 2018). Nine studies found that both OSE and CSE group showed better performance of several aspects of cognitive function than the control group (Dai et al., 2013; Huang C.J. et al., 2014; Jacobson and Matthaeus, 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Chueh et al., 2017; Yu et al., 2017; Li et al., 2018). Furthermore, seven of 14 (50%) studies reported that the OSE group had better cognitive function compared with the CSE group (Giglia et al., 2011; Dai et al., 2013; Wang et al., 2013a; Jacobson and Matthaeus, 2014; Tsai and Wang, 2015; Tsai et al., 2016; Yu et al., 2017). The cognitive function measured in these studies included attention and executive function (i.e., inhibitory control, cognitive flexibility, and problem solving).

Only one observational study was conducted with participants who were children (Becker et al., 2018). This study showed that the two exercise modes (both OSE and CSE) were not significantly associated with performance of executive function (inhibitory control, working memory and cognitive flexibility) (Becker et al., 2018). Seven observational studies were conducted in young adults (Giglia et al., 2011; Wang et al., 2013a,b; Jacobson and Matthaeus, 2014; Chang et al., 2017; Chueh et al., 2017; Yu et al., 2017); and six (Giglia et al., 2011; Wang et al., 2013a,b; Jacobson and Matthaeus, 2014; Chueh et al., 2017; Yu et al., 2017) of these seven studies observed that the OSE group had better performances on inhibitory control, cognitive flexibility, problem solving, visuospatial memory, or visuospatial attention compared with the control group, while four showed that the OSE group had better cognitive performance in the domains of inhibitory control, visuospatial attention, problem solving or cognitive flexibility than the CSE group (Giglia et al., 2011; Wang et al., 2013a; Jacobson and Matthaeus, 2014; Yu et al., 2017). In contrast, Chueh et al. (2017) found that the cognitive performance (visuospatial attention and visuoapatial memory) of the OSE and CSE exercise groups was better than the control group, though the two exercise modes were not differently associated with the participants' performance on cognitive function. Additionally, although a study by Chang et al. (2017) showed that participating in OSE and CSE was associated with improved physical fitness, this study found no significant difference in cognitive performance (executive function) among the three groups (OSE, CSE, and control group).

Of the 14 observational studies, the participants in six studies were adults older than 55 years (Dai et al., 2013; Huang C.J. et al., 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Li et al., 2018). Three of the six studies involving older adults (Dai et al., 2013; Tsai and Wang, 2015; Tsai et al., 2016) showed that OSE (versus the CSE and the control conditions) was more effective in enhancing performance on cognitive function (cognitive flexibility, or visuospatial attention). Guo et al. (2016) found that the OSE group demonstrated better performances on visuospatial working memory than the sedentary control group, but found no differences between the OSE and CSE groups. Meanwhile, both Huang C.J. et al. (2014) and Li et al. (2018) found that both OSE and CSE groups demonstrated better performance on executive function (i.e., inhibitory control and cognitive flexibility) compared with the sedentary control group, whereas only OSE group demonstrated a better electrophysiological performance (e.g., event-related potential P300 amplitudes).

Intervention Studies

Four (80%) intervention studies (Crova et al., 2014; Schmidt et al., 2015; O'Brien et al., 2017; Tsai et al., 2017) demonstrated that OSE led to improvements in some aspects of cognitive function (i.e., memory, audio-visual perception, cognitive flexibility, and inhibitory control), and three of these studies showed OSE to be superior to CSE for benefiting cognitive function (i.e., audio-visual perception, inhibitory control or cognitive flexibility) (Crova et al., 2014; Schmidt et al., 2015; O'Brien et al., 2017). Of the five intervention studies, two were conducted with children, with the exercise durations being 6 months and 6 weeks, respectively (Crova et al., 2014; Schmidt et al., 2015). The results consistently showed that OSE led to greater improvement of executive function (i.e., inhibitory control and cognitive flexibility) than CSE. Two intervention studies involved adults older than 55 years (O'Brien et al., 2017; Tsai et al., 2017), and one of these (Tsai et al., 2017) found a 6-month OSE intervention to yield improvements on executive function (i.e., cognitive flexibility) performance. In the same study, however, the CSE intervention resulted in better working memory performance compared with OSE (Tsai et al., 2017). The other study with older adults examined the acute effects of one-bout OSE and CSE intervention on cognitive function and found that immediate memory was improved in both exercise groups compared with control groups. The improvement of audio-visual perception was only found in the OSE group (O'Brien et al., 2017). Finally, one intervention study, using a crossover design, was conducted with young adults (Hung et al., 2018) and found that one-bout acute OSE led to a near significant trend of greater improvement in cognitive flexibility compared with CSE.

DISCUSSION

This systematic review critically evaluated the effects of OSE versus CSE on cognitive function. Collectively, we reviewed 19 study findings and found that 12 of 14 (86%) observational studies and four of five (80%) intervention studies supported cognitive benefits of OSE compared with control conditions. Furthermore, in seven of 14 (50%) observational studies and three of five (60%) intervention studies, participants in

OSE groups had superior performance on several aspects of cognitive function compared with participants in CSE groups. Although the existing evidence tends to support that OSE may be more effective in benefiting some aspects of cognitive function (i.e., visuospatial attention, problem solving, audio-visual perception, inhibitory control, and cognitive flexibility) compared with CSE, it is premature to draw a clear picture on the effects of OSE versus CSE on a specific domain of cognitive function.

Cognitive Benefits of OSE Versus CSE for Different Age Groups

Collectively, the findings of this systematic review suggested that the cognitive benefits of OSE versus CSE may vary across the developmental lifespan. Only three studies compared OSE versus CSE effects on cognitive function in children (Crova et al., 2014; Schmidt et al., 2015; Becker et al., 2018), and with the exception of the one observational study (Becker et al., 2018), the two intervention studies consistently demonstrated that the OSE intervention resulted in greater improvement of executive function than CSE (Crova et al., 2014; Schmidt et al., 2015). Previous studies suggested that the beneficial effects of physical exercise were more evident on executive function than on other aspects of cognitive function (Chaddock et al., 2011; Khan and Hillman, 2014). Evidence from the current review extends that impression from past literature by further suggesting that OSE may have superior benefits on executive function than CSE. Regular engagement in OSE likely stimulates brain regions that benefit brain development and executive function (Best, 2010). Thus, there are growing supports for integrating OSE into children's exercise intervention programs, perhaps through physical education in school, as an effective means of promoting executive function (Crova et al., 2014; Schmidt et al., 2015).

With regard to young adults, although most of the included studies supported the beneficial effects of the two modes of exercise on cognitive function compared with sedentary counterparts, evidence for superior cognitive function benefits of OSE (versus CSE) is relatively limited, due to a scarcity of long term or "chronic" intervention studies. Four of the observational studies supported better cognitive performance in OSE (versus CSE) group participants (Giglia et al., 2011; Wang et al., 2013a; Jacobson and Matthaeus, 2014; Yu et al., 2017), but in the one intervention study (Hung et al., 2018), there was only near significant greater cognitive benefits resulting from the acute OSE (versus CSE) intervention. Therefore, the cognitive effects of OSE (versus CSE) in this age group are inconclusive. It is speculated that the limited evidence of the superior beneficial effects of OSE on cognitive function may be attributed to the fact that brain maturation and cognitive ability peak in young adulthood (Casey et al., 2000). Therefore, OSE cannot exert additional benefits on cognitive function in young adults. This review article also found that there were no existing studies involved middle-aged participants (aged 36–55 years). Future studies may consider this age group as potential participants.

In the older adults, evidence from this review's six observational studies (Dai et al., 2013; Huang C.J. et al., 2014; Tsai and Wang, 2015; Guo et al., 2016; Tsai et al., 2016; Li et al., 2018) and two intervention studies (O'Brien et al., 2017; Tsai et al., 2017) consistently support a beneficial role of exercise on cognitive function. Furthermore, three observational studies (Dai et al., 2013; Tsai and Wang, 2015; Tsai et al., 2016) and two intervention studies (O'Brien et al., 2017; Tsai et al., 2017) suggested that, in this population, OSE may be more effective for improving attention, audio-visual perception, or cognitive flexibility. However, in this population as in others, it is worth noting that the beneficial effects of CSE (e.g., jogging) should not be neglected, even though there may be superior cognitive benefits for OSE.

Taken together, the results of the current systematic review indicate that OSE may be more effective in benefiting some aspects of cognitive function compared with CSE, especially in childhood and later adulthood. The findings not only help to clarify the differential cognitive effects of the two exercise modes, but also have some practical implications. For counteracting the prevalence of physical inactivity and sedentary behavior, it is reasonable to suggest that OSE should be incorporated into exercise promotion programs, as it may maximize the cognitive benefits of exercising.

Potential Mechanisms of the Superior Effects of OSE Versus CSE

In this systematic review, the findings suggest a superior benefit of OSE for enhancing some aspects of cognitive function, perhaps especially in childhood and in late adulthood, as these two periods either precede the prefrontal lobe brain maturation that supports executive function (Casey et al., 2000), or are associated with an aging-related decline incognitive function. Of course, this is speculative, as the potential mechanisms underlying the superior effects of OSE over CSE remain unclear. OSE involves more cognitive loads and demands than CSE and this may partially explain its superior benefits in this systematic review. When performing OSE, participants are required to accommodate a continually changing environment. As such, there are greater cognitive demands and greater practice with some aspects of cognitive function that includes visuospatial ability, information-processing speed, multi-tasking flexibility, and other executive functions such as working memory and inhibitory control (Di Russo et al., 2010; Tsai et al., 2016, 2017). In contrast, CSE is performed in a predictable and stable environment in which participants are less likely to be exposed to multi-sensory stimuli than in OSE (Brady, 1995; Di Russo et al., 2010). CSE thus offers relatively less cognition guidance toward accomplishing a challenging goal or coordinating the body to execute complex movements (Di Russo et al., 2010; Tsai et al., 2016, 2017). Collectively, across the studies in this review, OSE came closer than CSE to satisfying theory that the cognitive demands and challenges of complex motor movement may be a pathway underlying the beneficial effects of exercise on cognitive function (Best, 2010). Additionally, social interaction that occurs during OSE training may exert a further positive impact on cognitive function (Best, 2010).

Physiologically, complex motor leaning and movement seems to exert longer positive influences on the neurotrophic system [i.e., the production of brain-derived neurotrophic factor (BDNF) and its receptor functioning] in the cerebellum than moderate-intensity running (Klintsova et al., 2004). BDNF plays a critical role in neural plasticity and is considered as a biomarker of exercise-induced cognitive benefits (Poo, 2001; Huang T. et al., 2014). A recent study in young adults also showed that one bout of OSE induced a greater increase in serum BDNF compared with a CSE intervention (Hung et al., 2018). Therefore, the greater neurophysiological changes that resulted from OSE may also support its superior cognitive benefits.

Strength and Limitations

To the best of our knowledge, this was the first systematic review of the comparative effects of OSE versus CSE on cognitive function across the lifespan. Both intervention and observational studies were included in this review. In order to maximize between-study comparisons, we focused on studies that clearly defined the exercise modes based on a motor skill classification system yielding OSE and CSE categories. Despite the findings regarding cognitive benefits of both exercise modes (particularly to OSE) that we have outlined, the conclusions in this review must be considered within the context of its limitations. First, 14 of the 19 (74%) included studies were cross-sectional in design, and only five intervention studies were identified. These facts lend caution to making causal inferences. Yet, three of five (60%) included intervention studies supported a superior effect of OSE on some aspects of cognitive function compared with CSE, suggesting considerable value in further research pursuits. Second, we did not conduct a meta-analytic review due to the small number of randomized control trial (RCT) studies, the prevalence of diverse outcomes measures, and the wide age range of participants in these studies. Lastly, the search language we used was limited to English, increasing a risk of having omitted important research published in other languages.

CONCLUSION

This review article systematically evaluated the current evidence of the effects of OSE versus CSE on cognitive function based on existing observational and intervention studies. The review tends to support the notion that OSE is superior in improving some aspects of cognitive function compared with CSE. Given that most of the existing studies are observational in design, with relatively few intervention studies, more rigorous RCTs with long-term follow-ups are needed to further confirm the current findings.

AUTHOR CONTRIBUTIONS

TH, QG, and LZ conceived the study. All authors contributed to the investigation process, provided the methodology, and wrote, reviewed, and edited the manuscript and approved its final version of the manuscript. QG and TH wrote the original draft of the manuscript. TH supervised the manuscript and acquired funding.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.01707/full#supplementary-material

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How Does Exercise Improve Implicit Emotion Regulation Ability: Preliminary Evidence of Mind-Body Exercise Intervention Combined With Aerobic Jogging and Mindfulness-Based Yoga

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Purpose: The primary aim of the present study is to examine the effect of 8-week mind-body exercise intervention combining aerobic jogging and mindfulness-based yoga on implicit emotion regulation ability. The secondary aim is to explore the specific potential pathways by which the mind-body exercise intervention fosters implicit emotion regulation. This may help us to understand how the key components of exercise intervention contribute to emotional benefits.

Methods: Sixty participants were randomly allocated to one of two parallel groups: (1) the intervention group ($n = 29$) and (2) the waitlist control group ($n = 31$). Participants were asked to fill out scales measuring mindfulness and instructed to complete an emotion regulation task to assess implicit emotion regulation ability as well as the PWC 170 Test to evaluate aerobic fitness before and after the intervention.

Results: The results of the two-way repeated ANOVA revealed that 8 weeks of intervention improved implicit emotion regulation, mindfulness, and aerobic fitness levels. Path analysis showed that only improved aerobic fitness mediated the intervention effect on implicit emotion regulation ability, controlling for change in negative affect. Notably, the relationship between the effects on implicit emotion regulation ability and aerobic fitness was moderated by improved mindfulness.

Conclusion: Eight weeks of mind-body exercise intervention improves implicit emotion regulation ability. The aerobic fitness may be an essential pathway which mediates the efficacy on implicit emotion regulation ability. Furthermore, different components, such as aerobic fitness and mindfulness, may interactively contribute to such emotional benefits.

Keywords: mind-body exercise, aerobic jogging, mindfulness-based yoga, implicit emotion regulation ability, aerobic fitness, mindfulness, potential pathway

INTRODUCTION

Emotion regulation is conceptualized as the process by which an individual influences the occurrence, experience, and expression of emotions (Gross, 1998). This process can not only operate in explicit levels but also as an implicit process without the need for conscious supervision or deliberative intentions, and both processes contribute considerably to the effectiveness of emotion regulation as well as mental health (Gross and Thompson, 2007). Literature has emphasized the importance of emotion regulation in determining whether stressful life events result in psychological distress (Sheppes et al., 2015). Specifically, when high stress is perceived, the increase in psychological distress is associated with emotion regulation difficulties (Abravanel and Sinha, 2015). To improve the ability to regulate emotion, several psychological treatments have been developed, such as mindfulness-based cognitive therapy, emotion-focused therapy, and emotion regulation therapy (Mennin et al., 2002; Santor, 2003; Bishop et al., 2004). Additionally, exercise is another complementary intervention that might aid emotion regulation.

Recent research has demonstrated that exercise has salutary effects on emotion regulation ability (Bernstein and McNally, 2016, 2017; Edwards et al., 2017, 2018). However, the specific underlying mechanisms by which varieties of exercise interventions exert their influence on emotion regulation are not clear. One potential explanation for the impact might be aerobic fitness (Lott and Jensen, 2016), which is enhanced by aerobic exercise. Another explanatory pathway might be mindfulness improved by particular exercises, such as yoga or tai chi, which are closely related with emotion regulation. Changes in both aerobic fitness and mindfulness are potential health indicators that might mediate intervention effects on emotion regulation.

Aerobic Fitness and Emotion Regulation

Recent studies have indicated that habitual aerobic activity and aerobic fitness are associated with emotion regulation and mood benefits (Brown et al., 2013; Giles et al., 2017). Lott and Jensen (2016) implemented a cross-sectional study that indicated that executive control is a mediator of the association between aerobic fitness and emotion regulation. However, the causality cannot be inferred from the temporal precedence of the hypothesized associations in this study. Experimental studies need to examine the effect of aerobic activity on emotional regulation. Previous data from our laboratory provided evidence of causality, indicating that 8 weeks of aerobic exercise fosters the frequency of adaptive emotion regulation strategy and that the improvement of inhibition and switching mediate the effect of 8 weeks of aerobic exercise (Zhang et al., 2017). Regarding the effect on emotion regulation ability, the effect of chronic aerobic exercise has not been investigated but certainly exists because of the strong effect of even concentrated aerobic exercise. For example, evidence from a random control trial showed that individuals doing 30 min of jogging recovered faster than their counterparts who did not exercise after the same negative emotion induction (Edwards et al., 2017). Another random control trial indicated that an acute aerobic exercise facilitates the ability to down-regulate emotion, manifesting attenuating emotion responses to negative emotion cues (Bernstein and McNally, 2016). One potential explanation is that the emotion regulation benefits associated with acute aerobic exercise might be due to the improvement of executive function, in view of its essential role in emotion regulation (Ochsner and Gross, 2007). Given chronic aerobic exercise improves both aerobic fitness and emotion regulation ability, we assume that the improvement of aerobic fitness might mediate the effect on emotion regulation ability.

Mindfulness and Emotion Regulation

Mindfulness is conceptualized as a state of nonjudgmental attentiveness to and awareness of moment-to-moment experiences (Bishop et al., 2004) and is associated with decreased negatively biased cognition and explicit and implicit emotion processing (Kiken and Shook, 2012; Greenberg and Meiran, 2014). A neuroscience study suggested that the level of mindfulness is associated with increased prefrontal cortical activation and reduced bilateral amygdala activity during an affect-cue task (Creswell et al., 2007). This finding indicated that individuals with a high level of mindfulness are more likely to activate the cognitive control system to regulate emotional responses as the top-down approach (Ochsner and Gross, 2005; Creswell et al., 2007). In addition, mindfulness is enhanced by mindfulness-based training, with the consequence of improved emotion regulation (Guendelman et al., 2017). In the clinic, mindfulness has been integrated into the treatment programs of emotional disorders such as anxiety and depression disorder (Kabatzinn, 1982; Riemann et al., 2016). In sport psychology, a mindfulness-based program has been specifically designed for athletic performance enhancement (Gardner and Moore, 2005) *via* reductions in negative coping as well as an improved capacity to regulate negative emotions in competition (Josefsson et al., 2017). In exercise psychology, a growing body of empirical evidence has showed the unique efficacy of the type of mindfulness-based exercise on emotion regulation (Menezes et al., 2015).

To explain the effect, Garland et al. (2009) presented a causal model explicating the mechanism of mindfulness meditation action. According to the mindful coping model, mindfulness-based training made it easier for individuals to decenter to the mode of mindfulness, increasing attentional flexibility and broadening awareness, which played an important role in positively reappraising by attributing positive meaning to the event (Garland et al., 2009). Furthermore, researchers provided more evidence to verify the correspondence that increases in mindfulness are significantly correlated with reductions in avoidance and rumination during mindfulness-based intervention (Kumar et al., 2008). Against this backdrop, we assume the improved mindfulness might also explain emotion regulation ability improved in intervention.

Present Study

In the present study, we assume exercise intervention is just a medium or tool to contain different kinds of key components like aerobic fitness, mindfulness, and motor skills. The keys to underlie efficacy are "the active ingredients" in exercise intervention, not the intervention itself. Therefore, we are interested in "the active ingredients" in exercise intervention and evaluation of potential pathways that may underlie the effect on implicit emotion regulation. We attempt to deconstruct the role of different components of exercise to better understand their respective or/and interactive contributions to the effect.

To address this, we learned from previous study to design the mind-body exercise intervention (Alderman et al., 2016). The present intervention consisted of aerobic intervention and mindfulness intervention. In aerobic intervention, jogging was used, because of its simple component of aerobic. In mindfulness intervention, a specially designed mindfulness-based yoga training was applied, which maximized emphasis on the component of meditation in yoga practice, aiming to cultivate the state of mindfulness and minimized emphasis on intensity and motor skills, in order to maintain heart rate (not elevated) during yoga practice. All these designs tried to reduce confounding effects.

Although implicit emotion regulation playing an important role in emotion regulation is believed to be more representative of daily life requirements (Gross and Thompson, 2007; Rothermund, 2011), the effect of exercise on implicit emotion regulation has not been investigated. Based on these considerations, the primary aim of the present study is to examine the effect of mind-body exercise intervention on implicit emotion regulation ability. The secondary aim is to explore the specific potential pathways. Put concretely, do increases in aerobic fitness and/or mindfulness scores mediate the intervention effect? Do increases in aerobic fitness and mindfulness scores interactively contribute to the intervention effect?

Methods

Participants

Sixty female postgraduates were recruited from a university in Haidian District, Beijing. *A priori* G-Power analysis was used by G-Power 3.1 program, with a significance level $\alpha = 0.05$, required power $(1 - \beta) = 0.8$. In general, benefits of chronic exercise are no worse than acute exercise. Therefore, the η^2 expected from the study which tests the reduction of negative affect after an acute aerobic exercise during affective induction was 0.22 (Smith, 2013). The sample of 29 in exercise group and 31 in control group resulted in sufficient participation for this study.

All participants recruited were screened by completing several surveys to ensure that they met the inclusion criteria: (1) no previous training in or current practice of meditation; (2) low level of exercise experience [participants who responded with 1 or 2 (on a 1–5 scale) to all of the following statements were included: "What intensity of exercise do you usually participate in?," "How long do you exercise when you participate in the above-mentioned exercise," and "How many times have you participated in the above-mentioned exercise this month"]; (3) no anxiety disorders, defined as a score < 50 points on the Self-Rating Anxiety Scale-Chinese version (Duan and Sheng, 2012); and (4) no use of any medications that may alter mood. Of note is that additional surveys measured during recruitment to ensure that baseline psychological parameters and experience of meditation and exercise were homogeneous in the two groups. All participants provided written consent, and the protocol was approved by the institutional review board of *College of P.E and sports, Beijing Normal University*.

Measure

Emotion Regulation Task

The emotion regulation task was modified by previously reported emotion regulation paradigms (Gross and John, 2003) that assessed implicit emotion regulation ability by computing each participant's average magnitude of reduction in negative affect while responding to negative images with the manipulation was meant to induce implicit emotional down-regulation, compared to responding to matched negative images without manipulation. Forty pictures selected from the International Affective Pictures System (IAPS) (Lang et al., 1999) were divided into four matched blocks (2 blocks × 2 times, no significant difference in the valence of each block, according to the results of the pre-experiment in another sample of 32 female postgraduates, $F = 0.169$, $p = 0.917 > 0.05$). All stimuli were presented *via* E-prime (ver. 1.1).

The emotion regulation task consisted of two blocks: (1) watching without engaging in emotion regulation and (2) watching with subliminal goal priming. In each block, 10 pictures were presented. During subliminal goal priming, no subliminal priming was mentioned, and participants were asked to evaluate the presented adjectives (Chi and Lin, 2003) by pressing the "positive" or "negative" key on the keyboard. After the false task, the masked affective priming was closely modeled (Custers and Aarts, 2007). The priming words were proven to induce spontaneous emotional down-regulation (Du et al., 2014). At the end of each picture, a nine-point scale was used to measure subjective feeling from 1 (extremely unpleasant) to 9 (neutral).

Assessment of Aerobic Fitness

The Physical Working Capability 170 (PWC 170) test was used to assess improved aerobic fitness as a result of aerobic exercise intervention. For this test, participants cycled on a Monark834 cycle ergometer for two stages. For the first stage, each participant began at 30 W of resistance and maintained the work rate until her heart rate remained stable (recorded continuously every 5 s by the Polar RS800 heart watch). According to previous studies, the resistance in the second stage ranged from 66 to 88 W, based on the stable heart rate in the first stage to ensure the validity of the test. The literature has shown that the PWC170 test was just as valid a predictor of VO_2 max ($r = 0.84$) (Boreham et al., 1990).

Assessment of Mindfulness

The Mindful Attention Awareness Scale (MAAS; Brown and Ryan, 2003) is a six-item self-report measure assessing improved mindfulness as a result of yoga intervention. The MASS has been shown to have excellent internal consistency across a range of samples (Cronbach's α = 0.84). The Chinese version of the MASS has also shown great psychometric properties (Deng et al., 2011). Previous studies have shown a larger improvement of MASS scores with more intense practice and supported using the change of MASS scores as a "surrogate measure" that can reflect the intensity of mindfulness practice (Brown and Ryan, 2003).

Additional Assessment

Several surveys were employed to evaluate baseline demographic, behavioral, and psychological characteristics across the two groups. Briefly, the additional baseline parameters that were assessed included energy expenditure estimates (METs) per week (*via* the International Physical Activity Questionnaire-Chinese version) (Qu and Li, 2004), body fat percentage (*via* InBody human body composition analyzer), and anxiety (*via* the Self-Rating Anxiety Scale-Chinese version) (Duan and Sheng, 2012). Due to the potential effects of mood-congruent emotion processing bias (Beck and Aaron, 2008), negative affect was also assessed as a potential covariate (*via* the Positive and Negative Affect Scale-Chinese version) (Huang et al., 2003) before and after the intervention.

Mind-body Exercise Intervention

The whole intervention sessions were provided three times a week over an 8-week timeframe. Each of aerobic sessions lasted for 40 min and yoga sessions for 60 min. Two different interventions were provided alternately.

In the aerobic exercise session, participants jogged in three groups on a playground for 30 min and then walked and stretched to actively relax for 10 min. The intensity of jogging was set at moderate (60–70% of the predicted maximal heart rate) and monitored by portable heart watches. Each time, one participant was randomly selected from each group, and each of these three participants was asked to lead her own group to better control the heart rates of all participants by adjusting their running speeds based on her own heart rate.

Yoga training sessions followed a consistent sequence that included: (1) 10 min of breathing-regulation practice and 5 min of focused-attention meditation in a comfortable, cross-legged, seated position, (2) 30 min of postures and movement sequences practice integrated by mindfulness prompts, and (3) 10 min of mindfulness meditation and 5 min of loving-kindness meditation. This session was strictly designed using the following aspects.

Conscious Breathing

Different conscious practices of altering breathing patterns were conducted during breathing regulation, movement sequences, and meditation. In breathing regulation, the focus was simply on cultivating breath awareness and conscious breath regulation, including the depth and frequency of breathing. In movement sequences, breathing should precisely coordinate with movement. In focused attention meditation, breathing served as an object of attention.

A Combination of Postures and Movement Sequences

A series of pulling movements designed to warm up the extremities and spine were conducted before practicing sitting and standing postures. This was followed by seated postures practice, including forward bends, back arches and twists. Then, a series of spine releases were done to relax. As participants became more competent with practice, a series of standing postures were conducted to fully activate the nervous system and muscles of the whole body. Finally, participants lay on the floor and relaxed to calm down and restore their bodies.

Meditation

Focused-attention meditation was designed as the starting point to improve attention. Due to the consequences of focused attention, mindfulness meditation was easily conducted to cultivate mindfulness (observing without judgment). The session concluded with loving-kindness meditation, which involved showing compassion, appreciation, and acceptance of the self and others.

Procedure

Participants were randomly allocated to one of two parallel groups: (1) the intervention group and (2) the waitlist observational control group. All outcomes were collected at the baseline, 9 weeks (post intervention); in addition, pre- and post-assessments were identical and arranged at the same time of day for each individual to control the potential impact of biological rhythm. Assessments were conducted as follows in a consistent sequence: on arrival at the laboratory, participants were asked to fill out scales measuring mindfulness and negative affect levels. Then, participants were instructed to complete the emotion regulation task to assess implicit emotion regulation ability. After this, the Physical Working Capability 170 Test was conducted to evaluate aerobic fitness, and acute exercise potentially also helped to ease the negative impact of the previous affect-induction task.

Data Analytic Strategy

A 2 (Group: EI, WL) × 2 (Time: Pre, Post) repeated-measures analysis of variance (ANOVA) was run in SPSS version 20 to examine the effects on implicit emotion regulation ability, mindfulness, aerobic fitness, and negative affect.

Based on the hypothesis, improvement of health indicators not only physically but also mentally may mediate intervention effects on implicit emotion regulation ability. Path analyses were run in Mplus version 7.4 (Muthén and Muthén, 1998–2015) to examine the potential explanatory pathways with (1) the independent variable (expressed as two "dummy variables": exercise as Group 1, control as Group 2); (2) the mediating variable (improved aerobic fitness and mindfulness); (3) the dependent variable (improved implicit emotion regulation ability); and (4) the covariate (change in negative affect). Through bias-corrected nonparametric bootstrapping statistical analyses, data were re-sampled 1,000 times, and confidence intervals (BCIs) of the indirect and direct effects were set at 95%, with an α level of 0.05 (Preacher and Hayes, 2008).

The hierarchical multiple regression analysis was used to estimate individual and/or interaction contributions to improved implicit emotion regulation ability accrued by intervention-related factors, which entailed the following steps: (1) interaction variables were computed by multiplying the predictors (improved mindfulness × improved aerobic fitness). (2) Hierarchical multiple regression analyses with the forced entry method were run for the prediction of improved implicit emotion regulation ability. Potential covariate (change in negative affect) was entered in the first block for statistical control, while the factors related to intervention (improved mindfulness and aerobic fitness) were entered in the second block and the interaction term in the third block. (3) If the interaction term in the third block added to the model, a significant percentage of variance explained, *post hoc* analyses were run by simple slope testing (Aiken and West, 1991).

RESULTS

Descriptive characteristics and homogeneity test for baseline are displayed in **Table 1**, showing that there were no statistically significant differences in baseline parameters.

A 2 (Group: EI, WL) × 2 (Time: Pre, Post) repeated-measures analysis of variance was conducted on implicit emotion regulation ability, which indicated a main effect of time ($F_{1,59}$ = 4.75, $p < 0.05$, η_p^2 = 0.076), no effect of group ($F_{1,59}$ = 1.558, $p > 0.05$, η_p^2 = 0.026), and a significant interaction between group and time ($F_{1,59}$ = 7.289, $p < 0.01$, η_p^2 = 0.112). Follow-up within-group *t*-tests yielded pre-to-post-exercise increases in implicit emotion regulation ability ($t = -2.474$, $p < 0.05$) and no change for control group ($t = 0.889$, $p > 0.05$).

For aerobic fitness, the results showed a main effect of time ($F_{1,59}$ = 55.276, $p < 0.01$, η_p^2 = 0.488), and an effect of group ($F_{1,59}$ = 6.969, $p < 0.05$, η_p^2 = 0.107); furthermore, the interaction between time and group was significant ($F_{1,59}$ = 57.123, $p < 0.01$, η_p^2 = 0.496). Follow-up within-group *t*-tests yielded pre-to-post-exercise increases in aerobic fitness ($t = -7.304$, $p < 0.000$) and no change for control group ($t = 0.506$, $p > 0.05$).

A 2 (Group: EI, WL) × 2 (Time: Pre, Post) repeated ANOVA showed a main effect of time ($F_{1,59}$ = 19.891, $p < 0.01$, η_p^2 = 0.255) and group ($F_{1,59}$ = 5.299, $p < 0.05$, η_p^2 = 0.084), and a significant interaction between group and time for mindfulness ($F_{1,59}$ = 20.301, $p < 0.01$, η_p^2 = 0.259). Follow-up within-group *t*-tests yielded pre-to-post-exercise increases in mindfulness ($t = -4.446$, $p < 0.000$) and no change for control group ($t = 0.105$, $p > 0.05$).

As for negative affect, there was a main effect of time ($F_{1,59}$ = 13.822, $p < 0.01$, η_p^2 = 0.192), no effect of group ($F_{1,59}$ = 0.512, $p > 0.05$, η_p^2 = 0.009), and a significant interaction between group and time ($F_{1,59}$ = 4.231, $p < 0.05$, η_p^2 = 0.068). Follow-up within-group *t*-tests yielded pre-to-post-exercise decreases in negative affect ($t = 3.498$, $p < 0.000$) and no change for control group ($t = 1.425$, $p > 0.05$).

In the hypothesized model, two indirect pathways were included. The results showed that only improved aerobic fitness, but not mindfulness, was found to significantly mediate the effect of participating in intervention versus control on improved implicit emotion ability, as indicated by bootstrapped 95% confidence intervals that did not contain zero ($\alpha\beta = -0.411$, 95% BCI = −0.79 to −0.143). In addition, the path coefficient for the direct effect of group on improved implicit emotion regulation controlling for two mediators and covariate was not significant. Standardized coefficients, bootstrapped 95% confidence intervals (BCIs), and standard errors of direct effects are reported in **Table 2**.

Table 3 shows significant results of hierarchical regression analyses. With regard to the variance explained, improved implicit emotion ability was positively predicted by improved aerobic fitness, contributed to the prediction with 26.8%. The introduction of the interaction term to the model added a small but significant percentage of variance explained (8.9%), indicating the presence of a moderated effect. A *post hoc* analysis was conducted with change in negative affect as a covariate, improved aerobic fitness as a predictor of improved implicit emotion regulation ability, and improved mindfulness (high level, moderate level, and low level) as a moderator. Only at a high level and a moderate level of improved mindfulness

TABLE 1 | Baseline characteristics and homogeneity test of the analyzed sample.

Variable	Group		
	Exercise intervention (*n* = 29)	**Waitlist control (*n* = 31)**	***p***
Age	23.07 (1.51)	23.34 (1.52)	0.33
Body fat percentage	25.25 (4.39)	25.02 (4.36)	0.85
Implicit emotion regulation ability	−1.20 (1.45)	−1.09 (1.26)	0.76
Aerobic fitness	1.69 (0.33)	1.58 (0.38)	0.26
Mindfulness	3.48 (0.64)	3.29 (0.68)	0.28
Negative affect	2.79 (0.59)	2.73 (0.48)	0.68
Anxiety	40.17 (5.78)	40.84 (6.61)	0.68
Energy expenditure estimates	888.79 (620.08)	953.13 (620.66)	0.69

All values presented as mean (standard deviation). p's calculated via independent samples t-test.

TABLE 2 | Summary of direct effects of mediation model.

	Estimate	S.E.	Lower BCL	Upper BCL
Group→improved implicit emotion ability	0.109	0.239	−0.304	0.655
Group→improved aerobic fitness	**−0.704**	**0.100**	**−0.922**	**−0.524**
Group→improved mindfulness	**−0.509**	**0.120**	**−0.754**	**−0.283**
Improved aerobic fitness→improved implicit emotion ability	**0.584**	**0.218**	**0.166**	**1.056**
Improved mindfulness→ improved implicit emotion ability	0.041	0.175	−0.304	0.390

S.E., standard error; BCI, bootstrapped confidence interval.

could improvements in implicit emotion regulation ability be predicted by improved aerobic fitness (**Figure 1**).

DISCUSSION

The primary aim of the present study was to examine the effect of mind-body exercise intervention on implicit emotion regulation. To address this question, we investigated the changes in implicit ability to down-regulate negative affect before and after 8 weeks of intervention or control. The results of two-way repeated ANOVA revealed that only participants in the intervention group displayed significant improvement in implicit emotion regulation ability. Apart from one study that found the brief mindfulness manipulation fosters implicit emotion regulatory processes (Remmers et al., 2016), few studies have examined the effect on implicit emotion regulation, especially with long-term intervention. Thus, the present study extends previous empirical research on the benefits of exercise intervention on implicit emotion regulation and demonstrates that 8 weeks of mind-body exercise intervention improves the implicit emotion regulation ability.

The secondary aim was to explore potential mechanisms of the effect on implicit emotion regulation ability. Based on the premise, confirmed by our results, that an 8-week intervention improved aerobic fitness, mindfulness, and negative affect, path analyses indicated that only improved aerobic fitness mediated the intervention effect on implicit emotion regulation ability. In line with the neuronal plasticity hypothesis, the improvement of aerobic fitness may result in observable concomitant structural and functional changes in regions of prefrontal and parietal cortices (Colcombe et al., 2004; Hillman et al., 2008). These brain regions are regarded as important regions for realizing emotion regulation; for example, the ventral-anterior cingulate cortex (vACC) and ventro-medial prefrontal cortex (vMPFC) are involved in implicit emotion regulation (Kohn et al., 2014; Etkin et al., 2015), and for realizing cognitive control, which is, in turn, hypothesized to be the essential mechanism of top-down emotion regulation (Ochsner and Gross, 2007). Therefore, exercise intervention may directly model brain regions involved in emotion regulation through improved aerobic fitness but may also be involved in cognitive control, indirectly affecting emotion regulation. Unexpectedly, improved mindfulness did not mediate the intervention effect. The present findings fit with the mindful emotion regulation model, not the mindful coping model (Chambers et al., 2009). Mindfulness is not a process of cognitive reappraisal but a unique emotion regulation strategy exerted by the state of mindfulness. In contrast to the cognitive reappraisal strategy, mindful emotion regulation is mainly involved in the bottom-up approach (Chambers et al., 2009;

TABLE 3 | Hierarchical multiple regression analysis to predict improved implicit emotion ability.

Predictors	Beta (std)	*T*	*p*
Block 1			
Change in negative affect	−0.134	−1.028	0.308
ΔR^2		0.018	
Block 2			
Improved aerobic fitness	**0.519**	**4.104**	**0.000**
Improved mindfulness	**0.018**	**0.127**	**0.899**
ΔR^2		0.268	
Block 3			
Improved aerobic fitness × Improved mindfulness	**0.359**	**2.793**	**0.007**
ΔR^2		0.089	
Total R^2 = 0.375			
Adjusted total R^2 = 0.329			

VIF statistics ranged between 1.0 and 1.7, thus allowing to exclude problems of multicollinearity.

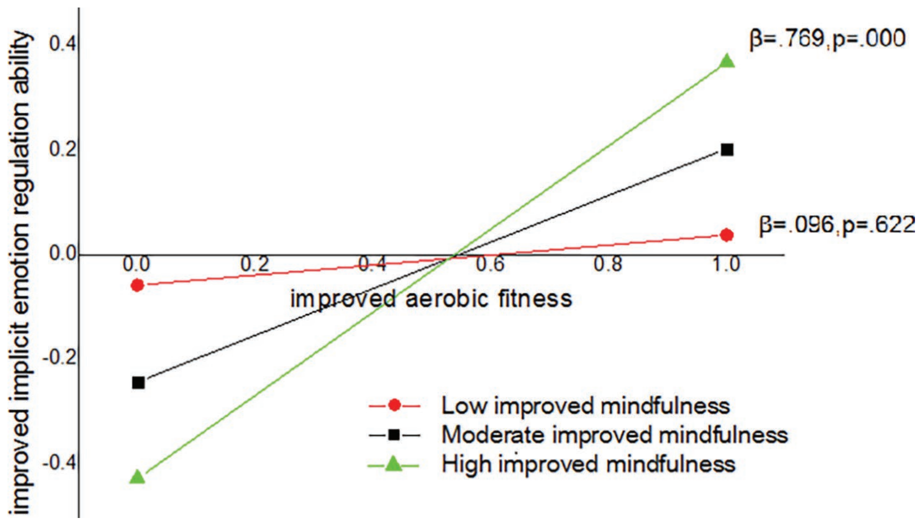

FIGURE 1 | Improved implicit emotion regulation ability as a function of improved aerobic fitness in lower and higher improved mindfulness: a moderated prediction.

Farb et al., 2012; Chiesa et al., 2013). No indirect effect of improved mindfulness was found in the present results, since the presented priming stimulus might mostly relate to the cognitive reappraisal strategy involving the top-down mechanism. In addition, as the medial prefrontal cortex is also involved in dopaminergic circuits, aerobic exercise may continuously stimulate the dopaminergic circuits through impacting related brain regions, with a consequence of better resistance to negative emotional influence (Codella et al., 2016).

Notably, the relationship between the effect of exercise intervention on implicit emotion regulation ability and aerobic fitness was moderated by improved mindfulness, and improved aerobic fitness could predict greater improvement of implicit emotion regulation ability, especially with higher levels of improved mindfulness in individuals. Although improved mindfulness could not predict improvement of implicit emotion regulation ability directly, exercise-involved mindfulness practice might amplify the effectiveness of simple aerobic exercise to improve emotion regulation, which indicated considerable advantages of a mixed exercise intervention. To our knowledge, studies have stated that exercise interventions involving more effective components, such as aerobic and cognitively engaging exercise, are more beneficial to cognition than simple aerobic exercise without thinking (Colcombe and Kramer, 2003; Best, 2010; Diamond, 2015). This view is also extended from cognitive to emotion regulation by the present empirical results.

The present experiment inevitably has limitations. First, we mainly focused on aerobic fitness as the only relevant outcome of aerobic jogging that may be associated with emotion regulation and on mindfulness as the only relevant outcome of mindfulness-based yoga that may be associated with emotion regulation. Although other outcomes of aerobic exercise and yoga may be not the key active ingredients that underlie the efficacy and some of them are difficult to assess, these outcomes may be potentially linked to emotion regulation through different pathways, such as motor fitness improved by postures, movement-sequence training, and self-compassion, acceptance cultivated by meditation skills (Laura et al., 2015), and these outcomes might be neglected.

In addition, as we have discussed before, mindful emotion regulation may be an implicit strategy involved in the bottom-up approach; however, the paradigm task in the present study was used to mainly evaluate the ability to top-down regulate emotion in the condition of subliminal goal priming. Although the top-down and bottom-up approaches are both comparably effective in emotion regulation, they may regulate negative emotion through different psychological mechanisms, with the consequence that we did not discover the pathway *via* mindfulness and thereby might have neglected its contribution to implicit emotion regulation ability. Future research in this domain would do well to address these limitations.

Finally, as a previous study has shown that mental and physical training, similar to present intervention, decreases maladaptive emotion regulation strategy (ruminative) and negative affect (Alderman et al., 2016). Even though the priming stimuli mainly involved one specific adaptive strategy and we also controlled the change in negative affect, the confounding variables may still exist.

These caveats notwithstanding, the present study sheds important new light on the interface between exercise and implicit emotion regulation. The results showed that exercise improves emotion regulation ability not only at the explicit level but also at the implicit level. However, the sample of present study and effective size for main dependent variable are relatively small, which means the magnitude of the difference is low. The reason might be the duration of intervention is relatively short, while longer intervention treatment such as 12-week interventions may show greater effects. Therefore, we should cautiously interpret the present results and seek a larger sample in future studies.

A further novelty of the study is that it furthers understanding of the potential pathways by which exercise intervention including different components fosters implicit emotion regulation. This may be useful in targeting interventions for those who want to benefit most. Although the findings from the present pilot study are preliminary, one potential mechanism by which exercise exhibits its beneficial effect might be aerobic fitness. For people who desire the benefits of emotional regulation from exercise, the components of exercise including aerobic are absolutely necessary, and the components could be enriched with more cognitive engagement like mindfulness at people's earliest convenience.

DATA AVAILABILITY

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The Institutional Review Board of School of PE And Sports, Beijing Normal University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YZ conceived and designed the work, drafted and led the work to the submission. In addition, he mainly acquired data and analyzed it. RF, LS and YG contributed to the revision. DT helped to perform the analysis with constructive discussions and approved the final version.

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The Effect of Traditional Chinese Mind-Body Exercise (Baduanjin) and Brisk Walking on the Dorsal Attention Network in Older Adults With Mild Cognitive Impairment

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A growing number of studies have shown that mind-body exercise is beneficial to cognitive function, especially memory, in elderly MCI patients. However, few studies have explored the effect of mind-body exercise on the attention of MCI population. We recruited 69 participants and divided them equally into Baduanjin, brisk walking (BWK) exercise or usual physical activity (UAP) control groups. The two exercise groups performed 60 min of exercise three times per week for 24 weeks. All subjects underwent whole-brain functional MRI and assessment of attentional abilities, including selective, divided, and sustained attention, and processing speed at baseline and after 24 weeks. The results show that: Baduanjin exercise significantly increased the selective attention of MCI patients, and Dorsal attention network (DAN) of Baduanjin exercise group exhibited functional connectivity decreased in right rolandic operculum (ROL. R), right middle temporal gyrus (MTG. R), right supramarginal inferior parietal, angular gyri (IPL. R), right precuneus (PCUN. R), and right fusiform gyrus (FFG. R) regions compared with the other two groups. The BWK exercise group had obviously functional connectivity increased in IPL. R and decreased in the MTG. R region compared to that in the UAP group. But no significant association between the changes of functional connectivity of DAN and the change of attentional ability test was observed. Thus, our data indicated Baduanjin exercise may be a potential beneficial intervention to improve the attention of the elderly with MCI. Further study with more samples is necessary to elucidate its imaging mechanism.

Keywords: mind-body exercise, Baduanjin, brisk walking, mild cognitive impairment, dorsal attention network

INTRODUCTION

At present, over 46 million people are living with dementia, and by 2050, this number will rise to almost 131.5 million worldwide; dementia has been identified as a global health priority due to the growing burden of the disease (Prince, 2015). Dementia is a progressive disease with a long duration. Pathological changes start taking place up to 20 years before the presentation of clinical symptoms. The currently available medications for dementia only alleviate the disease's symptoms but are not able to stop or slow its progression. Therefore, there is an urgent need for strategies to prevent people from developing dementia (Prince et al., 2016). Mild cognitive impairment (MCI) is a transitional state between normal aging and dementia, accompanied by the decline of memory, attention and other cognitive domains. People with MCI constitute a group at high risk for dementia, and MCI is increasingly prevalent among older age groups (Petersen, 2016). There is accumulating evidence for a breakdown in processes related to attention in older adults with MCI and in the early stages of dementia (Duchek and Balota, 2005; Belleville et al., 2008). Studies have shown that attention deficits in MCI patients may be the entry point for developing dementia and can be an early indication of subsequent changes in other cognitive functions (Marra et al., 2000; Zhou and Wang, 2005). Thus, early identification and intervention related to attention impairment in patients with MCI is very important.

Some recent studies have shown attention to be a key cognitive domain that benefits from physical activity (Iuliano et al., 2015; Condello et al., 2017). Brain function, as measured by functional magnetic resonance imaging (fMRI), has shown that physical activity is associated with increased activity in left dorsolateral prefrontal, posterior parietal, and anterior cingulate cortices (Rosano et al., 2010), which are important components of the core region of the dorsal attention network (DAN) (Kim, 2014). The DAN is consistently involved in attention and has been associated with working memory and episodic memory encoding (Majerus et al., 2018; Stawarczyk et al., 2018). Recent studies have found intranetwork and internetwork functional disruptions in the DAN in MCI patients (Qian et al., 2015; Bi et al., 2018). Therefore, some studies have suggested that functional change in the DAN could be used as a sensitive indicator of MCI disease progression (Li et al., 2012; Zhang et al., 2015). Given the relationship between attention and the DAN, it can be speculated that the DAN is a promising avenue by which increasing physical activity can promote the attention abilities of patients with MCI. However, previous measurements of physical activity have been imprecise, often in the form of self-reports, and have failed to provide an accurate picture for some specific types of physical activity.

Baduanjin is a traditional Chinese mind-body aerobic exercise of moderate intensity and is one of the most common forms of Qigong that has been practiced in China for over 1000 years. Unlike other types of aerobic exercise, practitioners are required to achieve coordination between mind and body when they are practicing Baduanjin exercise (Kim et al., 2016). Studies have demonstrated that regular practice of Baduanjin exercise can not only result in physiological benefits, such as improved cardiopulmonary function, balance, and reduced osteoarthritis, but also actually improve cognitive function in older people with or without cognitive impairment (Zou et al., 2018). However, no studies have reported the effect of Baduanjin exercise on attentional ability or the relationship between attention and the DAN in MCI patients.

MATERIALS AND METHODS

Participants

Participants in this study came from a randomized controlled trial, for which a total of 135 MCI patients were recruited from Fuzhou, China. Based on a 1:1:1 ratio, participants were randomly assigned to a Baduanjin group, a brisk walking (BWK) group and a usual activity control group with 45 participants each group (Zheng et al., 2016a). A total of 69 participants underwent baseline attention tests and MRI scans, of which 60 completed the post-intervention attention tests and MRI scans (20 individuals in each group). Inclusion criteria for study participants were an age of 60 years or older; conformity with Peterson's MCI diagnostic criteria (Petersen, 2004); and no regular physical exercise for at least half a year (regular exercise means exercise with a frequency of at least twice a week and at least 20 min per session).

This trial was approved by the Medical Ethics Committee of the Second People's Hospital of Fujian Province (approval number 2014-KL045-02). All participants provided written informed consent prior to participation.

Intervention Protocol

Baduanjin exercise Baduanjin (BDJ) exercise intervention was conducted according to the standards promulgated by the General Administration of Sport in China in 2003, which consisted of 10 postures (including the beginning and ending posture) (Health Qigong Management Center of General Administration of Sport of China, 2003). Participants gathered at a community center at 7 am and practiced Baduanjin supervised by a coach. Baduanjin training was assigned at two community centers (Cangxia and Longfeng Community Center in Fuzhou City) with 20–25 individuals per center. The exercise intervention lasted 24 weeks with a frequency of three sessions a week and 60 min per session. In addition, participants, including those in the usual physical activity (UAP) group, also received a health education program, which included instruction regarding cognitive disorders, healthy eating and living habits. Two professional coaches from Fujian University of Traditional Chinese Medicine (FJTCM) were employed to guide participants' training.

Brisk walking Participants received 24 weeks of BWK training at a frequency of three sessions a week and 60 min per session in addition to the health education courses described above. The intensity of exercise was controlled such that heart rate remained in the range of 55–75% of the maximum reserve heart rate (Ying, 2012).

Usual physical activity control Participants in the UAP group were instructed to maintain their original physical activity habits and only received health education training at a frequency of one session every 8 weeks, 30 min per session.

Attentional Ability Measurement

According to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-V) recommendations, attentional ability encompassing the four dimensions of selective attention, divided attention, sustained attention and processing speed were measured at baseline and after intervention in this study by using the Color-Word Matching Stroop task (cwmStroop), the divided and sustained attention Test of Attention Performance software (TAP V.2.3, Vera Fimm, Psychologische Testsysteme), and the digit-symbol coding task (DSC), respectively (Gong, 1983; American Psychiatric Association, 2013). cwmStroop task created in E-Prime software (version 2.0, Psychology Software Tools, Inc., Sharpsburg, PA, United States), two lines of text appear on the screen, participants are asked to determine whether the coloring of the first line of text matches the meaning of the next line as soon as possible, and to record the correct number and reaction time under three conditions. During the divided attention subtask, participants must consider both visual (mobile cross) and auditory (low and high) stimuli. When there are four intersections forming a square or when the sound interrupts alternately, press the response button as soon as possible. Record the correct number of reactions and the number of reaction times. During the sustained attention subtask, participants should keep an eye on the various graphics on the screen and press the button quickly when two consecutive identical graphics appear. DSC requires participants to convert numbers into corresponding symbols as soon as possible in 90 s.

fMRI Scan Parameters and Data Preprocessing

Magnetic resonance imaging (MRI) scans were obtained at baseline and after intervention using a 3.0-Tesla General Electric scanner (Milwaukee, WI, United States) with an eight-channel phased-array head coil. T1-weighted images were collected using a three-dimensional magnetization-prepared rapid acquisition gradient-echo (3DMPRAGE) sequence with the following parameters: echo time = min, field of view = 240 × 240 mm, flip angle = 15°, inversion time = 450 ms, slice thickness = 1 mm, and 164 slices per acquisition. An echo planar imaging sequence was performed for resting-state scans with the following parameters: repetition time = 2100 ms, echo time = 30 ms, echo spacing = 20 ms, field of view = 200 × 200 mm, flip angle = 90°, slice thickness = 3 mm with a 0.6-mm gap, voxel size = 3.125 × 3.125 × 3.6 mm^3, 42 slices, 64 × 64 matrix, phases per location = 160, bandwidth = 31.2, slice order: [1,3,. . .41,2,4,. . .42], Subjects were required to stay awake with their eyes closed and ears plugged during the MRI scan.

The preprocessing of the fMRI data was performed using the toolbox for Data Processing and Analysis for Brain Imaging, Version 2.3 (DPABI) in MATLAB (MathWorks, Inc., Natick, MA, United States). The preprocessing steps included slice-timing, realignment, coregistration, segmentation, spatial normalization, smoothing, and filtering. In this study, 42 slices of interlace scanning were implemented, and the second slice in the middle of scanning sequence was used as the reference slices for slice-timing. The Friston-24 model is used for head motion correction, and the data of participants with three-dimensional translation >3 mm and/or three-dimensional rotation >3 degrees are eliminated. Through linear transformation, the structure image is transformed into the function image space to match and overlay each other. Linear and quadratic trends are used as regression variables to remove low frequency drift of BOLD signals. Then use DARTEL tool to convert functional data from an individual native space to MNI space. Finally, performed spatial smoothing (FWMH kernel: 4 mm) and temporal filtering (0.01–0.1 Hz) to improve the signal-to-noise ratio (Yan et al., 2016).

Statistical Analysis

Behavioral Data Analysis

Behavioral data at baseline and after intervention were analyzed using the SPSS 24.0 (IBM, Chicago, IL, United States) software package. One-way analysis of variance (ANOVA) or a non-parametric test was applied to compare differences across the three groups. *Post hoc* tests (Bonferroni correction) were applied to explore between-group differences. Statistical significance was defined as two-sided $P < 0.05$. The scores of cognitive data pre-post change was further calculated, and covariance analysis was conducted. At the same time, gender, age, and education level were adjusted as covariates.

Resting-State fMRI Data Analysis

Independent component analysis (ICA) and the Group ICA/IVA of fMRI Toolbox (GIFT[1], version 4.0 a) were applied to analyze the MRI data. Performed the Infomax algorithm to group spatial ICA, and a Gaussian ICA method was used to back reconstruct components (Calhoun et al., 2001). The Z-value is a correlation coefficient between the time series of each single voxel and the time series of an independent component. Higher Z-value indicates stronger functional connectivity. Converting the correlation coefficient between time series of each voxels and independent components into Z-value, and the strength of functional connection is judged accordingly. The DAN was identified according to the rules reported in a previous study (Choe et al., 2015), and group statistics were performed in which we extracted the Z map from two components then reduced the Z-values before and after the intervention (pre-post-intervention). Results of the rs-fMRI data were corrected for multiple comparisons in group level and voxel level, one-way

[1] http://icatb.sourceforge.net/

TABLE 1 | Baseline characteristics of the participants (mean ± SD).

Characteristics	BDJ (*n* = 23)	BWK (*n* = 23)	UPA (*n* = 23)	$F(\chi^2)$	*P*
Age (year)	65.79 ± 4.35	64.88 ± 3.30	65.86 ± 5.28	0.488	0.783
Gender (male/female)	6/17	11/12	6/17	3.261	0.196
Average years of education (year)	11.22 ± 3.45	10.48 ± 2.47	11.35 ± 3.54	0.696	0.706
Handedness (right/left)	23/0	23/0	23/0	–	–
MoCA	22.30 ± 2.40	21.65 ± 2.35	20.83 ± 3.27	1.724	0.186
GDS[1] grade II/III, n	16/7	13/10	11/12	2.260	0.323
GDS[2] scores	6.09 ± 2.98	4.57 ± 2.68	5.26 ± 2.75	1.694	0.192

BDJ, Baduanjin exercise group; BWK, brisk walking group; UPA, usual physical activity control group. [1]Global deterioration scale. [2]Geriatric depression scale.

ANOVA was performed to analyze the changes in the Z-values across the three groups, and a *post hoc* test with the least-significance-difference (LSD) method was applied to analyze the between-group differences. Voxel level corrected using the AlphaSim correction, thresholds of voxel-wise $P < 0.01$, cluster-level $P < 0.05$ (Ke et al., 2018).

In addition, to explore the association between the changes of functional connectivity in the DAN and changes of behavioral

TABLE 2 | Comparison of attention ability among groups.

Outcomes	Groups	Numbers of participants	Baseline		Pre-post changes*	
			Mean @ SD	*P*-value	Mean @ SE	*P*-value
Selective attention (stroop test)						
Neutral reaction time (ms)	BDJ	23	1029.45 ± 113.04	0.681	−15.79 ± 20.91	0.918
	BWK	23	1039.48 ± 80		−16.96 ± 11.41	
	UPA	23	1052.55 ± 69.42		−3.45 ± 23.56	
Neutral correct number (times)	BDJ	23	44.48 ± 12.78	0.484	5.30 ± 2.20	0.340
	BWK	23	45.48 ± 7.95		3.61 ± 1.51	
	UPA	23	41.48 ± 13.46		0.20 ± 2.12	
Congruent reaction time (ms)	BDJ	23	1007.77 ± 111.61	0.941	−11.35 ± 20.34	0.225
	BWK	23	999.38 ± 75.48		0.48 ± 18.84	
	UPA	23	1006.28 ± 68.38		71.73 ± 29.06	
Congruent correct number (times)	BDJ	23	45.22 ± 13.48	0.690	6.55 ± 2.71	0.038[1]
	BWK	23	47.96 ± 8.79		2.12 ± 2.09	
	UPA	23	45.65 ± 11.92		−6.6 ± 3.55	
Incongruent reaction time (ms)	BDJ	23	1068.65 ± 121.71	0.326	31.34 ± 20.69	0.219
	BWK	23	1097.09 ± 93.22		−36.93 ± 25.63	
	UPA	23	1118.99 ± 122.54		−44.83 ± 51.18	
Incongruent correct number (times)	BDJ	23	29.48 ± 13.41	0.564	7.60 ± 2.55	0.264
	BWK	23	31.13 ± 11.1		6.53 ± 3.24	
	UPA	23	27.3 ± 11.72		−4.40 ± 3.83	
Divided attention (TAP test)						
Auditory reaction time (ms)	BDJ	23	720.65 ± 156.57	0.070	−8.15 ± 44.23	0.248
	BWK	23	718.30 ± 417.39		−105.71 ± 114	
	UPA	23	810.35 ± 282.23		−53.60 ± 69.05	
Auditory correct number (times)	BDJ	23	14.17 ± 3.08	0.213	−0.25 ± 0.93	0.633
	BWK	23	14.09 ± 3.60		1.29 ± 0.99	
	UPA	23	12.87 ± 3.43		−0.60 ± 1.73	
Visual reaction time (ms)	BDJ	23	1028.57 ± 202.12	0.116	−43.95 ± 80.26	0.586
	BWK	23	978.95 ± 230.55		−51.65 ± 54.61	
	UPA	23	1050.82 ± 181.61		8.20 ± 45.69	
Visual correct number (times)	BDJ	23	13.83 ± 3.75	0.754	0.50 ± 1.32	0.319
	BWK	23	14.32 ± 3.47		0.94 ± 0.52	
	UPA	23	14.55 ± 3.43		−0.40 ± 0.45	
Sustained attention (TAP test)						
Reaction time (ms)	BDJ	23	685.35 ± 132.21	0.094	4.50 ± 43.66	0.641
	BWK	23	624.00 ± 98.79		−32.55 ± 56.86	
	UPA	23	702.09 ± 119.08		−58.87 ± 42.45	
Correct number (times)	BDJ	23	39.52 ± 8.84	0.550	−3.50 ± 1.88	0.145
	BWK	23	39.91 ± 9.94		1.00 ± 2.65	
	UPA	23	38.17 ± 8.18		3.07 ± 2.49	
Processing speed (DSC test)						
DSC scores	BDJ	23	33.22 ± 10.63	0.675	4.50 ± 1.22	0.867
	BWK	23	34.65 ± 10.14		2.94 ± 1.28	
	UPA	23	31.89 ± 7.27		4.13 ± 2.02	

BDJ, Baduanjin exercise group; BWK, brisk walking group; UPA, usual physical activity contrl group. DSC, digit–symbol coding test. Post hoc test: [1]$P_{BDJ\ vs.BWK} = 0.442$, $P_{BDJ\ vs.UPA} = 0.008$; $P_{BWK\ vs.UPA} = 0.117$. **Covariance analysis pre-post changes of attention with adjusted gender, age, and education level.*

factors, we performed a multiple regression analysis including age, gender, and education as covariates.

RESULTS

Baseline Characteristics

Sixty participants completed MRI scans at baseline and after the intervention with 20 participants each group. There were no significant differences in the demographic data or the Montreal Cognitive Assessment (MoCA), Global Deterioration Scale level and Geriatric Depression Scale scores at baseline across the three groups (**Table 1**).

The Effect of Baduanjin Exercise on Attentional Ability

There was no significant difference in performance on the selective attention, divided attention, sustained attention or processing speed measures at baseline across the three groups. After the 24 weeks of the intervention period, covariance analysis pre-post changes of attention with adjusted gender, age and education showed only average number of correct congruent condition were significantly different between the three groups (P = 0.038); further *post hoc* analysis showed that the average number of correct congruent condition for the Baduanjin group was significant increase than that of the UAP group (P = 0.008). The group differences on other parameters of selective attention, divided attention, sustained attention and processing speed were not found (**Table 2**).

Dorsal Attention Network Changes

The results of the ICA are presented in **Table 3**. One-way ANOVA showed that after the 24-week exercise period, there were significant differences in the DAN in five regions (cluster-corrected at AlphaSim $P < 0.05$; voxels $P < 0.01$): right middle temporal gyrus (MTG. R), right fusiform gyrus (FFG. R), right rolandic operculum (ROL. R), right precuneus (PCUN. R), and right supramarginal inferior parietal and angular gyri (IPL.R). The results of *post hoc* analysis applied Bonferroni correction have no statistical difference among the three groups, and the results applied LSD method were shown in **Figure 1**. Compared to the BWK group or UAP group, IPL. R, ROL. R, MTG. R, PCUN. R, and FFG. R exhibited obvious functional connectivity reduced in the Baduanjin group, and all changes in Z-value were smaller than those in the other two groups (all $P < 0.05$). In IPL. R, the change in Z-value for the BWK group were functional connectivity increased and were significantly greater than that in the other two groups ($P_{BWK\ vs.BDJ}$ = 0.001, $P_{BWKvs.UPA}$ = 0.029). In ROL. R, the change in Z-value were significantly more functional connectivity reduced in the Baduanjin group than in the UAP group (P = 0.032). In MTG. R, the change in Z-value in the UAP group were functional connectivity increased and were significantly greater than that in the other two groups ($P_{UPA\ vs.BDJ}$ = 0.032, $P_{UPA\ vs.BWK}$ = 0.042). In PCUN. R, the functional connectivity reduced were significantly different between the Baduanjin group and the BWK group (P = 0.031). In FFG. R, the change in Z-value for the BWK group were functional connectivity increased and were significantly greater than that for the Baduanjin group (P = 0.032) (**Figure 1**).

To investigate the association between those functional connectivity changes and the correct congruent condition changes, we performed a multiple regression analysis adjusted with age, gender and education. We found no significant association between those functional connectivity changes and the average number of congruent condition changes across all participants ($P > 0.05$) (**Table 4**).

TABLE 3 | Regions show significant functional connectivity changes with the DAN across three groups.

Regions	Abbr.	MNI coordinates			Peak z-value	Cluster size (voxels)
		x	y	z		
Middle temporal gyrus R	MTG.R	57	0	−15	7.521	101
Fusiform gyrus R	FFG.R	30	−57	−9	8.5847	61
Superior frontal gyrus, medial R	ORB supmed.R	0	54	−6	7.8328	52
Insula L	INS.L	−36	0	3	9.062	58
Rolandic operculum R	ROL.R	45	−18	15	9.5218	62
Precentral gyrus L	PreCG.L	−36	−3	51	8.9678	49
Precuneus R	PCUN.R	15	−78	48	8.3251	48
Inferior parietal, but supramarginal and angular gyri R	IPL.R	39	−48	42	8.8844	58

Alphasim correction, $P < 0.05$, Minimum voxels collection = 46.

DISCUSSION

In this study, we investigated differences in attentional ability at baseline and after 24 weeks of Baduanjin practice compared with a BWK group and a UAP group in older adults with MCI. We found that compared to the UAP group, the Baduanjin group improved with average number of correct congruent condition on a test of selective attention ability. ICA showed that Baduanjin exercise group exhibited functional connectivity decreased in ROL. R, MTG. R, IPL. R, PCUN. R, and FFG. R region of DAN compared with the other two groups. The BWK exercise group had obviously functional connectivity increased in IPL. R and decreased in the MTG. R region compared to that in the UAP group. However, regression analysis does not show the significant association between attentional ability change and DAN functional connectivity change. Our data suggest that Baduanjin exercise has a potential benefit on improving the selective attention of MCI patients, but it still is uncertain that this potential effect may be related to changes in the functional connectivity of the DAN.

Accumulating evidence suggests that aerobic exercise has a positive effect on cognitive function in MCI patients

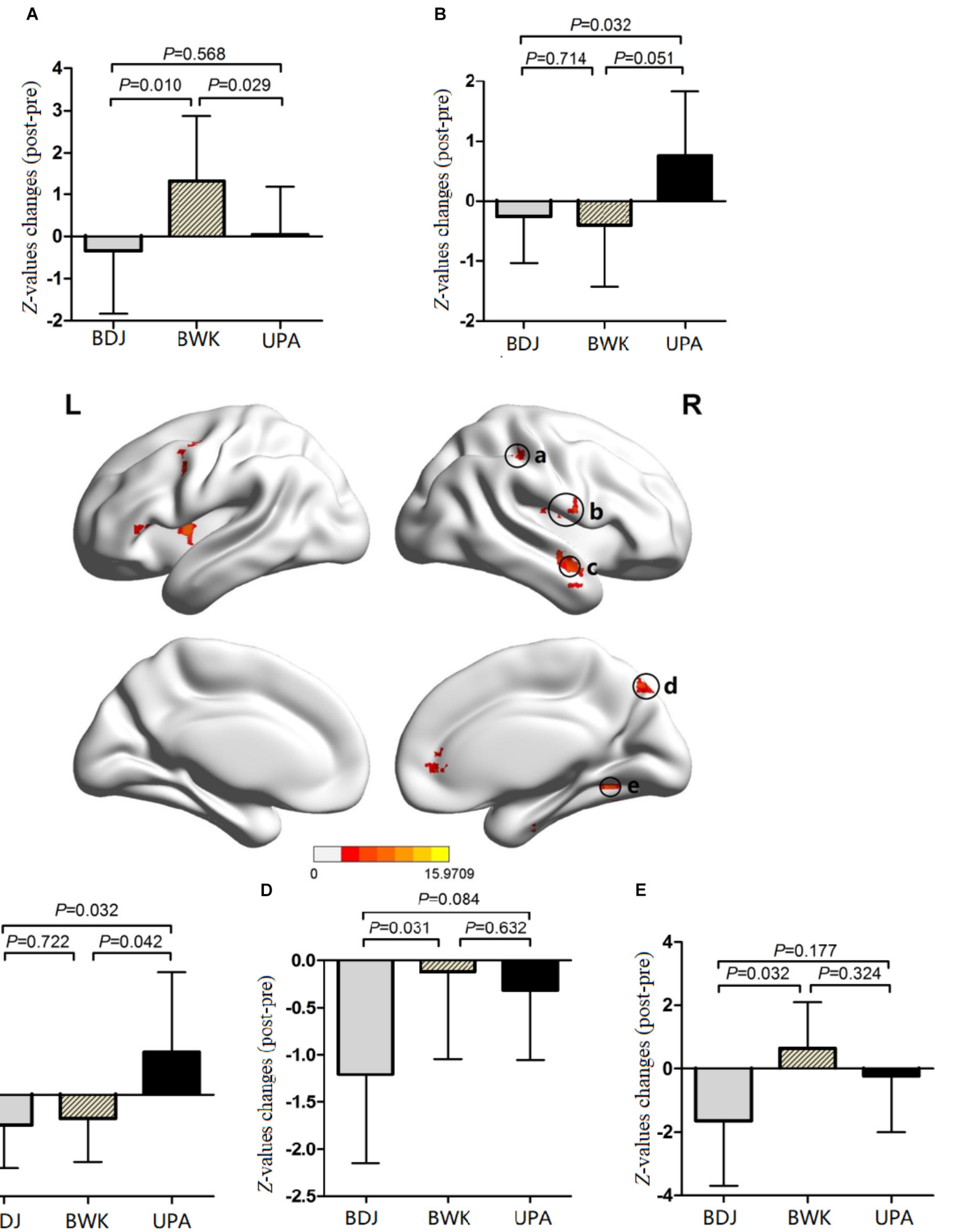

FIGURE 1 | One-way ANOVA and *post hoc* analysis results of DAN. One-way ANOVA showed that, after the 24-week exercise, there were significant difference at five regions in DAN (cluster-corrected at Alphasim $P < 0.05$; voxels $P < 0.01$): IPL.R(a), ROL.R(b), MTG.R(c), PCUN.R(d), and FFG.R(e). *Post hoc* analysis results are shown, compared to the brisk walking (BWK) group or usual physical activity (UAP) group, in these five regions in Baduanjin group had obvious negative activation, and all the Z-values changes were lower than other two groups. **(A)** The Z-values changes of BWK group appeared a positive change, significantly higher than the other two groups. **(B)** There were significant negative changes in Baduanjin group than UAP group. **(C)** The Z-values changes of UAP group appeared a positive change, significantly higher than the other two groups. **(D)** The negative changes were occurred across three groups, and there was significant difference between Baduanjin group and BWK group. **(E)** The Z-values changes of BWK group appeared a positive change, significantly higher than the Baduanjin group.

TABLE 4 | Regression analyses between functional connectivity changes and the correct congruent condition changes.

ROIs	Correct congruent condition changes		
	Beta	Standardized beta	*P*-values
MTG.R	4.603	0.273	0.872
FFG.R	18.754	0.269	0.516
ROL.R	6.69	0.008	0.819
PCUN.R	6.73	0.058	0.817
IPL.R	14.126	0.199	0.628

MTG.R, middle temporal gyrus R; FFG.R, fusiform gyrus R; ROL.R, rolandic operculum R; PCUN.R, precuneus R; IPL.R, inferior parietal, but supramarginal and angular gyri R. Adjusted gender, age, and education level.

(Zheng et al., 2016b; Sáez de Asteasu et al., 2017). Cognitive function can be divided into memory, attention, executive function and other domains. Currently, most studies focus on memory, but few focuses on whether exercise is beneficial to the attentional ability of patients with MCI. The results of a randomized controlled study showed that a moderate-intensity walking program, which consisted of two sessions a week for **1** year, decreased the reaction time in a Stroop task for women with MCI (Van Uffelen et al., 2008). Another study also showed that moderate aerobic exercise for 16 weeks significantly improved reaction time on Stroop incongruent and interference conditions in older individuals (Coetsee and Terblanche, 2017). Witte's research showed that there was a significant improvement in divided attention after a 5-month karate training (Witte et al., 2016). Consistent with previous studies, the results of this study also showed that accuracy on Stroop congruent tasks for the Baduanjin group was significantly improved over that of the **UAP** group. Although previous studies have shown that aerobic exercise enhances sustained attention by stimulating noradrenergic activity and that this effect may be related to exercise intensity and exercise type (Radel et al., 2018), this study did not find that **BWK** or Baduanjin exercise improved sustained attention in MCI patients.

Baduanjin, a traditional Chinese mind-body aerobic exercise with a lower intensity of exercise, yields the improvement in the selective attention domain in MCI patients. This result is similar to a previous study, which found that traditional Chinese mind-body exercise can improve Stroop task performance in older adults (Ji et al., 2017). According to the theory of traditional Chinese medicine, Baduanjin exercise involves a practice of mind-body integration to cultivate "*qi*" to maximize both physical and mental wellbeing. Furthermore, Baduanjin only includes eight movements and is more suitable than Tai Chi for cognitive deficits in older individuals (Xiong et al., 2015). Previous studies reported that Baduanjin had an improved effect on global cognitive function and memory in older adults (Tao et al., 2016, 2017a,b). Therefore, the findings of this study that Baduanjin may be beneficial to selective attention ability in MCI patients are consistent.

In Alzheimer's disease patients, the DAN and the ventral attention network have been shown to be completely impaired, while MCI patients suffered from severe DAN damage, but ventral attention network function was relatively preserved (Zhang et al., 2015). The DAN is a task-positive network, and it has an anticorrelated functional relationship with the default mode network (DMN). In the resting state, the DMN has been shown to be activated, but the DAN was inactivated. As age increases, this anticorrelation was reduced and more pronounced in MCI patients (Spreng et al., 2016; Esposito et al., 2018). Significant differences have been observed in the functional connectivity of the DAN between MCI patients and normal older control subjects, in regions such as the left FEF, left IPS, dorsomedial frontal lobe and posterior cingulate gyrus (Bi et al., 2018). One study demonstrated that abnormal brain regions in the DAN were associated with cognitive impairment in MCI patients (Tao et al., 2017a). Electrical or magnetic stimulation of the DAN core brain areas has been shown to improve attention in patients with MCI (Anderkova et al., 2018; Siddiqi et al., 2019). Aerobic exercise increases the frontal gray matter, including the anterior cingulate cortex, the supplemental motor area, middle frontal gyrus, superior frontal gyrus, and the superior and inferior parietal lobules, and its functional connections, which may be involved in top-down attentional processes (Colcombe et al., 2003, 2004). Our research showed that the functional connectivity of ROL. R, MTG. R and PCUN. R exhibited negative activation in the BWK group and that these changes may be beneficial in maintaining the anticorrelated functional relationship between the DAN and DMN. Additionally, this study showed that the functional connectivity of IPL. R, ROL. R, MTG. R, PCUN. R, and FFG. R exhibited more significant negative activation after 24 weeks of Baduanjin training. Baduanjin is a mind-body exercise, different from conventional aerobic exercise, and it also encompasses components of mindfulness and meditation, which require more attention and control. Mindfulness and meditation can improve attention in older individuals and ameliorate the coupling among the DAN, self-referential processes and affective responses (Froeliger et al., 2012; Doll et al., 2016). However, our study does not find the significant association between the negative activation of DAN and the change of attentional ability which may be related to the small sample size of this study or the short duration of intervention. Therefore, further study with more samples is necessary to elucidate its imaging mechanism.

There are several potential limitations to this study. First, the sample size of this study was so small that were not able to perform stringent multiple comparison corrections. Second, there were no thresholds for attentional impairment in the inclusion criteria, which led to heterogeneity in the participants' attentional abilities. Third, attention is a complex topic, and current measurement metrics may be limited. For example, the Stroop test has been used to evaluate selective attention in some studies and to reflect executive control function in other studies, which introduces confusion regarding the use of the Stroop test as an outcome measurement method. In addition, the intensity of Baduanjin exercise cannot be quantified, and the quality of the intervention may not be consistent, although we adopted strict quality control measures.

In summary, this study suggests that regular Baduanjin exercise might be potential beneficial to improve selective attentional abilities in patients with MCI, but current data does not thoroughly support that this effect is related to changes in the functional connectivity of the DAN. Further researches with more samples are necessary to clarify the effects of Baduanjin on the attentional abilities of patients with MCI, and the imaging mechanism in the functional connectivity of brain network.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study are available from the corresponding author upon request.

AUTHOR CONTRIBUTIONS

LC and GZ conceived and designed the study. RX and GZ wrote the manuscript. JT was in charge of coordination and direct implementation. RX, PQ, HL, BY, MW, and ML managed the training location and the follow-up. All authors contributed to drafting the manuscript, and have read and approved the final manuscript.

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How to Train Your Health: Sports as a Resource to Improve Cognitive Abilities in Cancer Patients

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From a cognitive-psychological perspective, physical exercise (PE) and sports are an interesting tool for improving people's cognitive abilities. One field of application for such a tool is decision making (DM) support in chronic patients, cancer patients, and survivors in particular. On the one hand, cancer patients and survivors have to continually take important decisions about their own care (e.g., treatment choice; changes in lifestyle), in collaboration with caregivers and health providers; on the other hand, side effects of treatment may be detrimental to cognitive abilities, such as attention, which make the health DM tasks even more demanding, complex, and emotionally disruptive for patients. Since cancer patients have to engage in healthy activities both for improving their own quality of life and for sustaining the effects of medications, clinical advice to engage in sport and PE is becoming more and more widespread within interventions. However, while sports are usually seen as healthy physical activities, their impact on cognitive abilities is mostly overlooked in the literature. The hypothesis of the present work is that sports could be fully exploited in their potential as focused exercises for cognitive ability training, in the field of cognitive training for chronic patients specifically. Indeed, literature shows that different sports (e.g., individual or team-based) influence and possibly augment cognitive abilities such as focused and divided attention, working memory, and DM under time constraints. Moreover, besides providing training for cognitive abilities, the experience of sports may represent an opportunity to explore, train and sharpen DM abilities directly: we identify five ways in which sport experiences may influence DM processes, and provide indications for future research on the topic.

Keywords: decision making, sport, cognitive functions, attention, oncology, psycho-oncology

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INTRODUCTION

Oncological treatments influence patients' physical and cognitive functions. Studies have provided evidence that cancer treatments, such as chemotherapy, radiotherapy, and hormonotherapy, can produce adverse effects including vascular complications, convulsion, mood disorders, and cognitive dysfunction (Alvarez et al., 2007; Dietrich et al., 2008). Many patients undergoing cancer treatment complain about so-called "chemobrain" (Brezden et al., 2000; McAllister et al., 2004), a cognitive decline associated with brain intoxication (Ahles and Saykin, 2001; Wefel et al., 2004; Butler and Haser, 2006).

Symptoms of "chemobrain" often persist after the completion of therapy and cause discomfort to survivors who are unable to return to daily life, finding difficulties at work and in other everyday life activities. Treatments have consequences not only in the post-treatment period, but also during the various phases of the disease, interfering with a patient's ability to make good decisions. The cancer continuum is characterized by several stages: prevention, screening, diagnosis, treatment, survival or end of life. Each phase requires at least one specific decision (Reyna et al., 2015; Gorini et al., 2018). This process requires good cognitive skills and cognitive flexibility both to make the right choice *per se* and to make the appropriate changes in lifestyle in order to adapt to the impact of the disease and the side effects of treatment (Nelson et al., 2007; Arnaboldi et al., 2016; Triberti et al., 2019b).

Ideally, along this cancer continuum, decisions should be based on clear benefits and fully understood drawbacks, associated with an understanding of alternative courses of action (Reyna et al., 2015). The patient must be fully aware of what is happening to him or her, the current state of the disease, comparing all the different notions and ideas, and the multiple representations of illness and its consequences (Sainio et al., 2001; Renzi et al., 2016; Triberti et al., 2019a).

In light of the literature that demonstrated the importance of physical exercise (PE) and sport in preventing cognitive deterioration (Chu et al., 2015; Witte et al., 2016; Mandolesi et al., 2018; Walton et al., 2018), the objective of the present work is to investigate how this can be useful in cognitive training for chronic patients, cancer patients and survivors specifically. We will analyze those aspects of health-related decision making (DM) processes that can be enhanced by improving the cognitive functions involved in sport performance and experience. Then, we will suggest five ways in which sport experience could directly train DM, in order to inform sports-based health interventions for cancer patients.

DECISION-MAKING

Decision making, or how people make choices among available alternatives (Edwards, 1954; Thokala et al., 2016), plays a significant role in everyday activities. Studies have focused on understanding why people choose one option instead of another when choosing between a set of alternatives and identifying the processes behind it (Marasso et al., 2014). The amount of information people have access to increases over time, allowing them to reach more accurate decisions and stimulating critical thinking (Gréhaigne et al., 2001).

In order to understand DM, it is important to consider the continuous exchange between the Self and the environment. Perception is so divided between interoceptive and exteroceptive influences (Mirams et al., 2013). The awareness of optimal/unpleasant emotions or intrusive thoughts is an essential step for recognizing what are available resources and how to recruit them (Hanin, 2013), taking into account external distraction (e.g., noise) (Toner et al., 2015). Every agent is indeed influenced by cognitive and somatic reactions to both internal and external stimuli, which become the target of self-regulation processes (Birrer and Morgan, 2010).

According to these studies, superior ability in DM does not depend on an accurate knowledge of information and alternatives only, but also on a well-developed procedural knowledge base; rather than limiting to a mere selection of alternatives, DM relies on knowledge about the environment and oneself. Personal beliefs and values are involved decisions, especially those related to life-relevant choices (Gorini et al., 2016).

Decision making processes involve a number of cognitive abilities ranging from memory to perception; however, especially when considering life-relevant choices such as those related to health management, the employment of cognitive processes may be reduced. On the contrary, experiential characteristics and individual differences should be taken into consideration.

The next sections will consider sports as a tool to improve cognitive abilities relevant in DM, and then the possibility for sports to train DM activity directly.

SPORTS AND COGNITIVE ABILITIES TRAINING

The impact that physical activity has on quality of life has always been known: the literature shows that regular physical activity favors the cardiovascular and musculoskeletal systems (Ploughman, 2008; Vincent et al., 2012; Thivel et al., 2018); helps to prevent certain diseases such as diabetes, obesity and cancer (U.S. Department of Health, and Human Services, 1996; Gao and Mandryk, 2012; Mandolesi et al., 2017, 2018); and promotes an improvement in mood and overall well-being (Coulson et al., 2008; Landi et al., 2010; Anderson and Shivakumar, 2013).

In addition to physical improvement, recent studies have shown the impact of sport and physical activity on cognitive functions. Studies on elderly subjects show that resistance exercises are a protective factor against cognitive decline, and in particular they favor preservation of executive planning and working memory (Gligoroska and Manchevska, 2012; Bherer et al., 2013; Kirk-Sanchez and McGough, 2013; Hsieh et al., 2016). It has been shown that cognitive functioning is empowered by physical activity in any age group (Anderson-Hanley et al., 2012; Benzing et al., 2016).

Research has shown specific improvements in executive functions (Tomporowski et al., 2008, 2011; Barenberg et al., 2011; Voelcker-Rehage and Niemann, 2013; Verburgh et al., 2014), mainly in children and adolescents (Verburgh et al., 2014; Donnelly et al., 2016). For example, Davis et al. (2011) tested the effect of about 3 months of regular aerobic exercise on executive functions of weight-bearing and sedentary students using fMRI, successful performance measures and cognitive assessment. The results showed that aerobic exercise improved cognitive performance and exercise dose-response benefits were found (Davis et al., 2011). Other acute benefits (i.e., short and temporary) were found in working memory; for example, Pontifex et al. (2009) evaluating 21 students showed that there is a shorter latency during a working memory activity which was performed immediately and 30 min after an acute period of aerobic exercise compared with the pretest (Riddle et al., 2005; Pontifex et al., 2009; Berridge and Devilbiss, 2011); other positive results regarding PE effects on cognitive abilities include concentration (Sibley et al., 2006; Gao and Mandryk, 2012) and duration of attention (Iuliano et al., 2015). Regarding neurobiological mechanisms, PE increases the level of neurotransmitters, which are theoretically responsible for neuroplasticity, neurogenesis, and neurotransmitters processes (Machado et al., 2015). In addition, endurance exercise leads to improved cardiorespiratory fitness (e.g., maximum oxygen uptake) that influences neutrophins, oxygen, and the stress-associated hormone cortisol. Improvement in neurotrophin level reduces the cortisol release and, as a consequence, the psychological stress response. These and other physiological changes are linked to prefrontal brain activation correlated with memory and cognitive control tasks. Moreover, neuroimaging research suggests that PE can indeed improve memory performance and cognitive control (Heinzel et al., 2018).

WHAT COGNITIVE ABILITIES ARE TRAINED BY SPORTS?

While a complete review of the relevant literature is out of scope for the present contribution, it is possible to outline the main cognitive areas affected by sports and PE. In general, any sport activity has both general and specific improvements in cognitive functions, based on their context. For example, knowing how to select the correct course of action is an important process in DM: being familiar with the duration of the training/competition, the goal and the physical sensations of fatigue and effort guide an athlete to an appropriate choice of play (Smits et al., 2014). So, athletes continuously decide "what to do" (action selection) and "how to do it" (action specification) to try making the perfect move in terms of technique and energy investment (del Campo et al., 2011; Smits et al., 2014) and to achieve a successful performance (Chamberlain and Coelho, 1993).

Cognitive flexibility is an important asset in sports: for example, long-jumpers do not execute a rigid-programmed pattern of stride lengths, instead they must assess each time what could be an optimal contact with the runway and the regulation of the length of the final stride for optimizing jump length (Craig, 2013). Therefore, the skill of assessing and regulating their own bodies in reference to the context each time is essential to obtain optimal results.

An improvement in working memory is found in athletes performing aerobic activities (Cassilhas et al., 2007; Diamond, 2015). This kind of PE, common to many sports, is associated with a faster cognitive processing speed (Hillman et al., 2005) and better performance in the ability of executive control (Ludyga et al., 2016). It is also associated with improved attention control (Shatil, 2013), executive control processes (e.g., inhibition and switching), linguistic verbal-auditory processing (Smith et al., 2013), and working memory (Maillot et al., 2012; Shatil, 2013). Research by Nagamatsu et al. (2013) found that both resistance training and aerobic training positively impacted on cognitive functioning and resulted in functional plasticity in healthy older adults, starting from the use of motor skills through tactical knowledge and DM (Práxedes et al., 2018).

Team ball games increase the ability to shift attention as a special perceptual skill, directing attention toward stimuli which initially appear as irrelevant. This kind of training also leads to the improvement of pattern recognition or the knowledge of situational probabilities (Abernethy and Russell, 2016). Many sensorial stimuli bombard athletes, who must consider the shared space and simultaneous participation of others, with a sort of uncertainty regarding the action of an opponent player (Práxedes et al., 2018). During the game, players must select and filter salient information by redirecting the focus of attention.

There are also instructions and rules that athletes must respect in the tactical DM of a team. For this reason, players do not pass the ball to obvious players (e.g., unmarked ones). Therefore, it is possible that players fail to find the optimal technical and tactical solution; in other words, concentration and attention are fundamental for players to be able to see the various opportunities during a specific moment of play (Memmert and Furley, 2016).

In collective sports, players have various roles, each with different requests and cognitive abilities in progress. For example, in soccer the goalkeeper tends to learn to wait longer with the scope of collecting more information about the ball's direction, increasing attention orienting. This strategy helps him or her to guide actions, resulting in more saves, learning how and when to stop the ball. At the same time, players near the goalpost have to make the decision whether to try a shot at the goal or pass the ball to a nearby teammate, evaluating the situation and choosing the most functional action more or less immediately (Gréhaigne et al., 2001; Cotterill and Discombe, 2016). It is essential to know, for example, what makes a movement deceptive (Brault et al., 2010).

In volleyball, as showed by Montuori et al. (2019), team roles are associated with different required degrees of cognitive flexibility. The integration between visual perception and all the other information presented during the game converge to DM as an integrated process of elaboration during specific times.

Indeed it has been demonstrated that expert athletes have greater fixation on relevant tasks and more successful experiences in DM than beginners (De Oliveira Castro et al., 2016). Specifically, Craig (2013) affirms that a player's decision is influenced by geometric and kinetic properties of the game that are, for example, a player's eye height and how high he must jump. In this sense, it is not sufficient to assess the physical properties of the environment (e.g., time and height), but also the athletes' perceptions of their own abilities. Visual-spatial attentional processing is, at the same time, increased and volleyball players have to train using perceptual-cognitive tasks constantly with high flexible attention (Alves et al., 2013).

In conclusion, not only context and circumstances make the difference; sports involve cognitive training as an essential part of performance. The domain of cognition especially involved in sports are: executive functioning, working and declarative memory (Morris, 2018), attention and processing speed (Gao and Mandryk, 2012; Iuliano et al., 2015; Prakash et al., 2015).

Athletes are extremely committed to empowering these processes in order to improve their role within the competition and achieve optimal performance.

SPORTS AND THE RELATION BETWEEN COGNITIVE ABILITIES AND DECISION MAKING

There are several studies that show how good performances in sport are characterized not only by the efficient execution of tactical movements, but also by a high level of DM. Indeed, an athlete will never achieve a positive outcome of his tactical movement if the selected skill is inappropriate to the context and to the specific situation in which it is performed (Liu et al., 2013). Therefore, DM is an ability that could be improved and modified through deliberate practice and the development of skills (Abernethy and Russell, 2016). To demonstrate this, there are numerous studies that compare the DM abilities of more and less experienced athletes, showing how the first, placed in a specific sport/competitive context, tend to perform more efficiently than the others in various steps of the DM process (Baker et al., 2003); moreover, expert athletes make decisions more quickly and more accurately than novices (Bar-Eli and Raab, 2006; Faubert and Sidebottom, 2012; Hepler and Feltz, 2012; Renfree et al., 2014; Vaughan et al., 2019) and are reported to have more sophisticated mental representations and procedural knowledge ("action plans") that help them to solve problems in a more intuitive and automatic fashion (Frank et al., 2013; Evans et al., 2017). In the end, elite athletes report a higher number of interoceptive stimuli during the action itself (Haase et al., 2015). In other words their self-awareness increases and so does performance management as a consequence (Toner et al., 2015) through the perception and continual monitoring of inner sensations.

Research comparing expert and novice athletes is useful to see how DM skills can be trained and possibly improved by continual sports practice; although it is not realistic to expect non-professional athletes to develop at a rate similar to elite ones, it is possible to prefigure the implementation of sport experiences to help people to train their ability to make decisions.

WHAT BENEFITS FOR CANCER PATIENTS?

Studies show that cognitive performance can be improved by duration of moderate to vigorous physical activity, for example in breast cancer patients and survivors (Hartman et al., 2018). Peterson et al. (2018) increased memory performance and executive functions in cancer survivors through a 12-week aerobic exercise intervention. Evidences of benefits of high-intensity interval training for aerobic fitness and cardiovascular risk factors are emerging in cancer patients (Northey et al., 2019). Specifically, Zimmer et al. (2016) show improvements in executive functions, especially attention, cognitive flexibility and planning, after exercise.

A high degree of interdisciplinary cooperation must be implemented to integrate medical treatment and sports, but a rapid change in well-being is commonly observed in oncological patients (Baumann and Bloch, 2013) during different phases: (1) treatment, (2) adjuvant therapy, and (3) exercises supervised by accredited physiologists and/or physiotherapists. A number of studies support the idea of benefits of exercise for cancer survivors, underlining significant health improvements (Irwin, 2009; Schmitz et al., 2010; Spence et al., 2010). In this sense, sports could be adapted to individual characteristics of patients: it is not important to turn patients into high-level athletes, but to help them to benefit from PE health outcomes, and to avoid contraindications related to health status.

We have seen how sports help to train cognitive abilities that are relevant to DM, possibly reducing the detrimental effects of the disease and side effects of treatment. We think that sports may share properties that help to train the ability to take decisions directly. At least five of such properties could be identified (resumed in **Figure 1**).

Decision Making Training Through Strategy and Tactics

Strategical and tactical DM is a component of any sport, which many athletes would consider as important as physical preparation and technical skills (Renfree et al., 2014; Memmert and Roca, 2019).

Sports always include a pre-competition activity (formal or informal), in which athletes and coaches carefully plan the actions to be implemented later. For example, team sports require study of the opponents' strategy and discussion of the choices and decisions in terms of team members placement and roles, and specific game actions to be enacted collectively or individually (e.g., deciding whether to conduct a more defensive or offensive match).

However, the actions previously planned must then be modified in the context of the competition, both by individual players and the team as a whole. This regards the necessity to implement tactical DM or being able to take novel decisions within a limited time frame, usually involving intuitive rather than rational thinking (Memmert and Furley, 2016; Memmert and Roca, 2019).

Cancer patients could benefit from the training of DM by sports activity. Sport provides the opportunity to train DM skills regardless of the sports context, thus allowing the patient to learn how to find possible solutions with others and then to implement them in his or her own situation.

Furthermore, training "tactical" and "strategic" DM allows one to both take decisions in the shortest time, an ability which should not be undermined when considering the importance of adhering to a therapy regimen (e.g., what should I do if I'm out of my medicine? Who should I call in case of emergency? etc.); and to forecast short and long-term consequences of choices, informing better DM processes in the present circumstance (e.g., will I be able to manage such a lifestyle change? Will my family do it too?)

It can be said that a patient's situation is inherently different from that of athletes, and maybe that those are

FIGURE 1 | Five ways in which sport experience can lead to training of decision making abilities with a focus on cancer patients' needs for health management.

incommensurable: in particular, patients have time to make important choices while athletes take decisions in a short time, as the sport context demands. However, Herrmann et al. (2019) suggest that patients have not appropriate time to make care-relevant decisions; their perception of time may change often, in concurrence with situational factors (e.g., course of the disease) (Butow et al., 1997; Rodríguez-Prat et al., 2019), for example they feel "time is running out" or it is not enough to decide. Taking into consideration the subjective time, training the ability to decide in complex contexts could be a fundamental resource that patients may be able to implement through sports, along with exercising the ability to regulate emotions.

Attention and Emotional Management

In any sport, athletes have to alternate focused and divided attention to monitor information important for managing the game or activity (Memmert, 2009; Liao and Masters, 2016). Moreover, such sophisticated attention management should often be maintained in the face of emotional activation, which could possibly be overwhelming and distracting (Corr, 2002; Jones, 2016). When in a disadvantageous position, or even when about to lose the game, a team and the individual players as well become able to control emotions and keep attentional functions at a high level.

Attention and emotional management, especially when trained together in a real-life context, are an important resource for taking desirable decisions and be confident in one's own judgment. People who have to manage a chronic health condition could benefit from such an attention training which could be more effective than abstract cognitive exercises.

Creative Decisions

Athletes very often have to find alternative solutions to the previously studied schemes, which do not fit to a specific situation; in such circumstances, creativity allows the athlete to "go beyond" basic rules and schemes in order to bring his or her own personal contribution to the athletic action, hopefully obtaining excellent results. This type of creativity is called "divergent thinking" or "tactical creativity" (Memmert and Roca, 2019); it refers to the ability to find the ideal, rare and flexible solution to a given problem.

For example, the great basketball player Earvin "Magic" Johnson is remembered for his so-called "*no-look-pass*," which he used to deceive his opponents by looking in the direction of a free teammate while then passing the ball to another player (Memmert and Roth, 2007). The tennis champion Roger Federer invented the so-called "sabr" (which stands for "sneak attack by Roger"), a technique wherein he rushes in during the opponent's second serve and takes the ball early.

These examples come from the world of high-level professional sport; however, they show how athletes approach problems with a creative stance, so that sport regulations, as well as PE *per se*, could be not limitations to problem solving but rather complex contexts that encourage divergent thinking and full expression of one's own playing style (Colzato et al., 2013).

Thanks to tactical creativity athletes learn to re-elaborate usual practices and behaviors and to find solutions that no one had ever thought of before. In other words, sports allow the athlete to learn to go beyond what appears to be the initial information and rules, developing alternative solutions.

Finding alternative solutions that move away from predefined patterns is a very useful resource for patients who have to take decisions on therapy and lifestyle changes because it provides them with the ability to deal with the problem not being overwhelmed but finding solutions that may have positive implications.

The Role of Self and Introspection

In sports, athletes may develop notable introspection processes. Indeed, they have to improve the knowledge about their own abilities, resistance to time pressure, personal characteristics, and strengths and weaknesses, in order to give their own contribution to the team and/or to develop their own personal playing style and approximate optimal performance. However, especially during the sport activity, they should be able to not be distracted by self-focused instead of performance-focused attention (Liao and Masters, 2016).

On the one hand, there is literature showing that introspection can negatively influence DM: "thinking too much" about one's own motives and feelings could diminish systematic process of information and the capacity to discriminate between more and less important problem features (Wilson and Schooler, 1991; Tordesillas and Chaiken, 2007). However, especially for what regards life-relevant choices, self-knowledge is fundamental: people may attribute excessive salience to problem features, this way undermining their own peculiarity. For example, in a healthcare context, a patient may decide to change his dietary behavior. But then, the patient slowly discovers that he or she is not able to maintain the healthy diet in everyday life, so that the therapeutic process may be not effective in the end because of frequent violations of the rules the patient him- or herself had originally set.

By promoting reflections on one's own capacity, as well as psychological introspection and metacognition, sports could help patients to learn how to take into consideration their own identity, personality, habits and peculiarities when facing important decisions, this way empowering their ability to manage their health status too.

Transferability of Sport-Related Problem-Solving Schemes

Health professionals interested in using sports in interventions should appreciate that sports are not only tools to train physical and cognitive abilities, but also *experiences* that may have an important formative value, and profoundly influence athletes' cognitive processes. When one has to win in a competition, he or she is driven to dedicate a notable amount of time to it, as well as cognitive resources even outside of the performances. For example, a boxer may mentally reproduce a fight in his or her own mind to forecast the opponent's attacks and possible responses; a basket player may recall playing schemes as spatial mental representations to plan individual and team movements and actions. Indeed, imagery practices have been analyzed in sports both by experimental and anecdotal evidence (Behncke, 2004; Murphy, 2006; Schuster et al., 2011). Sport strategies and methods could root deeply as mental representations of problems and solutions, in accordance with situated cognition theories which sustain that our cognitive processes are based on real-life contexts and practices (Hutchins, 1995; Clancey, 1997). A patient who has to decide over therapy options or lifestyle changes and related struggles could represent decisions in a similar manner to the abstract representations coming from the sport experience, e.g., specific obstacles can be represented as an opponent team member to be dealt with at different times, with more or less risk, alone or with the help of other teammates, and so on; a climber could easily represent a healthcare journey as a climbing route, with different phases, more or less difficult, as time consuming and requiring some tools or others. Such mental representations are not poetic metaphors; rather, being based on subjective, meaningful experiences they could give indications on how to perform decisions in different fields, even that of one's own health and disease management.

Such deep rooting of these mental representations tends to emerge only after long-lasting and dedicated experiences (Provvidenza and Johnston, 2009; Ennis, 2015; Bradley and Conway, 2016); this is another aspect of sports which should be taken into consideration and explored by health research, namely sports' abilities in supporting problem solving representations and thus informing new personal approaches to health DM.

DISCUSSION

In conclusion, the practice of sport and more PE provides positive exercise for the body and mind as, in addition to preventing diseases such as heart disease and diabetes, they also increase cognitive functions and especially the executive functions, including the DM process. In oncological diseases, DM plays a key role as the patient is in the position of having to decide on important aspects that concern the entire continuum of the oncological disease, from prevention to end of life.

Improving cognitive functions through sport can be the first step to increasing psycho-physical well-being, especially during cancer treatment, as long as the possible medical limitations are taken into consideration; secondarily, we have shown how sports *experience* could constitute an occasion to explore, train and sharpen one's own DM ability directly. Indeed, sport's outcomes for well-being should not be reduced to simple byproducts of PE only.

Implications for future research mean accounting for the complex outcomes of sport experience implementations within chronic patients care, for cancer patients and survivors especially. It is possible to test the effectiveness of sport and PE in the empowerment of DM skills of cancer patients and survivors, investigating which type of sport is most suitable for this purpose, distinguishing between patients and their specific situations. Furthermore, future studies should explore the effects of sports on patients' well-being after important healthcare decisions, in order to not reduce DM abilities to mere laboratory tasks, but instead analyzing its effects on everyday life and life-relevant choices. Systematic review efforts could be useful to identify evidence of transfer of sport-related experiences to DM in everyday life. In addition to quantitative research focused on outcomes, qualitative research could be employed to invite patients to narrate the experience of sports and the perceived transferability of sport skills and mental schemes to the management of healthcare decisions.

AUTHOR CONTRIBUTIONS

VS conceptualized the ideas presented in the study and wrote the first draft of the manuscript. LS contributed to the conceptualization and writing. ST supervised the writing and edited the manuscript. KM contributed important intellectual content and to the final revision. GP contributed important intellectual content and supervised the whole process.

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Relationships Between Reaction Time, Selective Attention, Physical Activity, and Physical Fitness in Children

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The objective of this study was to analyze the relationships between simple and complex reaction times (RTs) with the physical activity performed weekly, the physical fitness and selective attention in children of the third cycle of primary education. Participants were 119 children aged between 10 and 12 years (M = 10.71; SD = 0.77). The instruments used for data collection were the D2 attention test to analyze selective attention, various tests of the Eurofit and ALPHA-Fitness Battery to evaluate the physical condition, a bioimpedanciometer Tanita TBF 300 to evaluate the body composition, and the FITLIGHT Trainer to measure the simple and complex RTs. The group that carried out more weekly physical activity used less time in simple ($p < 0.05$, $d = -0.68$, 95% CI [−1.19, −0.17]) and complex RT tests ($p < 0.05$, $d = -0.63$, 95% CI [−1.14, −0.12]). Also, the results showed that the simple RT was related in a significant way with physical fitness, while the complex RT was related significantly to attentional capacity and physical fitness.

Keywords: reaction time, selective attention, FITLIGHT trainer, physical activity, physical fitness

INTRODUCTION

Reaction time (RT) is a relevant variable in areas such as sports, academics, and other tasks of daily life (Metin et al., 2016; Sant'Ana et al., 2016). It can be defined as the time that elapses from when a stimulus appears until a response is given and is considered a good measure to assess the capacity of the cognitive system to process information (Jensen, 2006; Kuang, 2017). From a physiological point of view, RT is a complex phenomenon whose functioning has been studied by numerous researchers (Kuang, 2017). The RT depends on the speed of the sensorimotor cycle, composed by the detection of the initial stimulus, transfer of the information through the afferent nerves, generation of the response from the central nervous system, and final response (Adleman et al., 2016; Greenhouse et al., 2017).

There are differences between simple and complex RTs. The first is defined as the interval time between when a stimulus appears, its detection, and the given response (Jayaswal, 2016). The second involves the identification and selection of a response to various stimuli (Boisgontier et al., 2014).

The simple RT is significantly shorter than the complex RT (Vences de Brito et al., 2011). The factors that influence the RT are numerous, being able to differentiate between those dependent on the own person and those related to the stimulus (Baayen and Milin, 2010). Among the first can be included the fatigue, physical condition, experience, motivation, gender, age, or dominance of the body member with which one responds. Second, the physical characteristics of the stimulus, its intensity, or duration (Der and Deary, 2006; Woods et al., 2015; Jayaswal, 2016).

In the set of internal factors, the influence of cognitive processes has been described as elements that determine the RT (Deary and Der, 2005; Leckie et al., 2014). Among them, attention would be a variable involved in the RT manifested by a person, which has been suggested in previous research (Prinzmetal et al., 2005; Vaportzis et al., 2013; Jehu et al., 2015). Attention is a cognitive function involved in the activation and selection processes, distribution, and maintenance of psychological activity (Chun et al., 2011; Greimel et al., 2011). It is a process of great anatomical and functional complexity, being able to differentiate manifestations as arousal, focal, selective, divided, alternating, or sustained attention (Petersen and Posner, 2012; Tamm et al., 2013). Specifically, selective attention would allude to the ability to attend to some specific stimuli and ignore others (Giuliano et al., 2014; Gomez-Ramirez et al., 2016).

It has been highlighted that physical activity and sports would be related to improvement in RT (Jain et al., 2015; Okubo et al., 2017; van de Water et al., 2017; Walton et al., 2018). The RT can be deliberately trained (Rabiner et al., 2010; Kirk et al., 2017), and physical activity and sports allow development of a wide variety of actions that would influence its development (Lynall et al., 2018; Walton et al., 2018). It is relevant in individual sports such as swimming or athletics, because it is necessary to respond quickly to start a movement (Nuri et al., 2013; Tønnessen et al., 2013). In other adversary or collective sports, such as badminton, karate, football, or basketball, RT is essential in multiple game situations, because athletes need to make quick decisions to be successful in their actions (Ruschel et al., 2011; Mudric et al., 2015; van de Water et al., 2017). Some studies had also shown that more fit people would be associated with less RT in a set of tasks (Luque-Casado et al., 2016; Westfall et al., 2018).

Previous research had also shown that physical activity and exercise and the improvement of physical fitness could support the development of cognitive functioning and specifically different aspects of attention (Hillman et al., 2009; Kao et al., 2017; Reloba-Martínez et al., 2017). For this reason, it could be considered that the practice of physical exercise and the development of physical condition could have an impact on RT, directly by the training of the capacity to respond to a given stimulus and indirectly by the impact it would have on cognitive functioning (Gentier et al., 2013; Syväoja et al., 2014).

To evaluate the RT, there are instruments, such as the FITLIGHT Trainer^{TM} (FITLIGHT Sports Corp., Canada) or the Dynavision^{TM} D2 Visuomotor Training Device (Dynavision International LLC, West Chester, OH), that have been implemented in different studies (Appelbaum and Erickson, 2018). Specifically, with the FITLIGHT Trainer, several investigations have been carried out. For example, Zwierko et al. (2014) conducted research with the FITLIGHT Trainer system, which showed that non-athletes had longer RTs than athletes. Likewise, Fischer et al. (2015) used this instrument for the training and analysis of the RT in the United States Air Force. On the other hand, Zurek et al. (2015) investigated the simple and complex RTs of 10 football players who had undergone knee surgery and a rehabilitation program to assess their recovery.

The literature consulted has highlighted the relationships between RT and variables such as selective attention and physical condition, although there are no previous studies that analyze them together in the preadolescent population. Therefore, the objective of the present study was to analyze the relationships between RT, selective attention, concentration, and physical condition in a sample aged from 10 to 12 years.

MATERIALS AND METHODS

Participants

One hundred nineteen students (65 boys and 54 girls) participated in the study, aged between 10 and 12 years old ($M \pm DT$: age = 10.71 $\pm$ 0.77 years; height = 1.45 $\pm$ 8.21 cm; weight = 42.58 $\pm$ 9.87 kg; body mass index = 19.96 $\pm$ 3.27 kg/m^2; fat mass = 22.73 $\pm$ 8.37%) from Alcalá la Real (Jaén, Spain). All of them were in the fifth and sixth years of primary school and did not present any physical or psychological difficulties that could affect the study.

Measures and Instruments

Reaction Time

The FITLIGHT Trainer (FITLIGHT Sports Corp., Ontario, Canada) was used to measure the RT. This is a wireless system consisting of eight sensors, which were placed on a table 1 m high and drawing a semicircle. They had a separation between them of 20 cm, with 40 cm from the central point. To perform the task, the student stood in front of it with his hand in contact with the table. Two tests were performed (simple RT and complex RT). The simple reaction test (SRT) was performed with the dominant hand and consisted of 60 luminous stimuli. The complex reaction test (CRT) was performed with both hands and also consisted of 60 stimuli. In this last one, the visual stimuli were of two colors, blue or green; to the first, one had to react with the left hand, while to the second, one had to react with the right hand. Two sequences of random numbers were programed for the creation of the tests, one for the SRT and the other for the CRT.

Physical Condition

Physical fitness tests were estimated with ALPHA-Fitness Battery (Ruiz et al., 2011) and Eurofit (1993). The following tests were carried out: (a) manual dynamometry, to evaluate the state of the isometric force in the upper train, in both dominant and non-dominant members (the digital dynamometer model TKK-5401 Grip D, Takei, Tokyo, Japan, was used); (b) horizontal jump test, to estimate the force of the lower train; (c) Course–Navette test to analyze the aerobic capacity of the participants, from which the VO2max was indirectly estimated (Léger et al., 1988).

For the specific calculation of oxygen consumption, the formula VO2max = $31.025 + 3.238V - 3.248E + 0.1536VE$ was applied (V = the speed reached in the last completed stage; E = the age of each participant); (d) speed test 5×10 m to analyze travel speed, agility, and general coordination.

Selective Attention and Concentration

The D2 attention test was used (Brickenkamp, 2002). Participants had to selectively attend to certain relevant aspects of the task while ignoring irrelevant ones. The test, in this investigation, was administered collectively and lasted between 8 and 10 min. There are 14 lines with 47 elements each (total = 658 items). The elements were letters "d" or "p," which are accompanied by small lines at the top or bottom of each letter; these small lines could be in pairs or individually. The work that the participant had to do was to check from left to right each line and to mark every letter "d" that is accompanied by two lines (two above, two below, or one above and one below). The participant had 20 s to complete each line. The scores that can be obtained are as follows: TA (total number of attempts), TH (total number of hits), O (omissions or number of relevant stimuli not crossed out), C (omissions or errors), TET [total effectiveness in the test = TP − (O + C)], CON (concentration = TS − C), and VAR [index of variation between the last stimulus analyzed between different rows = (TP+) − (TP−)]. TP+ is the last stimulus analyzed in the row with the most attempted elements, and TP− is the last stimulus analyzed in the row with the fewest attempted elements. This test possesses a test–retest reliability in the original study superior to 0.90.

Anthropometry and Body Composition

Anthropometric data were measured with the Tanita body composition analyzer TBF 300 and the mechanical measuring rod kern MSF 200. Data obtained were height, weight, body mass index, and percentage of fat mass.

Level of Physical Activity and Manual Dominance

An interview was conducted with each subject whose objective was to collect the extracurricular sports activity of each participant in order to separate the participants according to their level of physical activity. The groups were classified into the following: (1) students who did not engage in any type of extracurricular physical activity; (2) students who engaged in 1–3 h of extracurricular physical activity per week; and (3) students who engaged in more than 3 h of extracurricular physical activity per week. Data were also collected from participants on their dominant hand, i.e., whether they were right-handed or left-handed.

Procedure

In order to carry out the research, the participating schools were contacted, and permission was requested from the school management for their participation. In addition, informed and written consent was obtained from parents or legal guardians for students to participate. Throughout the research process, the principles established in the Declaration of Helsinki (World Medical Association, 2013) were respected, and approval was obtained from the Ethics Committee of the University of Jaén, Spain (Ref. ABR.16/6).

The tests were performed at the school in 2 days. First, anthropometric data were collected from the participants, and then physical condition tests were performed. Anthropometric measurements were taken in the school gymnasium, with light clothing (shorts and t-shirt), without footwear, and without any metallic object on the body (earrings, chains, watches, etc.). Also, to improve the reliability of body composition measures, the following guidelines were indicated: avoid strenuous exercise the previous day, do not significantly alter the diet the day before the test, wear comfortable clothing, control the taking of medicines that may alter body water levels, and do not retain fluids. As for the physical condition tests, the order was as follows: manual dynamometry, horizontal jump, 5×10 m speed test, and 20 m round-trip test. Both were carried out in the school's sports facilities (multisport courts and gymnasium). The dynamometry, horizontal jump, and speed tests were performed twice, and each participant's best mark was scored while the Course–Navette test was performed only once.

On the second day, the attention tests and interview were conducted, and the RT was measured. The D2 test was performed collectively in the classroom of the participants. They were previously instructed according to the test manual, and doubts were clarified. The RT was measured in a classroom on an individual basis. First, the simple task was done, and second, the complex task was performed. At the end of the RT test, the student was interviewed to obtain data related to his or her weekly physical activity.

Participants were divided into three groups based on their physical activity habits and routines, not including the physical activity that took place at school during physical education classes. The three groups formed were (a) group 1 (n = 57), children who did not carry out any type of physical activity outside school hours; (b) group 2 (n = 41), children who carried out between 1 and 3 h a week of physical activity outside school hours; and (c) group 3 (n = 21), children who carried out more than 3 h a week of physical activity and/or competed for being federated in some sport.

Statistical Analysis of Data

The RT measured with the FITLIGHT Trainer was studied. The reliability of the device was studied using the intraclass correlation index (IC), the standard error of measurement (SEM), and the minimal difference (MD). In addition to descriptive data, ANOVAs were performed with the RT as a dependent measure and to see its variation depending on the type of task in all cases, taking into account the position of light in the test, the 10 trials in which the subjects responded, and gender and age.

We analyzed the RT in the three physical activity groups by means of ANOVA of a factor, as well as the Bonferroni and Cohen d statistics. Also, correlation analysis (Pearson and Spearman) between physical condition, body composition, and attention measurements with RT values was performed. Linear regression analysis was performed by successive steps to predict the SRT and CRT from the rest of the variables. Data were analyzed with the SPSS statistical program (SPSS Inc., v.20.0, Chicago, IL, United States).

RESULTS

Reaction Time (FITLIGHT Trainer)

Table 1 shows the RTs for each of the eight sensor positions and the total mean.

A reliability analysis was performed by calculating the ICC, the SEM, and the MD (Weir, 2005). The $ICC_{2,1}$ was calculated for two halves (Wells et al., 2014) by calculating the mean RT for the lights at positions 1, 3, 5, 7 and 2, 4, 6, 8. The type of ICC(2, 1) used considered the effect of trials as a random factor while trials were considered as a sample of possible levels. The results showed $ICC_{2,1} = 0.92$, SEM = 39.87, and MD = 110.51 ms for the simple task (SRT). For the complex task (CRT), the reliability indices were $ICC_{2,1} = 0.85$, SEM = 63.50, and MD = 176.00 ms, which can be considered as adequate reliability indices.

ANOVA of repeated measurements was performed to evaluate the effect of the type of task and the position of light in the RT. The Mauchly sphericity assumption was previously analyzed, obtaining significance for the position ($W = 0.11$; $p < 0.001$) and the interaction of both variables ($W = 0.48$; $p < 0.001$), so the Greenhouse–Geisser statistic was used. The results showed that the variable type of task was significant ($F_{1,118} = 982.98$; $p < 0.001$; $\eta^2 = 89$; $1 - \beta = 1.00$) with lower time in SRT, as well as the position of the light ($F_{3.57,420.92} = 32.44$; $p < 0.001$; $\eta^2 = 0.22$; $1 - \beta = 1.00$) and the interaction between both ($F_{5.65,668.53} = 23.15$; $p < 0.001$; $\eta^2 = 0.16$; $1 - \beta = 1.00$). Peer comparisons for light positions showed significant differences ($p < 0.05$) in all cases except for 1–7, 2–8, 3–6, 3–8, 4–5, and 5–6. The lights located at the ends (1, 2, 7, and 8) obtained lower RT, positions 3 and 6 had intermediate RT, and those located in positions 4 and 5 had higher RT.

In the comparisons by type of task and position of light, it was observed that in the RT of the SRT, there were differences ($p < 0.05$) between all the cases except between 1–2, 1–3, 2–8, 3–6, 4–5, and 7–8. In the CRT, all differences were significant ($p < 0.001$ in all cases except between light 1 and all others, as well as couples 4–7 ($p = 0.003$) and 7–8 ($p = 0.006$). It can be seen that in the SRT, the RT increases for the most central positions, while in the CRT, the position with the least RT is position 1, followed by position 7, with the rest having more or less the same times, the greater being that relating to light in position 4.

An analysis of the RT was done according to the test in which the RT was measured with the aim of studying whether fatigue affects the RT differentially. We have considered the average RT for every 10 trials in each subject. Since each of us performed 60 trials, we compared six dozen trials (**Table 2**).

An ANOVA of repeated measurements was performed to study the effect of the type of task and tests in RT, with the Mauchly sphericity test previously performed, being significant for the variable trial ($W = 0.74$; $p = 0.001$) but not for the interaction type of task × trial ($W = 0.83$; $p = 0.079$). Therefore, only Greenhouse–Geisser was applied in the first case. The variable type of task, as it happened before, was significant ($F_{1,118} = 10{,}008.22$; $p < 0.001$; $\eta^2 = 0.89$; $1 - \beta = 1.00$), with time being higher in the complex task. In terms of the trial, significant differences were obtained between the six levels ($F_{4.42,521.69} = 19.08$; $p < 0.001$; $\eta^2 = 0.14$; $1 - \beta = 1.00$) and also in the interaction of type of task × trial ($F_{5,590} = 22.96$; $p < 0.001$; $\eta^2 = 0.16$; $1 - \beta = 1.00$). In the comparisons of Bonferroni by pairs of the trial variable, there was a significance ($p < 0.05$) of the first and second tens with all the others, while there were no differences between the third, fourth, fifth, and sixth tens. That is to say, the RT was lower in the first ten, increased significantly in the second, increased significantly in the third, and did not increase until the end.

As for the interaction in the simple type, differences were found between tens 1–3, 2–3, 2–5, 3–4, and 4–5 ($p < 0.01$) although there is no tendency to increase or decrease as the tens increase, but rather a sawtooth trend was produced, the RT being greater in the odd tens than in the pairs. However, in the complex task, there was an increase in the RT as the tens increased except between the fifth and sixth tens that had practically equal RT although only these increases are significant between the first ten compared with all the others ($p < 0.01$) and the second ten compared with the fifth ($p < 0.01$) and sixth ($p = 0.04$) tens.

Finally, with regard to the FITLIGHT system, the aim was to study whether there were differences between the RTs according to the two tasks in terms of gender and age (**Table 3**).

ANOVA showed significant differences for the variable type of task ($F_{1,113} = 822.97$; $p < 0.001$; $\eta^2 = 0.88$; $1 - \beta = 1.00$) and age ($F_{2,113} = 5.86$; $p = 0.004$; $\eta^2 = 0.09$; $1 - \beta = 0.87$) but not gender ($F_{1,113} = 3.56$; $p = 0.06$; $\eta^2 = 0.03$; $1 - \beta = 0.46$). There was also no significance in the interaction type of task × age ($F_{2,113} = 0.38$; $p = 0.68$; $\eta^2 = 0.01$; $1 - \beta = 0.11$), type of task × gender ($F_{1,113} = 2.23$; $p = 0.14$; $\eta^2 = 0.02$; $1 - \beta = 0.32$),

TABLE 1 | Descriptive statistics (*M* and *SD*) for the RT in the simple and complex tasks of the 119 subjects as a function of the eight positions of the sensor and the total (dominant hand).

		Total	1L	2L	3L	4L	5L	6L	7L	8L
SRT (ms)	M	632.03	613.71	603.19	644.17	713.36	695.51	645.44	572.06	585.38
	SD	97.38	99.21	100.76	124.44	158.51	163.74	123.58	93.093	84.764
CRT (ms)	M	840.68	792.10	840.76	838.69	871.54	854.22	855.60	827.00	862.08
	SD	110.79	129.83	137.2	134.77	152.87	142.43	138.96	132.09	121.21

SRT, simple reaction time; CRT, complex reaction rime; L, light; M, mean; SD, standard deviation.

age × gender ($F_{2,112} = 0.63$; $p = 0.54$; $\eta^2 = 0.01$; $1 - \beta = 0.15$), or type of task × age × gender ($F_{2,113} = 0.27$; $p = 0.76$; $\eta^2 = 0.01$; $1 - \beta = 0.09$).

Reaction Time and Physical Activity

Table 4 shows descriptive and normal analyses (Kolmogorov–Smirnov, $n > 50$; Shapiro–Wilk, $n < 50$) of reaction time (simple and complex) for each physical activity group.

ANOVA was performed for each RT measure, with differences observed between groups for SRT ($F_{2,116} = 4.43$; $p < 0.05$) and CRT ($F_{2,116} = 5.04$; $p < 0.01$). Bonferroni's statistic was applied to analyze the differences between the groups, observing differences between group 3 and group 1 in SRT ($p < 0.05$, $d = -0.68$, 95% CI [−1.19, −0.17]) and CRT ($p < 0.05$, $d = -0.63$, 95% CI [−1.14, −0.12]), as well as differences between group 3 and group 2 in CRT ($p < 0.01$, $d = -1.01$, 95% CI [−1.56, −0.45]) (**Figure 1**).

TABLE 2 | Descriptive statistics (*M* and *SD*) for the RT in the simple and complex tasks of the 119 subjects according to the six dozen trials.

		1D	2D	3D	4D	5D	6D
SRT (ms)	M	639.84	612.04	647.21	621.99	643.99	627.12
	SD	107.79	100.49	111.90	107.79	116.13	110.20
CRT (ms)	M	768.00	833.64	848.97	859.74	868.21	865.53
	SD	118.51	132.04	121.01	141.32	138.99	139.93

SRT, simple reaction time; CRT, complex reaction time; D, dozen; M, mean; SD, standard deviation.

TABLE 3 | Descriptive statistics (*M* and *SD*) for the RT in the simple and complex tasks according to gender and age.

	Age	10		11		12	
	Gender	Boys	Girls	Boys	Girls	Boys	Girls
SRT (ms)	M	642.58	668.22	591.15	632.62	551.51	625.00
	SD	116.58	73.23	75.91	115.75	55.76	86.66
CRT (ms)	M	874.58	868.81	800.74	832.97	767.80	816.83
	SD	131.42	94.51	93.13	123.77	53.80	99.88

SRT, simple reaction time; CRT, complex reaction time; M, mean; SD, standard deviation.

TABLE 4 | Descriptive statistics (*M* and *SD*) for the RT in the simple and complex tasks according to physical activity.

	M	*SD*	*S*	*K*	K–S	S–W
SRT group 1 (ms)	646.70	108.41	0.98	1.66	0.57	–
SRT group 2 (ms)	635.17	81.02	−0.24	−0.53	–	0.98
SRT group 3 (ms)	577.94	76.98	0.51	−0.12	–	0.92
CRT group 1 (ms)	847.12	123.83	0.82	1.03	0.30	–
CRT group 2 (ms)	865.08	95.32	−0.29	0.76	–	0.97
CRT group 3 (ms)	775.54	74.30	0.16	−0.58	–	0.96

SRT, simple reaction time; CRT, complex reaction time; M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov; S–W, Shapiro–Wilk.

Reaction Time, Physical Condition, and Attention

Table 5 shows the descriptive statistics for the variables of physical condition, selective attention, and RT, as well as the existing correlation with the RT in the two tasks.

Two regression analyses (successive steps) were performed, one for SRT and another for CRT, using as predictive variables the physical condition and measurements of the D2 attention test. The linearity assumptions were met in the relationship between predictor variables and criteria, homoscedasticity, and normal waste distribution. Durbin–Watson values were 2.05 and 1.93, so it can be assumed that the waste is independent, and the assumption of independence of the independent variables with respect to the dependent one is fulfilled (Pardo and Ruiz, 2005).

In the case of SRT, the regression model included two variables, velocity test ($\beta = 0.30$) and dynamometry (non-dominant) ($\beta = -0.23$). The following values were obtained for this model: $R = 0.43$; $R^2 = 0.19$; R^2 adjusted = 0.17; $F = 11.09$; $p < 0.001$. The tolerance (0.90) and variance inflation factor (1.11) values of the model were adequate.

In the case of CRT, the regression model included dynamometry (dominant) ($\beta = -0.40$), concentration (D2-CON) ($\beta = -0.40$), and VO2max ($\beta = -0.40$). The following values were obtained for this model: $R = 0.44$; $R^2 = 0.20$; R^2 adjusted = 0.17; $F = 7.92$; $p < 0.001$. The tolerance (0.93–0.97) and variance inflation factor (1.04–1.08) values of the model were adequate.

DISCUSSION

The objective of the present study was to analyze the relationships between RT with selective attention and concentration and also with weekly physical activity volume and physical fitness in a sample of children with ages from 10 to 12 years. Likewise, this investigation evaluated whether cognitive functioning and physical condition were adequate predictors of RT, both simple and complex. The results showed the relationship between RT and weekly physical activity volume, physical fitness, selective attention, and concentration. In general, physical fitness predicted RT scores. However, only cognitive functioning was a predictor of complex RT.

First, the amount of weekly physical activity has been related to simple and complex RTs. Those who did more hours of physical activity a week showed less RT on both tasks. These results are congruent with previous research that had pointed out these associations (Zwierko et al., 2014; Jain et al., 2015; Okubo et al., 2017; van de Water et al., 2017). Although the groups have not been divided according to the type of physical activity or sports performed, these results would support the idea that physical practice could be a useful activity to develop RT. When doing physical exercise, it is necessary to act effectively in a series of events, so this type of practice could have favored an increase in the capacity to act with greater speed and effectiveness in similar tasks (Nuri et al., 2013; van de Water et al., 2017; Lynall et al., 2018; Walton et al., 2018), transferring this ability to others

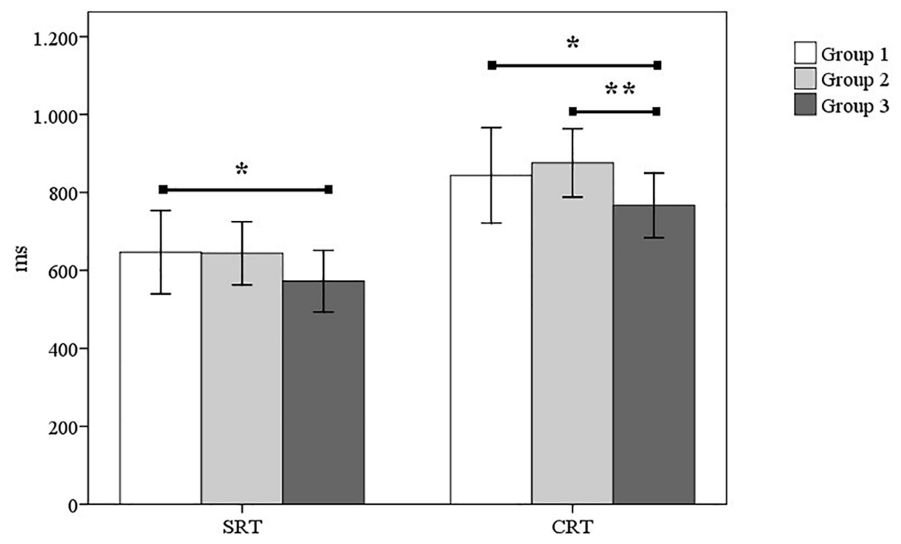

FIGURE 1 | Differences between groups for SRT and CRT. SRT, simple reaction time; CRT, complex reaction time. *$p < 0.05$; **$p < 0.01$.

such as those evaluated in this work (Rabiner et al., 2010; Kirk et al., 2017).

Second, relations have been observed between the level of physical fitness, attentional capacity, and concentration with RT, which would approximate studies that had previously pointed out this phenomenon (Vaportzis et al., 2013; Jehu et al., 2015; Luque-Casado et al., 2016; Westfall et al., 2018). Being a correlational study, it is not possible to determine causal effects, but according to the findings found in various investigations, there could be multiple links between the variables studied. Reloba-Martínez et al. (2017) highlighted that a high-intensity exercise program had positive effects on selective attention and fitness. Therefore, the combination of physical exercise and the development of cognitive functioning could be an appropriate formula to improve RT in people.

Specifically, linear regression analyses have shown that the simple RT has been predicted solely by physical condition measurements. However, the model generated for the complex RT has combined physical condition and attentional measures. Specifically, the dominant manual dynamometry, concentration, and maximum oxygen consumption have been included variables. This is consistent with previous studies that had highlighted a greater relationship between these measures in situations requiring greater cognitive control (Westfall et al., 2018). The complex RT requires selecting a response to different possibilities (Boisgontier et al., 2014), so the demands to respond effectively are greater. In this work, the RT has been evaluated by means of an oculo-manual coordination task using the FITLIGHT Trainer system, which suggests that a better physical condition and a greater capacity to concentrate could have influenced the developed behavior, as indicated by the data obtained.

It is interesting to note that the physical fitness measurements that predicted the values in complex RT were manual dynamometry and maximum oxygen consumption. Cardiorespiratory fitness has been widely documented as an ability linked to improved cognitive ability and improved performance on tasks requiring cognitive control (Kao et al., 2017; Westfall et al., 2018). However, the dominant manual dynamometry has been the strongest factor in the regression equation. This could have happened because of the type of task analyzed, which required

TABLE 5 | Descriptive statistics for the variables of physical condition, selective attention, and anthropometry and their correlation with the two RT tasks.

	M	*SD*	*S*	*K*	K–S	TS	TC
BMI	19.96	3.27	0.76	0.89	0.92	−0.05	−0.01
% fat mass	22.73	8.37	0.28	−0.13	0.68	−0.02	−0.01
Dyn_dom	16.49	3.64	0.25	−0.76	0.79	−0.28**	−0.36***
Dyn_non-dom	15.64	3.99	0.68	0.61	1.09	−0.29**	−0.32**
HJT	121.69	22.85	0.05	0.10	0.54	−0.31**	−0.25**
5 × 10	22.60	2.05	0.75	0.93	1.27	0.39***	0.21*
VO2max	44.16	4.26	0.34	−0.05	1.25	−0.27**	−0.26**
D2_TA	329.34	66.67	0.85	3.11	0.77	−0.09	−0.10
D2_TH	125.73	24.65	−0.47	0.31	0.63	−0.22*	−0.23**
D2_O	9.95	12.96	2.34	7.70	1.79**	−0.04	−0.05
D2_C	6.12	9.85	2.93	10.33	2.59***	0.01	0.10
D2_TET	307.71	56.13	−0.38	0.39	0.65	−0.19*	−0.25**
D2_CON	118.42	32.41	−0.82	1.30	0.89	−0.24**	−0.31**
D2_VAR	15.57	7.65	1.33	2.04	1.84**	−0.13	−0.06
SRT	632.03	97.38	0.77	1.55	0.63	–	–
CRT	840.68	110.79	0.59	0.95	0.92	–	–

M, mean; SD, standard deviation; S, skewness; K, kurtosis; K–S, Kolmogorov–Smirnov; BMI, body mass index; Dyn_dom, dynamometry (dominant); Dyn_non-dom, dynamometry (non-dominant); HJT, horizontal jump test (cm); 5 × 10, speed test 5 × 10 m (s); VO2max, maximum oxygen consumption (ml/kg/min); D, D2 test; TA, total number of attempts; TH, total number of hits; O, omissions; C, commissions; TET, total effectiveness in the test; CON, concentration index; VAR, variation index; SRT, simple reaction time; CRT, complex reaction time. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

a quick and efficient motor action of the upper limbs in the face of the visual stimuli of the FITLIGHT Trainer test. Probably, the neuromuscular requirements intrinsic to the task itself could have conditioned the results found. This could indicate that it is important, when carrying out this type of studies, to take into account the type of activity analyzed, given that the nature of the activity could modulate the conclusions derived from it.

This paper presents a number of limitations. On the one hand, the analysis of oxygen consumption has been carried out indirectly, which is data with a certain margin of error. In future works, it would be interesting to use a type of direct gas analysis test in an incremental stress test to obtain more reliable data. On the other hand, the type of design used does not allow establishing causal relationships between the variables analyzed. It would be interesting to carry out longitudinal or quasi-experimental work to observe how the data evolve as a function of changes in the physical condition or in the cognitive functioning of the study sample. In any case, this research carries out an interesting analysis in which it has linked variables of cognitive functioning, physical practice, and physical condition with RT, providing data that allow us to delve deeper into this phenomenon and that increase empirical evidence of the internal factors that could condition RT in preadolescents.

The findings found in this study suggest that better development of attention and concentration, as well as physical condition, could help improve RT at these ages. This could contribute to improving efficiency in tasks that are important for the personal and social growth of children and adolescents. Therefore, it would be interesting to contribute to its improvement when considering psychomotor development programs in this population.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the University of Jaén, Spain (Ref. ABR.16/6). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SB, IM, AH-M, VM-S, RR, and RJ-R participated in the study design and data collection, performed the statistical analyses, contributed to the interpretation of the results, wrote the manuscript, and approved the final manuscript. RR, AH-M, SB, and IM conceived the study and participated in its design and coordination. AH-M, VM-S, RR, RJ-R, SB, and IM contributed to the interpretation of the results, and reviewed and provided feedback to the manuscript. All authors made substantial contributions to the final manuscript.

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ORIGINAL RESEARCH
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Effects of a Computerized Training on Attentional Capacity of Young Soccer Players

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The purpose of this work was to analyze the effects of a computerized training on attentional capacity in a group of young soccer players. Seventy-five male adolescents from two soccer clubs in the city of Malaga (Spain) and aged between 14 and 18 (15.45 ± 1.43 years) participated in the investigation. A quasi-experimental design was used, and the adolescents were divided into control ($n = 38$) and experimental ($n = 37$) groups. The experimental group underwent a computerized training (Rejilla 1.0) of their attention during 9 weeks and 27 sessions. In addition, the D2 attention test was used to analyze the evolution of participants after the intervention program. The results showed positive effects of the computerized intervention program on selective attention, observing changes both in the executions of the software used ($p < 0.001$, Cohen's $d = 1.58$, 95% CI [1.06, 2.11]) and in the main measures of the D2 test, total effectiveness ($p < 0.001$, Cohen's $d = 0.62$, 95% CI [0.15, 1.08]) and concentration ($p < 0.01$, Cohen's $d = 0.48$, 95% CI [0.02, 0.94]).

Keywords: attention, cognitive functioning, soccer, computerized training, sport

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INTRODUCTION

Scientific literature has highlighted in recent years that cognitive functioning of athletes could be a determinant of their performance and predictor of their level of expertise (Romeas et al., 2016; Fink et al., 2018). Some research has indicated that athletes who show better cognitive functioning show increases in performance, especially in those disciplines that require continuous adaptation to play and a great ability to anticipate and maintain attention (Verburgh et al., 2014). For example, Huijgen et al. (2015) observed in a group of elite soccer players between 13 and 17 years old better scores in inhibitory control and cognitive flexibility than in a group of sub-elite soccer players. Verburgh et al. (2014) compared two groups of soccer players between 8 and 16 years old, indicating better scores on inhibitory control and the ability to reach and maintain alertness in the most talented group. Vestberg et al. (2017) investigated a group of soccer players between 12 and 19 years old, revealing that executive functions are cognitive abilities that predict sport success.

Specifically, some works have highlighted that aspects such as attention and concentration are significantly related to the behavior of athletes (Weinberg and Gould, 2010; Carraça et al., 2018; Love et al., 2018). Among existing research, Williams et al. (2011) revealed that visual attention training may influence performance in sports modalities in which moving objects such as a ball are used. Roca et al. (2018) analyzed 44 soccer players with an average age of 20.8 years old and observed that creativity shown in the decision making before different simulated game actions was modulated by attentional aspects. Thus, they indicated that a greater capacity to attend to the stimuli presented was a determinant to present more creative solutions during the game.

Attention has been widely explored in numerous works and is considered a fundamental cognitive capacity for humans, because it allows to select the necessary information and to facilitate a correct functioning (Desimone and Duncan, 1995; Chun et al., 2011; Rosenberg et al., 2017). In addition, the development of attentional capacity is linked to other dimensions of cognitive functioning, such as memory, executive control, or learning (Logue and Gould, 2014; Bialystok, 2015; Campillo et al., 2018). For all these reasons, the evaluation and development of attention have been the object of interest in different social areas such as relevant as clinical, educational, work, or sports area (Memmert et al., 2009; Memmert, 2011; Gray et al., 2016; Kirk et al., 2016; Spaniol et al., 2018).

Attention is a complex construct that has different manifestations such as attentional, selective, serial, divided, or sustained span, among others (Posner and Petersen, 1990; Estévez-González et al., 1997). Specifically, one of the dimensions that have aroused the most interest among researchers is selective attention, which would refer to the ability to attend to specific stimuli and ignore others, which is very relevant to adapt to multiple tasks and functioning adequately in contexts such as education or sports (Estévez-González et al., 1997; Bar-Eli et al., 2011; Giuliano et al., 2014). For example, it is considered that in soccer, this capacity is involved in habitual processes during the game, such as determining to which player the ball has to be passed to or which movements of both teammates and opponents are decisive for the development of a game (Romeas et al., 2016; Gonçalves et al., 2017).

Research has shown that attention can be trained in populations of different characteristics and through different methods (Wass et al., 2011; Posner et al., 2015; Olfers and Band, 2018). Among others, positive effects of systematic training of this cognitive capacity in people with generalized social phobia, anxiety, autism, traumatic brain injury, or attention deficit hyperactivity have been indicated (Amir et al., 2009; Christiansen and Oades, 2010; Bar-Haim et al., 2011; Powell et al., 2016; Séguin et al., 2018). Likewise, different strategies have been used in sport to train perceptive and attentional processes with the aim of improving the response of athletes to different game situations and of trying to increase their performance (Calmels et al., 2004; Romeas et al., 2016).

In recent years, the use of computerized tools for attention assessment and training has increased (Hernández-Mendo and Ramos-Pollán, 1995a,b; Reid et al., 2009; Rabiner et al., 2010; Chamberlain et al., 2011; Hernández-Mendo et al., 2012; Montani et al., 2014; Bogdanova et al., 2016; Kirk et al., 2016). The development of technology and adaptation of instruments to digital environments has increased the resources to analyze cognitive functioning in people. This type of tool offers greater versatility for collecting and handling information, processing stored data, adapting its operation to the performer, or modifying characteristics of the exercise that may increase motivation during the performance of the exercises (González de la Torre and González de la Torre, 2003; Fernández-Calvo et al., 2011).

Based on the precedents described, the purpose of this work is to analyze the effects of a computerized training program of selective attention through the software Rejilla 1.0. 4 (Hernández-Mendo et al., 2012) in a group of young soccer players (see **Supplementary Video S1**).

METHODS

Sample

Seventy five male teenagers and young men from two soccer clubs in Malaga (Spain), aged between 14 and 18 years old ($M \pm$ SD: age $= 15.45 \pm 1.43$ years old), took part in this research. Participants trained 3 or 4 days/week, lasting ~90 min per session. Everyone had at least 5 years of soccer practice experience. The exclusion criteria were physical and psychological health problems that could affect the research or no informed consent (no participant had to be suppressed). The sample was organized into two groups: control (they did not participate in the attention training program and did not perform alternative tasks) and experimental (they participated in the intervention program at times other than sports training).

Instruments and Measures

Rejilla v. 1.0

This program is described in Hernández-Mendo et al. (2012). The program is a Windows desktop application made under the .NET platform in the C# programming language and with the Visual Studio programming environment. The program is downloaded from the online evaluation platform MenPas (www.menpas.com) (González-Ruiz et al., 2010, 2018). When the application is started, an initial screen appears requesting the user name and password for the MenPas platform. The main screen of the program appears in **Figure 1** (see **Supplementary Material**). This program can work with six types of stimuli (numbers, colors, letters, images, alphabet, and windings) and, depending on the programming of the time and that is performed with/without pairing, can work with different types of attention. It is possible to program the sizes of stimuli and background colors and to change place by time intervals, presentation times, and the use of distracting stimulus such as lines (you can program the color and width), sounds, or metronome. It allows to know the time between each stimulus and the latency times. It calculates efficiency and effectiveness indicators as well as percentages of relative/absolute hits/errors. The main type of attention that can be evaluated and trained with this software is selective or focal attention/serial attention (Estévez-González et al., 1997). You can also train/sustained assessment when no time limits are set or it is set at 15 min or more. One could also work on attention to visual hemifield displacement (Estévez-González et al., 1997) using the pairing option. For this study, the hits and errors of each task have been recorded.

D2 Attention Test (Brickenkamp, 2002)

It is a test that is used to explore the capacity to attend to the relevant stimulus of a task in a fast and precise way, ignoring

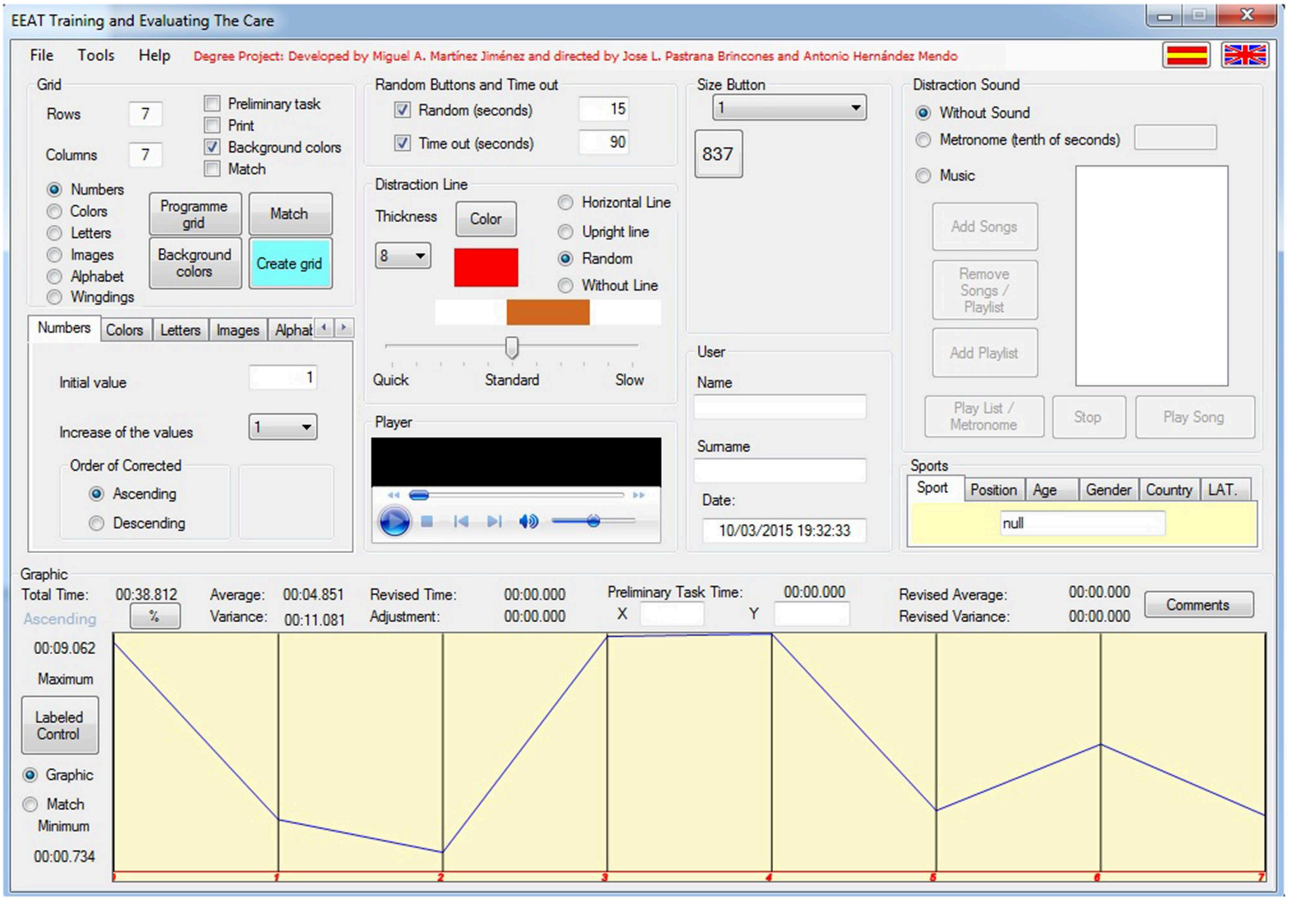

FIGURE 1 | Main screen of the program Rejilla 1.0.

the irrelevant ones, being considered a manifestation of selective attention and concentration. The test is based on discriminating between 47 characters in each of the 14 rows, with a total of 658 elements. You have 20 s to make each row. Stimulus contains the letters "d" or "p," which may be accompanied by one or two stripes at the top of the item, at the bottom, or both. In order to perform the test properly, the "d" must be crossed out with two lines (regardless of position), considered as relevant stimulus. The test is always carried out from left to right and from top to bottom. The scores that can be obtained are as follows: TA (total number of attempts), TH (total number of hits), O (omissions or number of relevant stimuli not crossed out), C (omissions or errors), TET (total effectiveness in the test = TA—[O + C]), CON (concentration = TH—C), TA+ (last stimulus analyzed in the row with the most attempted elements), TA– (last stimulus analyzed in the row with the fewest attempted elements), and VAR (index of variation between the last stimulus analyzed between different rows = [TA+]—[TA–]). This test possesses a test–retest reliability in the original study superior to 0.90.

Procedure

The sports clubs were contacted, and permission from the sports management and coaches was obtained to carry out the research. In addition, informed and written consent was achieved to participate in the study (for those athletes under-18, consent from parents or legal guardians was required). In addition, authorization was also obtained from the Ethics Committee of the University of Malaga (CEUMA, no. 243, 19-2015-H), and the ethical principles of the Declaration of Helsinki (World Medical Association, 2013) were respected during the research process.

Two evaluations were carried out for D2 attention test, initial and final, and three assessments for Rejilla 1.0 software, initial, midterm, and final. The computerized exercises (Rejilla 1.0) consisted of eight tasks: (1) cancellation of numbers (in pairs and without disappearing) in color matrix, 10 × 10 size, and distracting line; (2) cancellation of numbers (in pairs and disappearing) in color matrix, 10 × 10 size, and distracting line; (3) cancellation of numbers (no pairs and without disappearing) in color matrix, 10 × 10 size, and distracting line; (4) cancellation of numbers (no pairs and disappearing) in color matrix, 10 × 10 size, and distracting line; (5) cancellation of numbers (in pairs and without disappearing) in color matrix, 11 × 11 size, and distracting line; (6) cancellation of numbers (in pairs and disappearing) in color matrix, 11 × 11 size, and distracting line; (7) cancellation of numbers (no pairs and without disappearing) in color matrix, 11 × 11 size, and distracting line; and (8) cancellation of numbers (no pairs and disappearing) in color matrix, 11 × 11 size, and distracting line.

During the intervention, the experimental group was involved in attention training programs using Rejilla 1.0 software, 3 days/week during 9 weeks. In each session, they performed eight tasks: (1) cancellation of numbers (in pairs and disappearing) in color matrix, 7 × 7 size, and distracting line (**Figure 2**); (2) cancellation of numbers (no pairs and without disappearing) in color matrix, 7 × 7 size, and distracting line; (3) cancellation of numbers (in pairs and disappearing) in color matrix, 8 × 8 size, and distracting line; (4) cancellation of numbers (no pairs and without disappearing) in color matrix, 8 × 8 size, and distracting line; (5) cancellation of numbers (in pairs and disappearing) in color matrix, 9 × 9 size, and distracting line; (6) cancellation of numbers (no pairs and without disappearing) in color matrix, 9 × 9 size, and distracting line; (7) cancellation of numbers (in pairs and disappearing) in color matrix, 10 × 10 size, and distracting line; and (8) cancellation of numbers (no pairs and without disappearing) in color matrix, 10 × 10 size, and distracting line. The control group did not participate in the attention training program and did not perform alternative tasks, although they did continue training soccer.

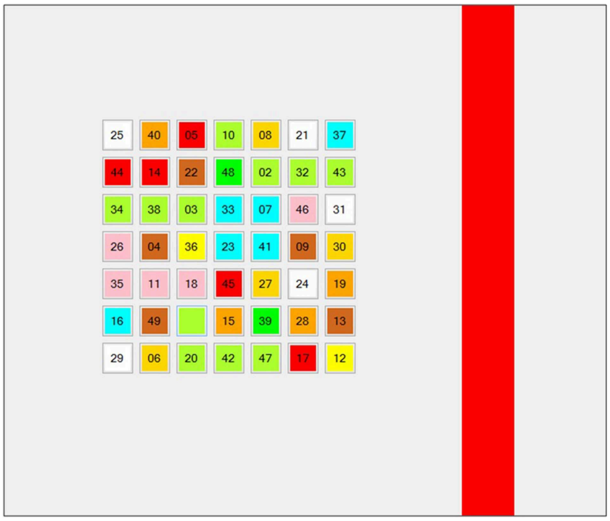

FIGURE 2 | Example of task (cancellation of numbers (in pairs and disappearing) in color matrix, 7 × 7 size, and distracting line).

Data Analysis

Descriptive and inferential analyses were used to process the information collected. The values of mean, standard deviation, skewness, kurtosis, and *Shapiro–Wilk* test were obtained. Intragroup means were compared using the Friedman and Wilcoxon tests. Intergroup means were compared through the Mann–Whitney *U*-test. Cohen's *d* statistic was performed to calculate the effect size. Data were

TABLE 1 | Hits and errors (mean and standard deviation) in Rejilla 1.0 tests for both groups and differences between groups.

	Control group			Experimental group		
	Initial	Midterm	Final	Initial	Midterm	Final
	$M \pm SD$	$M \pm SD$	$M \pm SD$	$M \pm SD$	$M \pm SD$	$M \pm SD$
H1	1.97 ± 1.15	2.05 ± 1.35	2.26 ± 1.37	2.27 ± 1.54	2.97 ± 1.72^{a}	4.16 ± 2.05^{c}
H2	2.84 ± 1.44	2.08 ± 1.26	2.29 ± 1.74	2.62 ± 1.21	2.70 ± 1.60	4.03 ± 1.85^{c}
H3	2.21 ± 1.23	2.55 ± 1.57	2.16 ± 1.24	2.89 ± 1.71	3.65 ± 2.20^{a}	5.92 ± 2.65^{c}
H4	2.79 ± 1.83	2.87 ± 1.61	2.58 ± 1.08	4.00 ± 2.08	3.73 ± 2.38	6.38 ± 3.10^{c}
H5	2.16 ± 1.44	1.87 ± 0.93	1.76 ± 0.91	2.05 ± 1.31	3.57 ± 2.43^{c}	4.11 ± 1.79^{c}
H6	2.37 ± 1.20	1.79 ± 0.78	1.79 ± 1.09	2.35 ± 1.46	2.62 ± 1.77	4.19 ± 1.90^{c}
H7	2.05 ± 1.14	1.87 ± 1.02	2.47 ± 1.69	2.81 ± 1.76	2.73 ± 1.94^{a}	5.24 ± 2.62^{c}
H8	2.55 ± 1.39	2.29 ± 1.21	2.37 ± 1.89	2.89 ± 1.54	3.14 ± 2.20	5.97 ± 2.93^{c}
T (H)	2.37 ± 0.64	2.17 ± 0.61	2.21 ± 0.84	2.74 ± 0.91	3.14 ± 1.44^{c}	5.01 ± 1.81^{c}
E1	2.37 ± 3.19	2.55 ± 3.27	2.61 ± 3.45	0.92 ± 1.09^{a}	1.11 ± 1.24	1.27 ±0.99
E2	2.00 ± 2.94	1.82 ± 2.64	2.47 ± 3.34	1.22 ± 1.51	1.08 ± 1.09	0.97 ±0.96
E3	2.87 ± 3.50	2.37 ± 3.14	2.39 ± 3.08	2.22 ± 2.63	1.62 ± 2.34	0.70 ± 1.51^{b}
E4	1.29 ± 2.73	2.32 ± 3.35	1.58 ± 2.56	0.89 ± 1.98^{b}	0.81 ± 1.93^{a}	0.38 ±0.64^{a}
E5	2.11 ± 3.06	1.76 ± 2.75	2.24 ± 2.97	1.32 ± 1.97	0.81 ± 1.10	1.19 ± 1.08
E6	1.37 ± 2.33	1.95 ± 2.75	2.63 ± 3.55	1.11 ± 1.76	0.76 ± 0.98	0.95 ± 1.22
E7	2.26 ± 3.37	2.61 ± 3.37	2.34 ± 3.16	1.46 ± 2.73	1.38 ± 2.19	0.59 ± 1.28^{c}
E8	1.61 ± 2.80	1.61 ± 2.88	1.05 ± 2.60	0.76 ± 1.55	0.59 ± 1.72	0.59 ± 1.01^{a}
T (E)	1.98 ± 2.35	2.12 ± 2.16	2.16 ± 2.29	1.24 ± 1.22	1.02 ± 0.96	0.83 ± 0.46^{a}

M, mean; SD, standard deviation; H, hits; E, errors; T, total.
Cross-group: $^{a}p < 0.05$; $^{b}p < 0.01$; $^{c}p < 0.001$.

analyzed with SPSS statistical program (SPSS Inc. v.24.0, Chicago, IL, USA).

RESULTS

Tables 1, **2** show descriptive and normal statistics for initial, intermediate, and final assessments in Rejilla 1.0 tests and for both groups. As can be seen, the results indicate that the distributions did not meet the criterion of normality in most cases.

Table 3 shows the comparisons between the different assessments in each group. As it can be observed, the scores in hits for the experimental group manifested greater differences between evaluations than for the control group. For total scores, there were differences in the experimental group in initial vs. midterm ($p < 0.05$), midterm vs. final ($p < 0.001$), and initial vs. final assessment ($p < 0.001$).

TABLE 2 | Skewness, kurtosis, and Shapiro–Wilk tests for both groups and different Rejilla 1.0 tasks.

	Initial			Midterm			Final		
	S	***K***	***S-W***	***S***	***K***	***S-W***	***S***	***K***	***S-W***
CONTROL GROUP									
H1	1.51	2.79	0.79***	2.59	9.50	0.70***	1.56	2.85	0.81***
H2	0.29	−0.87	0.91**	1.64	3.20	0.77***	3.63	17.14	0.61***
H3	1.67	4.79	0.81***	1.07	0.90	0.85***	1.38	1.91	0.81***
H4	0.88	0.16	0.87***	1.45	2.40	0.84***	1.61	3.79	0.78***
H5	2.04	4.23	0.71***	1.11	1.67	0.80***	0.95	−0.04	0.78***
H6	0.83	0.68	0.88***	0.76	0.28	0.81***	2.01	5.07	0.72***
H7	0.94	−0.05	0.82***	1.41	1.79	0.77***	2.00	5.34	0.78***
H8	0.49	−0.98	0.87***	0.67	−0.47	0.86***	3.01	11.43	0.65***
T (A)	0.12	−0.88	0.98	-0.23	−1.11	0.95	2.51	9.63	0.77***
E1	1.72	1.66	0.68***	1.36	0.60	0.75***	1.28	0.24	0.74***
E2	1.83	2.49	0.69***	1.72	2.21	0.72***	1.49	1.03	0.73***
E3	1.25	0.25	0.76***	1.34	0.66	0.74***	1.42	0.98	0.76***
E4	2.74	6.69	0.51***	1.41	0.59	0.71***	1.98	3.37	0.68***
E5	1.97	2.70	0.65***	1.63	1.74	0.70***	1.39	0.71	0.75***
E6	2.92	8.98	0.59***	1.81	2.64	0.72***	1.36	0.33	0.71***
E7	1.47	0.79	0.69***	1.41	0.70	0.74***	1.74	1.85	0.69***
E8	2.24	4.52	0.62***	2.01	3.03	0.61***	2.86	7.37	0.46***
T (E)	2.47	6.00	0.65***	1.42	1.49	0.81***	1.60	1.82	0.78***
EXPERIMENTAL GROUP									
H1	1.26	1.09	0.80***	0.73	0.30	0.90***	0.63	0.19	0.94*
H2	0.30	−1.02	0.89**	0.56	−0.93	0.87***	0. 43	−0.35	0.93*
H3	0.95	0.58	0.88***	1.10	0.61	0.87***	-0.17	−0.68	0.96
H4	1.25	2.33	0.90**	1.72	3.15	0.80***	0.27	−0.68	0.95
H5	1.07	0.01	0.78***	2.34	8.45	0.79***	0.66	0.45	0.94
H6	1.11	0.52	0.83***	1.28	1.44	0.82***	0.51	−0.17	0.95
H7	0.95	0.11	0.87***	2.53	8.70	0.74***	-0.07	−1.00	0.95
H8	0.33	−0.95	0.91**	1.26	1.49	0.86***	-0.10	−0.65	0.94
T (H)	0.83	1.70	0.94*	1.94	4.92	0.83***	0.10	−1.49	0.91**
E1	1.67	4.11	0.77***	1.90	5.47	0.76***	-0.04	−1.23	0.84***
E2	1.86	3.92	0.74***	0.78	−0.05	0.85***	0.86	0.94	0.82***
E3	1.50	1.36	0.78***	2.13	4.68	0.71***	3.63	15.63	0.52***
E4	2.87	8.00	0.51***	3.48	14.34	0.48***	1.50	1.15	0.62***
E5	2.73	9.77	0.68***	1.58	2.22	0.74***	0.59	−0.25	0.87***
E6	3.25	12.11	0.57***	2.38	8.64	0.69***	1.45	2.01	0.77***
E7	2.11	3.49	0.60***	2.22	4.42	0.64***	3.86	17.86	0.50***
E8	3.30	13.12	0.55***	4.84	26.00	0.38***	1.76	2.68	0.65***
T (E)	2.33	7.03	0.75***	2.46	6.98	0.72***	1.21	1.12	0.89**

S, skewness; K, kurtosis; S-W, Shapiro–Wilk; H, hits; E, errors; T, total.
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

TABLE 3 | Differences between evaluations (Friedman and Wilcoxon) in both groups for Rejilla 1.0 tests (control and experimental).

	Control group				Experimental group			
	Friedman (χ^2)	Assessments			Friedman (χ^2)	Assessments		
		A vs. B	B vs. C	A vs. C		A vs. B	B vs. C	A vs. C
H1	0.82	–	–	–	21.76***	<0.05	<0.05	<0.001
H2	4.79	–	–	–	21.31***	–	<0.001	<0.001
H3	0.67	–	–	–	21.11***	–	<0.001	<0.001
H4	0.76	–	–	–	18.31***	–	<0.001	<0.01
H5	1.56	–	–	–	27.24***	<0.01	–	<0.001
H6	7.11*	<0.05	–	<0.05	19.89***	–	<0.001	<0.001
H7	7.13*	–	<0.05	–	20.44***	–	<0.001	<0.001
H8	0.15	–	–	–	28.01***	–	<0.001	<0.001
T (H)	0.51	–	–	–	36.02***	<0.05	<0.001	<0.001
E1	0.44	–	–	–	2.09	–	–	–
E2	3.04	–	–	–	1.09	–	–	–
E3	1.53	–	–	–	9.65**	–	–	<0.01
E4	0.54	–	–	–	0.07	–	–	–
E5	1.58	–	–	–	2.34	–	–	–
E6	2.71	–	–	–	0.38	–	–	–
E7	1.87	–	–	–	3.55	–	–	–
E8	3.10	–	–	–	0.58	–	–	–
T (E)	0.18	–	–	–	1.70	–	–	–

A, initial assessment; B, midterm assessment; C, final assessment.
$^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

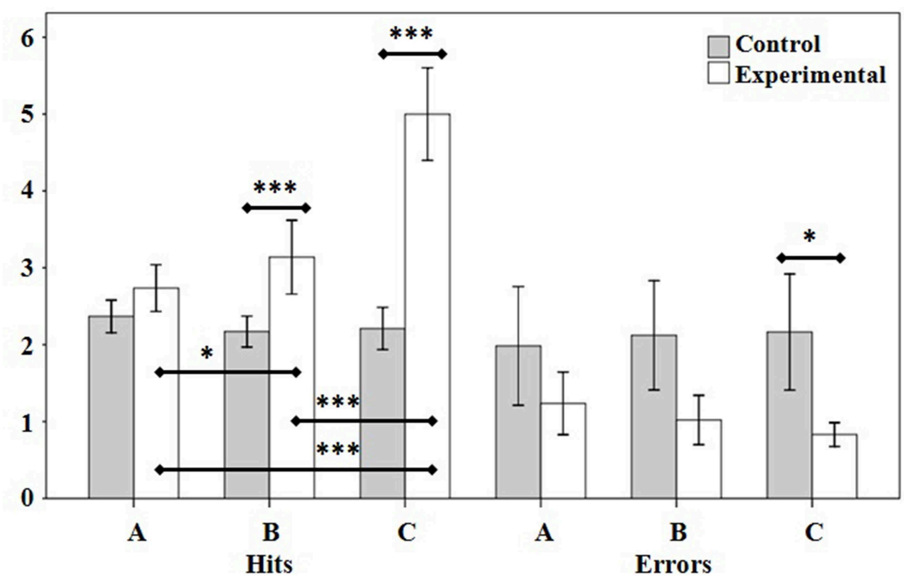

FIGURE 3 | Intragroup and intergroup scores and comparisons for the initial, intermediate, and final measures of hits and errors ($M \pm$ DT) of the Rejilla 1.0 exercise scores. A, initial assessment; B, midterm assessment; C, final assessment. $^*p < 0.05$; $^{***}p < 0.001$.

Figure 3 shows the average hit and error scores of the Rejilla 1.0 exercises used.

Table 4 shows the descriptive and normality statistics (Shapiro–Wilk) for the pre-measurements and post-measurements of D2 attention test for both groups. As can be seen, the results indicate that the distributions did not meet the criterion of normality in many scores.

Table 5 shows intergroup and intragroup differences between D2 attention test measures. As can be seen, the differences between the groups increased after the training program in

TABLE 4 | Descriptions and normality test (*Shapiro–Wilk*) of the values obtained in the D2 test measurements.

	Pre-test					Post-test				
	M	***SD***	***S***	***K***	***S-W***	***M***	***SD***	***S***	***K***	***S-W***
CONTROL GROUP										
D2-TA	59.50	17.28	0.19	−1.08	0.95	65.68	20.29	−0.31	−0.67	0.93*
D2-TH	58.16	20.37	−0.03	−0.42	0.94	62.63	21.92	0.16	−0.98	0.93*
D2-O	43.26	19.87	−0.39	−0.34	0.96	46.18	22.41	−0.11	−1.27	0.92*
D2-C	43.50	20.25	0.33	−0.33	0.93*	45.21	27.78	0.77	0.26	0.90**
D2-TET	65.42	20.66	−0.03	−0.77	0.95	68.47	20.94	−0.12	−0.90	0.91**
D2-CON	60.79	25.25	−0.10	−1.23	0.90**	64.11	23.60	−1.11	0.23	0.79***
D2-(TA+)	61.03	17.08	−0.51	−1.15	0.88**	66.58	16.60	−0.97	−0.01	0.84**
D2-(TA–)	63.84	20.63	−0.52	−0.96	0.89**	67.74	22.85	−1.00	0.01	0.83**
D2-VAR	54.66	21.83	−0.01	−0.54	0.98	56.47	22.44	0.06	−0.71	0.96
EXPERIMENTAL GROUP										
D2-TA	63.65	19.98	−0.01	−1.34	0.91**	72.51	25.33	−1.73	2.87	0.73***
D2-TH	65.73	22.00	−0.36	−0.47	0.93*	75.86	23.77	−1.72	2.74	0.75***
D2-O	45.84	21.46	0.14	−0.19	0.98	47.95	21.13	0.06	−0.92	0.95
D2-C	42.59	28.32	0.86	−0.52	0.84***	44.97	29.06	1.25	1.21	0.84***
D2-TET	66.95	20.79	−0.09	−1.15	0.91**	78.84	17.65	−1.44	4.82	0.82***
D2-CON	63.05	22.64	−1.28	0.08	0.68***	73.65	21.30	−3.40	12.13	0.42***
D2-(TA+)	63.27	17.74	−1.50	1.76	0.74***	67.38	16.64	−2.98	9.50	0.53***
D2-(TA–)	68.57	21.61	−1.35	0.85	0.77***	74.49	21.73	−1.87	2.37	0.60***
D2-VAR	48.22	27.01	0.33	−0.99	0.92*	49.76	29.13	0.94	0.24	0.88**

S, skewness; K, kurtosis; D2, D2 test; TA, total number of attempts; TH, total number of hits; O, omissions; C, commissions; TET, total effectiveness in the test; CON, concentration index; (TA+), last stimulus analyzed in the row with the most attempted elements; (TA–), last stimulus analyzed in the row with the fewest attempted elements; VAR, variation index.
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

TABLE 5 | Comparisons between intergroups and intragroups.

	Group		*Factor*	
	***Control* Pre vs. post**	***Experimental* Pre vs. post**	***Pretest* C vs. E**	***Posttest* C vs. E**
D2-TA	−1.87	−2.87**	−.77	−1.55
D2-TH	−2.07*	−2.44*	−1.73	−2.56*
D2-O	−0.22	−0.83	−0.30	−0.76
D2-C	−0.12	−0.14	−0.59	−0.93
D2-TET	−1.10	−3.65***	−0.26	−2.08*
D2-CON	−0.98	−3.11**	−0.16	−2.01*
D2-TA+	−1.74	−1.97*	−0.55	−0.51
D2-TA–	−1.59	−2.21*	−1.55	−1.60
D2-VAR	−0.25	−0.50	−1.15	−1.24

D2, D2 test; TA, total number of attempts; TH, total number of hits; O, omissions; C, commissions; TET, total effectiveness in the test; CON, concentration index; (TA+), last stimulus analyzed in the row with the most attempted elements; (TA–), last stimulus analyzed in the row with the fewest attempted elements; VAR, variation index.
$^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

TH ($p < 0.05$, Cohen's $d = 0.58$, 95% CI [0.12, 1.04]), TET ($p < 0.05$, Cohen's $d = 0.43$, 95% CI [−0.03, 0.89]) and CON ($p < 0.05$, Cohen's $d = 0.42$, 95% CI [−0.03, 0.88]) (**Figure 4**). Significative increases were observed in both groups in TH (control: $p < 0.05$, Cohen's $d = 0.21$, 95% CI [−0.24, 0.66]; experimental: $p < 0.05$, Cohen's $d = 0.44$, 95% CI [−0.02, 0.91]) but not in the experimental group in the measures TA ($p < 0.01$, Cohen's $d = 0.39$, 95% CI [−0.07, 0.85]), TET ($p < 0.001$, Cohen's $d = 0.62$, 95% CI [0.15, 1.08]), CON ($p < 0.01$, Cohen's $d = 0.48$, 95% CI [0.02, 0.94]) (**Figure 4**), TA+ ($p < 0.05$, Cohen's $d = 0.24$, 95% CI [−0.22, 0.69]), and TA– ($p < 0.05$, Cohen's $d = 0.27$, 95% CI [−0.18, 0.73]).

DISCUSSION

The aim of this work was to assess the effects of a 9 week computerized program on selective attention in a group of young soccer players. To this end, an intervention was carried out using the software Rejilla 1.0 during 27 sessions and 9 weeks on the experimental group. During the program, three evaluations were carried out using the computerized tool but with different exercises from those of the intervention. Likewise, the D2 test was used before and after the training program to evaluate in a complementary way the changes produced in this cognitive capacity. The results have highlighted differences between the two groups, suggesting positive effects on the experimental group and satisfying the research objectives.

First, the scores recorded from Rejilla 1.0 exercises have highlighted changes in the hit variable in the experimental group, although not in errors significantly. The control group

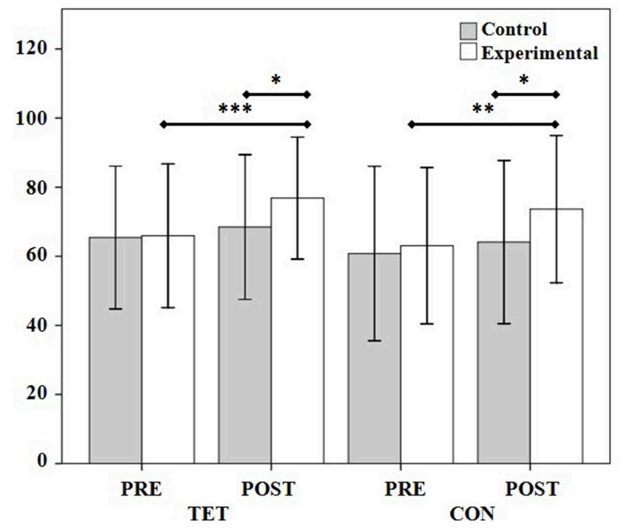

FIGURE 4 | Intragroup and intergroup scores and comparisons for the pretest and posttest measures of the main measures of the D2 test (TET and CON). TET, total effectiveness in the test; CON, concentration index. **p* < 0.05; ***p* < 0.01; ****p* < 0.001.

did not show important changes, only some residual measures that do not show a clear trend and that could probably be caused by chance or by the learning effects of the instrument. This suggests, first, what previous research has pointed out, indicating that attention is a capacity that can be trained (Wass et al., 2011; Posner et al., 2015; Olfers and Band, 2018). Specifically, this work provides the possibility to evaluate this tool as an appropriate way for this purpose, adding to other instruments that had previously been used for the training and assessment of attention (Hernández-Mendo and Ramos-Pollán, 1995a,b; Chamberlain et al., 2011; Montani et al., 2014; Kirk et al., 2016).

However, the effects produced in the experimental group could be due to the learning of the computerized tool itself, which needs to be contrasted with other criteria. Although the evaluation and intervention have been performed on different exercises, the execution procedures are similar and could be influencing the results. Evaluations using the D2 test have made it possible to analyze this phenomenon. The results of this test have indicated significant changes in the experimental group. In addition, differences between groups have been accentuated in measures such as responses, hits, concentration, or attention. Therefore, the results suggest the effectiveness of the intervention program and reinforce the use of this type of intervention to improve this cognitive capacity (Reid et al., 2009; Rabiner et al., 2010; Bogdanova et al., 2016).

These findings have relevant implications in sports contexts, given previous studies that have shown the importance of attention to the performance of athletes, including soccer players (Weinberg and Gould, 2010; Carraça et al., 2018; Love et al., 2018; Roca et al., 2018). In fact, previous literature has shown that better overall cognitive functioning could contribute to improving the performance of athletes (Verburgh et al., 2014; Huijgen et al., 2015; Romeas et al., 2016; Fink et al., 2018). Therefore, such interventions could improve their skills to act during the course of the game. Improving cognitive functioning could help you react better to game situations that require effectively perceiving, issuing a quick response, discriminating against different stimuli, or deciding on a response. In sports like soccer, which are very variable, training this type of ability could allow for greater success. For this reason, using this type of training in a complementary way to other habitual routines in soccer could increase the preparation of the sportsmen to increase the efficiency in their game and, by extension, the performance of the team. In addition, the use of technology can increase the motivation of users to perform training tasks, being able to adapt for devices such as mobile phones or tablets easily accessible to young athletes who are accustomed to their use (Bordignon and Iglesias, 2016; De La Torre-Salazar et al., 2017). In addition, this type of tool facilitates the fast storage and analysis of the data obtained, allowing the technical team to easily monitor the progress of athletes.

This study has a number of limitations. On the one hand, the intervention time is only 9 weeks, which may not be preventing us from seeing more robust results on some measures. More protracted programs would probably offer more significant changes in the measures of attention assessed. On the other hand, it would be necessary to extrapolate this program to other populations, with different characteristics such as age, gender, category, or level of studies, in order to analyze whether these variables would modulate the results found. Finally, it would be interesting to use other complementary instruments such as criteria to contrast the evaluated measures and to observe more clearly the changes in the constructs under study.

In any case, the present study provides data that help to highlight the usefulness that computerized training in sportsmen and sportswomen could have for improving their cognitive functioning, and its possible implications in this type of context. In addition, it offers a versatile tool that can be used in sports sciences as a complement to other instruments that have already been used and that can be used to provide more resources to professionals working in this field.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of the University of Malaga (19-2015-H). Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AH-M, VM-S, RR, JM-B, RJ-R, and FG-G participated in the study design and data collection, performed statistical analyses and contributed to the interpretation of the results, wrote the manuscript, and approved the final manuscript as presented. RR, AH-M, and FG-G conceived the study and participated in its design and coordination. AH-M, VM-S, RR, JM-B, RJ-R, and FG-G contributed to the interpretation of the results, reviewed, and provided feedback to the manuscript. All authors made substantial contributions to the final manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02279/full#supplementary-material

Supplementary Video S1 | This video presents an example of the programming of some of the exercises presented to young footballers. For more information about the program you can consult the article that presents the training program of the attention that appears in the article Hernández-Mendo et al. (2012). The Grid program can be downloaded from the online Psychosocial Assessment Platform MenPas (www.menpas.com ->Work Area I ->Attention->Download Grid). It is free and is distributed free of charge.

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Dynamics of Executive Functions, Basic Psychological Needs, Impulsivity, and Depressive Symptoms in American Football Players

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Executive functions play an important role in sports since the ability to plan, organize, and regulate behavior to reach an objective or goal depends on these functions. Some of the components of executive functions, such as inhibition of impulsive behavior and cognitive flexibility, are necessary for contact sports (e.g., American football) to carry out successful plays on the sports field. Executive functions have been studied in the sporting environment, but their relationship with the athletes' basic psychological needs (BPN), such as autonomy, competence, and relatedness, remains unexplored. Due to the importance of motivational processes over cognitive functions and in the generated adaptive results in athletes, this relationship should be taken into account. Therefore, the aim of this study was to analyze and compare executive functioning and psychological need thwarting overimpulsivity and psychological distress, before and after the season (4 months) in 28 undergraduate football players. Neuropsychological and psychological tests were applied. The results showed that there was an improvement in inhibition and planning at the end of the season. There was also an increase in attention and motor impulsiveness, and a decrease in need thwarting at the end of the season. A positive association between executive function, impulsiveness, psychological needs, and affective symptoms were also found. Our findings reveal the dynamics of sport-related psychological variables throughout the sport season in American football players, the association of these for the achievement of sport success, and the importance of encouraging proper management of emotions.

Keywords: inhibition, frustration, football, impulsivity, motivational processes

INTRODUCTION

The development of maximum sporting capacities depends on different components, such as physiological, technical, cognitive, emotional, personality-related, and motivational factors. The harmonic interaction of these components results in optimal trainability (Harre, 1987) and in the attainment of sport mastery.

The cognitive component refers to the set of mental processes carried out by individuals. Among these processes, executive functions are the mental skills essential to perform effective, creative, and socially accepted behavior (Lezak, 1995). Accordingly, executive functions are considered abilities that make it possible to organize and plan a task, appropriately select objectives, start and keep in mind an action plan, be flexible in strategies to reach a goal, or inhibit irrelevant stimuli (Shallice, 1994; Soprano, 2003; Banich, 2009). Also, executive function is a construct that comprises a series of cognitive abilities involved in the control of thought and behavior (Zelazo and Carlson, 2012). This is why, in the sporting environment, these abilities or functions are involved in a variety of tasks performed within physical practice (Lezak, 1993; Hillman et al., 2003; Davidson et al., 2006). The benefits derived from physical activity comprise not only physiological or physical health improvement but also better cognitive function, which has been a topic of great interest. Several studies have reported a positive association between cognitive function and physical activity, e.g., improvement in planning ability (Davis et al., 2011), better inhibitory control (Hillman et al., 2009; Wu et al., 2011), improvement in working memory (Kubesch et al., 2009; Rigoli et al., 2012), greater cognitive flexibility (Buck et al., 2008), and better responses in cognitive tests measuring aspects related to executive function (Stroth et al., 2009). The impact of physical practice on cognitive performance, and specifically on executive functions, may be derived from cognitive demands inherent to exercise, physiological changes produced in the brain, and the existing cognitive implications when performing a complex motor task (Castelli et al., 2007; Tomporowski et al., 2008; Best, 2010). Collective sports entail tasks with a great cognitive load, such as collaborating with teammates, anticipating the actions of opponents, developing strategies to achieve a successful play, or inhibiting secondary stimuli, and focusing on important ones, which, in turn, stimulate executive functions since great cognitive involvement is required that generates greater brain activation.

Another important component for sports performance, closely linked to executive functioning, is impulsiveness, which plays an important role in personality theories (Eysenck and Eysenck, 1985; Cloninger et al., 1991). Impulsiveness is defined as a predisposition to quickly and spontaneously react to both internal and external stimuli without considering the negative consequences for oneself and others. In clinical settings, this variable is associated with several psychiatric issues (Eysenck and Eysenck, 1978; Barratt, 1983, 1985, 2004; Moeller et al., 2001; Chahín, 2011; American Psychiatric Association [APA], 2013). However, in the sporting environment, impulsiveness has had different connotations, both positive (functional) and negative (dysfunctional), and has been associated with high levels of aggressiveness, functionality, and athlete success (Hickmann, 2004), as well as predisposition to a specific sport choice (Svebak and Kerr, 1989).

From a motivational perspective, the self-determination theory (Ryan and Deci, 2017) and, more specifically, the subtheory of basic psychological needs (BPN) sustain that needs play an important role in the development of psychological well-being and optimal functioning (Ryan and Deci, 2000) in athletes' performance. The theory postulates the existence of three BPN: autonomy, competence, and relatedness. This theory has a "dark side" in which frustration of BPN is analyzed. Frustration is referred to, in Bartholomew et al. (2011b), as an experience, a "state of mood." Autonomy satisfaction refers to the experience of self-determination, full willingness, and volition when carrying out an activity. In contrast, autonomy frustration involves feeling controlled through externally enforced or self-imposed pressures (deCharms, 1968; Deci and Ryan, 1985). Relatedness satisfaction refers to the experience of intimacy and genuine connection with others (Ryan, 1995), while relatedness frustration involves the experience of relational exclusion and loneliness (Bartholomew et al., 2011a). Competence satisfaction involves feeling effective and capable to achieve desired outcomes (Deci, 1975; Ryan, 1995), while competence frustration involves feelings of failure and doubt about one's efficacy (Bartholomew et al., 2011a); when thwarted, these needs are associated with dysfunction and are indicators of discomfort/ill-being (Stebbings et al., 2012; Vansteenkiste and Ryan, 2013). Concretely in sports, they are associated with symptoms of physical and psychological discomfort (Mars et al., 2017). Moreno-Murcia and Cervelló (2010) state that the lack of satisfaction of these basic needs leads to a series of cognitive, affective, and behavioral consequences, as well as exhaustion (Bartholomew et al., 2011b), somatic complaints (Bartholomew et al., 2014), burnout (Balaguer et al., 2012; Castillo et al., 2012; Bartholomew et al., 2014), negative affect (Gunnell et al., 2013), and affective disorders, such as anxiety and depression (Jowett and Felton, 2014).

From a physiological perspective, sport training involves variations throughout the training period for competition purposes, and from the pre-competitive to the competitive season (see, for example, Koutedakis, 1995); these variations are specific to every sports discipline and depend on its demands and the organization of training sessions. Intuitively, these physiological variations are expected to occur along with the described sport-related psychological components. To our knowledge, there are no studies investigating these variations. On the other hand, as stated at the beginning of this section, the harmonic interaction of the different components that make up sport performance guarantees optimal trainability. In general, this association between executive function and impulsiveness has been previously demonstrated (Hickmann, 2004). Specifically, in the sporting environment, the association between thwarting of psychological needs and indicators of psychological distress, such as depression and anxiety, was also studied (Gunnell et al., 2013; Jowett and Felton, 2014). However, the existing evaluations of the interaction between these components are not systematic, in particular among cognitive and motivational components, although some hypotheses linking executive functioning and satisfaction of psychological needs, particularly autonomy, have been proposed (Ryan and Deci, 2006).

Therefore, the first objective of this study was to compare the performance of executive function, impulsiveness, psychological needs thwarted, and indicators of psychological distress, before and after the season in a semi-professional, college football team. The second objective of this study was to provide evidence on the association of these sport-related psychological components in the population described. If we consider the dynamics of a sports environment during the season, then we can suppose that all the components implicated in sports performance such as cognition, motivation, and emotion, should be dynamic as well; i.e., we could hypothesize differences in these components between the beginning and end of the sports season. On the other hand, if a harmonic interaction of these components is necessary for optimal sport performance, as we stated above, then we could hypothesize a significant association between these components, mainly in their relationship with cognitive functioning, which has been less explored in previous studies.

MATERIALS AND METHODS

Participants

Twenty-eight college football players from a semiprofessional team with mean age = 21.77 (*SD* = 1.77), mean years of schooling = 14.39 (*SD* = 1.87), and mean of months of sports practice = 153.14 (*SD* = 63.25) were recruited. The participants included in this study did not report a history of psychiatric or neurological pathology. All the athletes participated voluntarily, and after being fully informed about the experimental procedures and their rights, individual informed consent to participate in the study was obtained. Participants were rewarded with a detailed report of the results of their psychological and neuropsychological tests. The study was carried out in accordance with the Helsinki declaration and was presented to the American Football Team Commission who gave their approval.

Instruments

To measure Executive Functions, the following tests were applied:

(a) The Montreal Cognitive Assessment (MoCA, version 7.1) validated for Latin America (Loureiro et al., 2018). MoCA evaluates executive functions, visuospatial ability, memory, attention, concentration and working memory, language, and orientation. The maximum score is 30 points, and the cutoff score for subjects without cognitive impairment is 26. The administration time is approximately 10 min.

(b) The Trail Making Test (TMT) included in the Halstead–Reitan Battery (Reitan and Wolfson, 1985) measures visual search speed, scanning, attention, sequencing, and cognitive flexibility; it consists of two parts: TMT-A and TMT-B. In TMT-A, the participant is instructed to draw a line to connect 25 numbers in ascending order (1, 2, 3 . . . 25), which are randomly distributed throughout a sheet of paper (Letter size). In TMT-B, the participant alternates numbers and letters in an ascending sequence (1-A, 2-B, 3-C . . . 12-L, 13). The total time to perform each test, in seconds, is recorded. The time limit for TMT-A is 100 s, and 300 s for TMT-B. For this study, the number of correct answers per test (numbers/letters correctly connected in ascending order) was also recorded, and error types such as omissions (number or letter), order (number or letter), errors of perseverance, and error corrections (going back) were qualitatively analyzed.

(c) The Stroop Effect subtest of the Neuropsychological Battery of Executive Functions and Frontal Lobes Version 2 (BANFE-2; Flores et al., 2012) was used. This subtest evaluates the ability of the participant to inhibit an automatic response and select a response based on arbitrary criteria (word color or reading the word). The maximum score is 84 with an administration time of up to 5 min. Correct answers (number of words correctly read) and the time used to complete the test (in seconds) were recorded.

To measure impulsiveness, the Barratt Impulsiveness Scale Version 11 for adults (BIS-11; Patton et al., 1995) was applied. The BIS-11 is a Likert-type scale composed of 30 items with four response options regarding frequency: 1 = *rarely or never*, 2 = *occasionally*, 3 = *often*, 4 = *always or almost always*. The total score ranges from 30 to 120 and evaluates global impulsiveness, as well as three second-order factors: attentional impulsiveness (5, 6, −9, 11, −20, 26, 28), motor impulsiveness (2, 3, 4, 16, 17, 19, 21, 22, 23, 25, −30) and unplanned impulsiveness (−1, −7, −8, −10, 12, −13, 14, −15, 18, 27, −29). The Spanish version validated in Chilean population was applied (Cronbach's alpha of 0.77; Salvo and Castro, 2013).

To measure psychological needs, the Psychological Need Thwarting Scale (PNTS; Bartholomew et al., 2011b) in its version validated for the Mexican context was applied (Cronbach's alpha of 0.95; López-Walle et al., 2013). PNTS is a Likert-type scale composed of 12 items, which can be classified into a global dimension of need thwarting and three factors: autonomy (items 1, 3, 5, and 7), relatedness (items 4, 8, 10, and 12), and competence (items 2, 6, 9, and 11). The response options range from 1 to 7 in ascending order (from 1 = *totally disagree* to 7 = *totally agree*), and the maximum scores range from 7 to 84 in the global dimension, and from 4 to 28 in each factor.

To measure the affective state, two scales were used:

(a) The Spanish version (Sanz et al., 2003) of the Beck Depression Inventory-II (BDI-II; Beck et al., 1996) validated in non-clinical samples of the Mexican general population and undergraduate students. This validation showed high internal consistency in the general factor (Cronbach's alpha = 0.9). BDI-II is a self-reported inventory that evaluates the intensity of depressive symptomatology through 21 items with four response options (from 0 to 3) ordered from low to high intensity of symptoms. Scores range from 0 to 63 points (0–13 = *without depression*, 14–19 = *mild depression*, 20–28 = *moderate depression*, and 29–63 = *severe depression*). The inventory is answered considering the mood during the two previous weeks including the administration day.

(b) The Generalized Anxiety Disorder questionnaire 7 (GAD-7) has been validated in the Spanish population with a Cronbach's alpha of 0.93 and a high criterion and construct validity (García-Campayo et al., 2009). GAD-7 screens for generalized anxiety disorder testing the presence of symptoms listed in the DSM-V. GAD-7 is a Likert-type scale of seven items with four response options: 0 = *never*, 1 = *several days*, 2 = *more than half the days*, and 3 = *nearly every day*. The scores range between 0 and 21 and are classified into four categories depending on the level of anxiety: 0–4 = *minimum*, 5–9 = *mild*, 10–14 = *moderate*, and greater than 14 = *severe*.

Procedure

Semi-professional college football players were invited to participate in the research project, which consisted of two evaluations during the season, i.e., Time 1 = pre-season, and Time 2 = post-season. In the first evaluation (Time 1), the procedure was explained and informed consent per participant was obtained, after which a general data questionnaire was administered (demographics, current sport, and clinical history); finally, the cognitive, affective, impulsiveness, and psychological needs assessments described above were administered. This was done in classrooms of their university with the necessary facilities (a desk, two comfortable chairs, good lighting, and air conditioning) at specific times (morning/evening) for two continuous weeks. The second evaluation (Time 2) was carried out at the end of the season (5 months after the first session), and consisted of the application of the same protocol, except for the presentation, informed consent, and interview.

Data Analysis

Statistical analyses were performed using SPSS software version 24 (Ibm Corporation, 2016). To analyze the normal distribution of our data, the Kolmogorov–Smirnov test for one sample was applied to every variable for pre- and post-season evaluations.

The variables that did not reach the normal distribution criterion were subjected to mean-comparison analyses for related samples using the Wilcoxon signed-rank test: cognitive evaluation (Total MoCA, Stroop correct answers, Stroop time, TMT-A time, TMT-A correct answers, TMT-B time, and TMT-B correct answers), depression (Total BDI-II), anxiety (Total GAD-7), and psychological need thwarting (Autonomy, Relatedness, and Competence). FDR (False Discovery Rate) corrections for multiple comparisons were applied to the variables belonging to the same construct: mental flexibility (TMT-A and TMT-B) and psychological need thwarting (Autonomy, PNT-A; Relatedness, PNT-R; and Competence, PNT-C).

For variables that reached normality, *t*-tests for related samples were used: psychological need thwarting (total PNT). For impulsiveness (total BIS-11, attentional impulsiveness, motor impulsiveness, and unplanned impulsiveness), a two-way ANOVA test was performed with time (pre-season and post-season) and impulsiveness (attention, motor and non-planned) as factors. The Greenhouse–Geisser correction for sphericity violation was applied when there was more than one degree of freedom in the numerator.

Finally, to test the prediction and association between variables, a series of stepwise multiple linear regressions, to evaluate the explanatory function of the independent variable on dependent variables, were performed according to the model explained below. In addition, Pearson correlation coefficients between the variables included in the model were obtained.

(a) To test whether *executive functions* predicted *impulsiveness*, the independent variables used were total MoCA, TMT-A/B (correct answers and time) and Stroop (correct answers and time); total and partial scores of *impulsiveness* (attention, motor and non-planned) were used as dependent variables.

(b) To test whether *executive functions* predicted *autonomy* (dependent variable), the independent variables used were Total MoCA, TMT A/B (correct answers and time), and Stroop (correct answers and time).

(c) To test whether *impulsiveness* (dimensions) predicted *autonomy* (dependent variable), the independent variables used were attentional impulsiveness, motor impulsiveness, and unplanned impulsiveness.

(d) To test whether *psychological need thwarting* (factors) predicted *depression* (dependent variable), the independent variables used were autonomy, relatedness, and competence.

(e) To test whether *psychological needs thwarting* (factors) predicted *anxiety* (dependent variable), the independent variables used were autonomy, relatedness, and competence.

RESULTS

Normality Test

Most of the variables did not show a normal distribution (see **Table 1**); therefore, different statistical tests (parametric and non-parametric) were used for comparisons in further analyses.

TABLE 1 | Normality test results.

	Pre-season		Post-season	
Variables	**K-S**	***p*-value**	**K-S**	***p*-value**
Executive functions				
MoCA total	0.19	0.009	0.17	0.023
Stroop test hits	0.21	0.002	0.28	<0.001
Stroop test time	0.17	0.027	0.10	0.200
TMT-A time	0.25	<0.001	0.23	0.000
TMT-B time	0.20	0.003	0.25	0.000
Psychological need thwarting				
Autonomy	0.14	0.150	0.17	0.028
Relatedness	0.19	0.008	0.20	0.004
Competence	0.17	0.028	0.18	0.014
PNT total	0.10	0.200	0.16	0.062
Affective assessment				
GAD-7	0.17	0.029	0.14	0.129
BDI-II	0.21	0.002	0.18	0.015
Impulsivity				
BIS-11 total	0.11	0.200	0.13	0.184
Attention impulsiveness	0.11	0.200	0.10	0.200
Motor impulsiveness	0.12	0.200	0.11	0.200
Non-planning impulsiveness	0.10	0.200	0.10	0.200

Results of the test to evaluate normal distribution of the variables using Kolmogorov–Smirnov are shown for the pre- and post-season evaluation; n = 28. MoCA = Montreal Cognitive Assessment; TMT = Trail Making Test; PNT = Psychological Need Thwarting; GAD-7 = Generalized Anxiety Disorder-7 Scale; BDI-II = Beck Depression Inventory-II; BIS-11 = Barratt Impulsiveness Scale-11.

Pre–Post Comparisons

The purpose of these analyses was to evaluate the differences between pre- and post-season in the scores of cognition, impulsiveness, psychological needs, and affective symptoms in this group of athletes. For the analysis of variables with a non-normal distribution, results showed a significant difference in the percentage of correct answers in the Stroop test, where athletes showed higher scores in post- compared to pre-season, as well as a greater number of correct answers in the TMT-B in the post-season and longer time spent executing TMT-A and TMT-B in post-season. Total Psychological Need Thwarting and Relatedness decreased significantly in post-season (see **Table 2**).

Parametric analysis of normally distributed variables showed significant differences in main effects of Impulsiveness and Time and in Impulsiveness × Time interaction. Pairwise comparisons revealed that Motor Impulsiveness was greater than Unplanned Impulsiveness and Attention Impulsiveness. The Total Impulsiveness score increased in post- compared to pre-season. The *post hoc* analysis of Time × Impulsiveness interaction showed that, in pre-season, Motor Impulsiveness was greater than Attention Impulsiveness and Unplanned Impulsiveness; in the post-season evaluation, Motor Impulsiveness was greater than Unplanned Impulsiveness. Finally, Motor Impulsiveness and Attentional Impulsiveness increased in post-season (see **Table 3**).

Prediction and Association Between Variables

Pre-season

Pre-season linear regression analyses for the first step (a) showed that among the Executive Function variables, time of Stroop test significantly predicted Unplanned Impulsiveness; likewise, correct answers of TMT-A predicted Total and Motor Impulsiveness. In the fourth step (d), Psychological Need Thwarting of Autonomy predicted Depression. Finally, for the fifth step (e), the Autonomy factor of Psychological Need Thwarting predicted Anxiety (see **Table 4**).

In the second step (b), in addition to the predictability using Unplanned Impulsiveness, a significant correlation between Stroop test time and Total Impulsiveness was found. For the third step (c), no predictions were found but Total Impulsiveness and Unplanned Impulsiveness correlated with Autonomy (PNT-A). In the fourth step (d), the Competence factor of Psychological Need Thwarting correlated with Depression (see **Table 5**).

The second step (b) for pre-season showed no predictions or correlations between cognitive factors and Autonomy (PNT-A).

Post-season

Linear regression analyses for post-season showed results similar to those found in the pre-season analysis. Specifically, for the first step (a), TMT-B time predicted Total and Unplanned Impulsiveness, and in the fourth step (d), the Autonomy factor of Psychological Need Thwarting predicted Depression (see **Table 6**).

For the third step (c), no predictions were found but Motor Impulsiveness correlated with Autonomy. In the fourth step (d), the Competence factor of Psychological Need Thwarting correlated with Depression, and in the fifth step (e), a correlation between the Autonomy factor and Anxiety was found (see **Table 7**).

For the second step (b) of post-season, neither predictions nor correlations between cognitive factors and Autonomy (PNT-A) were found.

TABLE 2 | Comparison of pre- and post-season.

Variable	Pre-season Median (IQR)	Post-season Median (IQR)	Z	p-value	Effect Size (r)[x]
Executive functions					
MoCA total	27.00 (2.00)	26.00 (2.75)	−1.69	0.090	–
Test of stroop hits	98.80 (3.27)	99.40 (2.08)	−2.17	*0.029	0.41
Test of stroop Time	64.50 (14.50)	66.00 (14.75)	−0.02	0.980	–
TMT-A	24.00 (10.00)	31.00 (8.00)	−3.42	*0.002[a]	0.65
TMT-B	48.00 (34.00)	65.00 (26.00)	−2.41	*0.016[a]	0.45
Psychological needs thwarting					
Autonomy	9.50 (3.75)	8.50 (8.75)	−0.67	0.750[a]	–
Relatedness	9.50 (8.50)	7.50 (5.00)	−2.67	*0.021[a]	0.50
Competence	8.50 (5.00)	8.00 (9.00)	−0.01	0.987[a]	–
Affective assessment					
GAD-7	3.00 (5.00)	3.00 (4.75)	−0.85	0.391	–
BDI-II	5.00 (8.00)	6.50 (7.75)	−0.37	0.705	–
	Mean (SD)	**Mean (SD)**	**t(df)**	**p-value**	**Effect Size (Cohen's d)[x]**
PNT total	28.64 (9.35)	26.28 (12.69)	$t(27) = 1.331$	0.194	–

*IQR = interquartile range. [a]FDR correction was used to correct for multiple comparison in variables belonging to the same construct. [x]Effect size (r) is only reported when significant results were found. *significant results with $p < 0.05$.*

TABLE 3 | Two-way ANOVA (pre/post-season × impulsivity dimensions) results.

Main Effect	***F***	***Df***	***p***	η_p^2	ε	**Power estimate**
Impulsivity	6.98	1.7, 48.9	0.003	0.206	0.89	0.88
			Pairwise comparisons			
	Motor > attention		MD = 0.17		*p* = 0.009	
	Motor > non-planning		MD = 0.17		*p* = 0.002	
Time	17.97	1.00, 27.0	<0.001	0.400	1.00	0.98
			Pairwise comparisons			
Time 2 > Time 1			MD = 0.14		*p* = 0.000	
Interaction	***F***	***Df***	***p***	η_p^2	ε	**Power estimate**
Impulsivity × time	4.58	1.95, 52.8	0.015	0.145	0.978	0.74
			Pairwise comparisons			
	Motor time 1 > attention time 1		MD = 0.24		$p \leq 0.001$	
	Motor time 1 > non-planning Time 1		MD = 0.19		*p* = 0.024	
	Motor time 2 > non-planning Time 2		MD = 0.19		*p* = 0.010	
	Attention time 2 > attention time 1		MD = 0.26		$p \leq 0.001$	
	Motor time 2 > motor time 1		MD = 0.11		*p* = 0.023	

DISCUSSION

The present study had two objectives: on one hand, to compare and analyze the behavior of executive functioning, impulsiveness, psychological need thwarting, and indicators of psychological distress (depression and anxiety) before and after the season in a semi-professional college American football team as part of the sport-related psychological variations that occur throughout a training period, and, on the other hand, to provide evidence on how these components are associated to integrate sport performance.

In general, the results showed, as hypothesized, that the components evaluated varied throughout the sports season, as observed for executive functions, which improved in the post-season, with a significantly increased number of correct answers in the tests that measured inhibition (Stroop) and planning (TMT-A/B). It is well known that an increase in the level of physical activity is associated with improvements in physical health and cognitive functioning in populations either with or without psychological difficulties (Colcombe et al., 2004; Booth et al., 2013). In the last decades, numerous studies have examined the association between physical activity and cognitive functioning. Recent results indicated that physical activity not only improves general cognitive function but also improves performance in tasks that rely on executive functioning (Khan and Hillman, 2014; Tomporowski et al., 2015; Donnelly et al., 2016). The different dimensions of cognitive performance, such as processing speed, planning, and control strategies, and working memory, may also improve with physical exercise and regular physical activity (Romero et al., 2017). Likewise, this improvement in executive functioning in athletes who are considered experts, that is, with more experience in the sport that they practice, as occurs in the sample of the present study, can be understood and explained from the perspective of increased neuronal flexibility. These expert athletes carry out sensory, perceptual, and cognitive processes in a more efficient way, which may be reflected in their performance on the sports field. Spinelli et al. (2011) established the concept of neural flexibility to explain this phenomenon of sports excellence in expert athletes; e.g., a study in martial arts athletes found that expert athletes showed better performance in tasks that evaluated executive functions compared to novice and non-athletes (Sanchez-Lopez et al., 2014, 2016). Though the

TABLE 4 | Pre-season stepwise linear regressions.

Independent	**Dependent**	R^2	***F* (df1, df2)**	***P***	**β (*p*-value)**
Stroop time	Non-planning	0.152	4.670 (1, 26)	0.040	−0.39 (0.040)
Autonomy	Depression	0.243	8.363 (1, 26)	0.008	0.49 (0.008)
Autonomy	Anxiety	0.178	5.636 (1, 26)	0.025	0.42 (0.025)

TABLE 5 | Pre-season bivariate correlations.

Bivariate correlations	***r* (Pearson)**	***p*-value**
(a) Executive functions – impulsivity		
Stroop time – BIS-11	−0.362	0.029
Stroop time – non-planning	−0.390	0.020
(c) Impulsivity – autonomy		
BIS-11 – autonomy	0.341	0.038
Non-planning – autonomy	0.363	0.029
(d) PNT – depression		
Autonomy – BDI-II	0.493	0.004
Competence – BDI-II	0.356	0.032
(e) PNT – anxiety		
Autonomy – GAD-7	0.422	0.013

TABLE 6 | Post-season stepwise linear regressions.

Independent	Dependent	R^2	F (df1, df2)	p	β (p-value)
TMT-B	BIS-11 total	0.168	5.049 (1, 25)	0.034	0.41 (0.034)
TMT-B	Non-planning	0.358	13.940 (1, 25)	0.001	0.59 (0.001)
Autonomy	Depression	0.209	6.862 (1, 26)	0.015	0.45 (0.015)

TABLE 7 | Post-season bivariate correlations.

Bivariate correlations	r (Pearson)	p-value
(a) Executive functions – impulsivity		
TMT-B – BIS-11	0.410	0.017
TMT-B – non-planning	0.598	0.000
(c) Impulsivity – autonomy		
Motor impulsiveness – autonomy	0.328	0.044
(d) PNT – depression		
Autonomy – BDI-II	0.457	0.007
Competence – BDI-II	0.356	0.032
(e) PNT – anxiety		
Autonomy – GAD-7	0.370	0.026

mentioned study compared two groups cross-sectionally, its consideration, in order to explain the present results, may suggest that physical and technical–tactical training throughout the season favors improvements in cognitive functioning of athletes, perhaps as a process of greater general cognitive flexibility resultant from sport training or as part of a mechanism of greater and better adaptability to the demands of championship-driven sports tasks.

Increases in impulsiveness were found in the post-season evaluation, with motor and attentional impulsiveness showing higher scores. In a study conducted by Svebak and Kerr (1989), where impulsiveness played a role in the preference of sports type such as "explosive," "endurance," "paratelic," and "non-paratelic," the authors concluded that athletes involved in explosive and telic sports (search for excitement) types, where American football belongs, showed higher levels of total and unplanned impulsiveness (BIS-11). Although the results of Svebak and Kerr are in agreement with the high levels of impulsiveness found in American football athletes in the present study, their findings do not explain the variations of these scores in the post- compared to the pre-season. To our knowledge, there are no studies that analyze the variations of impulsiveness over time in an athlete population. We propose that the variations in impulsiveness throughout the season may result from increases in so-called functional impulsiveness, as reported in the study conducted by Hickmann in 2004 with NFL players where most players scored higher on functional, compared to dysfunctional, impulsiveness in the Functional/Dysfunctional Impulsiveness Inventory (FDI). In turn, these scores positively correlated with higher scores in BIS-11. In this same study, Hickmann found that players described as more impulsive also showed higher levels of sports success. From this point of view, in the present study, the athletes likely show a sort of increase in functional impulsiveness that enhances the availability of physical and psychological resources to efficiently solve the sports task.

Psychological need thwarting decreased significantly in the post-season; that is, lower thwarting perception was found in the second evaluation compared to the first. On one hand, some longitudinal studies that assessed BPN have found that the three psychological needs remained stable at moderate to high levels during competitive seasons (Adie et al., 2012). However, another study found that over a competition period, players' feelings of vitality increased as a result of overcoming the continuous challenges of competition; in other words, thwarting perception decreased. In this study, the decrease in thwarting of BPN may be attributed to the fact that it is an active process, in which the training style contributed throughout the season, and as the games were played, the feeling of affection toward and from the team increases, especially when winning. It is important to consider that the American football players recruited for this study have relentlessly been league champions for several years. This may increase their sense of belonging and group cohesion, which has a positive effect not only on the group but also on the individuals.

Regarding the association between the components evaluated, we found that executive functions predict impulsiveness in both evaluation times (pre- and post-season) with a different direction in the linear regression corresponding to pre-season, in which athletes showed greater planning performance (TMT-A correct answers) and inhibitory control (Stroop time), thus predicting better planning ability (less unplanned impulsiveness) and less impulsiveness (Total BIS-11); i.e., longer times spent by players in the Stroop test corresponded with better planning ability. On the other hand, in the post-season evaluation, results showed that if an athlete has better processing speed and cognitive flexibility (TMT-B) and greater cognitive control for response planning, BIS-11 Total/no planning may be predicted. Similarly, another study found that soccer players evaluated with the Barratt scale and the Tower of London obtained mean scores that, in turn, showed that longer planning time was associated with better problem solving (Culbertson and Zillmer, 2001).

On the other hand, executive functions failed to predict or correlate with autonomy thwarting. A publication by Ryan and Deci in 2006 describes the neurobiological basis of autonomy by explaining that autonomy requires the coordination among prefrontal cortical regions responsible for regulation, striatal–thalamic regions to promote or inhibit motivation, and inputs from the hippocampus and amygdala to provide contextual and affective information (e.g., Bradley, 2000; Chambers et al., 2003 cited by Ryan and Deci, 2006). Walton et al. (2004) stated that neuronal mechanisms operate depending on whether the medium informs us what to do or whether we act autonomously. Therefore, Walton et al. (2004) and Ryan and Deci (2006) suggest that executive functions must be both selective and fully informed by affective and memory-related processes to support and improve autonomy, which may be a reason why no correlation between these variables was found. Nevertheless, impulsiveness, as an important component of personality, mediated the association between executive functions and the BPN of autonomy. In this study, the pre-season results showed that if a player shows better inhibition (Stroop time) and planning (TMT-A correct answers), lower impulsiveness (BIS-11 Total) may be predicted, which, in turn, is associated with better perception of self-control (PNT-A), and in post-season, when players showed a higher processing speed and cognitive flexibility, greater capacity of cognitive control for response planning (BIS-11 Total/no planning) may be predicted, but if athletes tend to think before acting (BIS-11 Motor impulsiveness), an association with better perception of self-regulation (Autonomy) is found. Our results suggest the importance of impulsiveness as a mediator between executive functioning and the psychological need for autonomy for optimal performance in athletes.

In both evaluation times, the levels of need thwarting of autonomy (PNT-A) allowed the prediction of the affective state, that is, the increase or decrease of depression symptoms, which may also be related to anxiety symptoms. The latter supports the previous findings that associate psychological need thwarting with symptoms of physical and psychological discomfort (Mars et al., 2017).

From a theoretical point of view, this study highlights the importance of assessing emotions and analyzing their role in sports success. Negative emotions are not always bad for cognitive functions in sports.

CONCLUSION

In conclusion, our results showed the dynamics of sport-related psychological variables throughout the sport season in American football players. It is important to highlight the variations in cognitive functioning, impulsiveness, and BPN thwarting as a functional characteristic in the team at the end of the sports season, as well as the interaction between these variables for the improvement of sports performance. Our findings might be a useful tool for coaches to create selection profiles that support the prediction of sport success in the recruitment of sport talents. Further research is necessary to evaluate larger samples and other sport disciplines to increase the knowledge about the dynamics and association of sport-related psychological variables in sports performance.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

Ethical approval was not provided for this study on human participants because the study was presented to the team of coaches of the University, who in turn informed the authorities of the University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XO-J and YR-C contributed to the conception and design of the study. JS-L and YR-C organized the database and performed the statistical analysis. YR-C and JS-L wrote the first draft of the manuscript. YR-C, JS-L, XO-J, and JL-W wrote sections of the manuscript. All authors contributed to the manuscript revision, and read and approved the submitted version.

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Physical Activity, Sports Practice, and Cognitive Functioning: The Current Research Status

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The evidence for the benefits of physical activity on cognitive functioning has increased in recent years. Although the relationship between these variables has been analyzed for decades, the development of evaluation techniques has resolved several issues and advanced this area of knowledge. Moreover, several authors have pointed out the association between the cognitive functioning of athletes and their performance in competition. These recent studies suggest that some specific cognitive abilities of athletes could help them become more effective and improve their chances of success. The objective of this paper was to identify the most relevant advances in these areas of study and to highlight more promising lines of research for the next few years. We have discussed findings from the application of different physical activity programs as well as the most significant cognitive performance variables for sports practice. The limitations of the findings were also discussed.

Keywords: cognitive functioning, physical activity, physical-sports, brain, cognitive abilities

PHYSICAL ACTIVITY, SPORTS, AND THE BRAIN

The relationship between physical exercise and cognitive functioning has received much attention in recent years (Northey et al., 2018; Moran et al., 2019). This has been an object of interest for decades, but much remains unknown. Neuroscience has advanced significantly, improving knowledge of brain functioning in response to different situations and its evolution over the course of people's lives (Cabeza et al., 2018; Dumoulin et al., 2018). Scientists studying physical activity and sports have integrated this knowledge of brain functioning, using it to explain the contribution of physical exercise and how cognitive performance may increase performance in certain facets of sport (Fink et al., 2018; Hsu et al., 2018).

Techniques such as electroencephalography (Cheron et al., 2016; Gutmann et al., 2018), functional magnetic resonance imaging (Chaddock-Heyman et al., 2013; Fontes et al., 2015; Chen et al., 2016), positron emission tomography (Boecker and Drzezga, 2016), single photon emission tomography (Shih et al., 2019), or magnetoencephalography (Huang et al., 2016) have all improved the visualization and understanding of cognitive processes generated and developed in physical activity and sport contexts. The core of their contribution is the observation of brain changes during exercise, the impact of various tasks, and improvements in physical condition, which reflects this phenomenon (Becker et al., 2016; Jonasson et al., 2017; Schwarb et al., 2017).

In addition, research based on these techniques is complemented by other procedures developed in neurobiology and neurophysiology to explain changes in the brain that are attributable to physical exercise. Specifically, hypotheses such as neurogenesis, synaptogenesis, or angiogenesis and the action of biomolecules such as irisin, brain-derived neurotrophic factor (BDNF), insulin-like growth factor-1 (IGF-1), vascular endothelial growth factor (VEGF), cathepsin B or interleukin-6 (Tari et al., 2019) have been proposed. However, these theoretical foundations are still in the process of consolidation for humans. In addition, some of these hypotheses arouse controversy among researchers, such as neurogenesis in humans throughout the life cycle, though this should be resolved in the coming years (Sorrells et al., 2018; Lourenco et al., 2019; Pontifex et al., 2019; Voss et al., 2019).

In addition to an increased number of techniques available to assess the connection between physical exercise and brain functioning, other factors may have influenced the proliferation of this line of research. On the one hand, there have been warnings about increased sedentariness of lifestyles in some societies, prompting recommendations for physical activity to improve health among various sections of the population (Hynynen et al., 2016; Zylke and Bauchner, 2016). In this regard, it has been proposed that brain functioning would benefit from physical activity, allowing better development in childhood and adolescence or acting as a protector in aging processes (Erickson et al., 2015; Costigan et al., 2016). On the other hand, elite sport requires increased performance from athletes, thus encouraging the search for variables to improve the probability of success in competition. Cognitive functioning therefore has been an area of knowledge to which numerous researchers have aimed to contribute (Krenn et al., 2018; Sakamoto et al., 2018).

In professional sports, differences between athletes are sometimes very subtle. Although it is difficult to eliminate all uncertainty from their performance, technical staff and research groups have sought to analyze and identify variables influencing this outcome. Thus, it is unsurprising that there are innumerable studies of physical preparation, technical and tactical aspects, or psychological influences (Fister et al., 2018; Dalen et al., 2019; Henriksen et al., 2019). Among these studies, brain analysis has attracted intense attention in recent years, becoming a prolific field of study and application that will probably continue in future as technical resources are perfected.

PHYSICAL ACTIVITY AND COGNITIVE FUNCTIONING IN CHILDREN, ADOLESCENTS, AND THE ELDERLY

Childhood and Adolescence

Analysis of the benefits of physical activity on people is especially relevant in childhood and adolescence. These are stages when future lifestyles are established, and acquired habits have a very strong influence on the state of health throughout life. However, during childhood and adolescence the brain is under construction and requires appropriate learning processes. In addition, children and adolescents are in a phase when their personal and social development is conditioned by multiple changes, to which they must make efforts to adapt. Therefore, the possible benefits of the cerebral functioning that physical exercise could produce become essential elements for children's and adolescents' growth and integration into the environment (Wenner et al., 2013; Lubans et al., 2016). In fact, adequate cognitive development during early stages is thought to contribute to improvements in wellbeing and mental health in adulthood (Gale et al., 2012).

In recent years, multiple studies have highlighted significant associations between physical practice and abilities, such as attention and concentration, executive functions, cognitive functioning speed, memory, or language (e.g., Chaddock et al., 2011; Scudder et al., 2014; Donnelly et al., 2016; Li et al., 2017; Xue et al., 2019). Various investigations have analyzed the acute effects of physical exercise (Hillman et al., 2009b; Ellemberg and St-Louis-Deschênes, 2010; Chang et al., 2012a), the effects of a prolonged exercise program (Hillman et al., 2014; Reloba-Martínez et al., 2017), as well as correlations between cognitive functioning with people engaged in regular physical activity or physical fitness exercises (Hillman et al., 2005; Carson et al., 2016; Pérez-Lobato et al., 2016).

Numerous papers have studied the relationship between physical activity and cognitive functioning, highlighting the importance of physical fitness (Hillman et al., 2009a). That is, the effect of exercise on the brain is modulated by the overall impact of physical exertion on the body. Therefore, not only is physical exercise necessary, but it should have specific characteristics that improve study participants' physical condition (Hötting and Röder, 2013; Reloba-Martínez et al., 2017; Reigal et al., 2019a). Among the manifestations of physical fitness, aerobic capacity best explains the association between physical exercise and cognitive development in children and adolescents, as several authors have highlighted (Pontifex et al., 2011; Herting et al., 2014).

Studies using neuroimaging techniques to explore these relationships have linked structural changes in the brain to exercise and the physical condition of children and adolescents. Authors such as Chaddock et al. (2010) have observed a higher volume in the hippocampus and the striated dorsal body with higher levels of aerobic fitness in children. Furthermore, Chaddock-Heyman et al. (2018) found an increase in the white matter microstructure of the genu of the corpus callosum after a 9-month program of moderate and vigorous physical activity in children. Likewise, in a group of obese children, Esteban-Cornejo et al. (2017) observed a relationship between cardiorespiratory capacity and speed/agility with the volume of gray matter in frontal, temporal, and subcortical regions, such as the premotor and supplementary motor cortex, the hippocampus, the caudate nucleus, as well as the inferior, superior, and parahippocampal temporal rotation.

Elderly People

The relationship between physical exercise and brain functioning has also been analyzed with great intensity in elderly people. There is a decline in certain physical and cognitive capacities that compromise normal functioning and autonomy during this stage of life (Schiebener and Brand, 2017). In addition, events such as retirement, the appearance of age-related illnesses, or the reduction in social relationships due to the loss of loved ones may occur, leading to greater isolation. In recent years, a number of studies have suggested that physical exercise in elderly people has benefits for aspects of brain functioning, such as attention, memory, or executive functioning (Bherer et al., 2013; Kramer and Colcombe, 2018; Crespillo-Jurado et al., 2019). Regular moderate to vigorous physical exercise has been described as being protective against cognitive impairment and effective in maintaining adequate functioning in later life (Zhu et al., 2017). Therefore, promoting physical practice has become a potent strategy to improve elderly people's adaptation to the environment, maintaining, or improving their state of health and increasing their quality of life.

It has been observed that improvements in aspects such as aerobic capacity, balance, strength, or body composition would reduce the impact of aging on the deterioration of the brain, cushioning its effects and maintaining mental skills for longer periods of time (Chang et al., 2012b; Kerr et al., 2013; Wilczyński et al., 2017). As with other populations, cognitive functioning in elderly people is associated with their physical condition and changes in the structure of the brain support their functional development (Reiter et al., 2015; Fernandes et al., 2017). For example, Erickson et al. (2011) observed that increases in aerobic capacity may be associated with improvements in spatial memory as well as increased BDNF concentration and volume in the hippocampus. Boyle et al. (2015) found that elderly people who were more active and had a lower body mass index had greater brain volume in areas such as the frontal and occipital lobes, in specific areas such as the frontal orbital cortex or the anterior cingulate gyrus, and had less dilation of cerebral ventricles.

In recent years, analyses of the impact of physical activity on neurodegenerative processes have received great attention. Several studies suggest that physical activity may be beneficial in response to conditions such as Alzheimer's disease, both delaying its onset, mitigating its neuropathological effects, and improving brain functioning in patients (Phillips et al., 2015). Authors such as Lautenschlager et al. (2008) observed that, after a 24-week program of physical activity by elderly people, the rate of cognitive impairment in those at risk of dementia was reduced, suggesting that this type of intervention may inhibit the onset of the disease. It has also been observed that, in elderly people with a genetically increased risk of Alzheimer's disease, improvements in aspect so the physical conditions, such as cardiorespiratory capacity, may mitigate the risk of Alzheimer's disease (Tari et al., 2019). For this reason, it is considered that combined pharmacological treatments and more active lifestyles may be effective ways to counter this type of illness and other forms of dementia (Mortimer and Stern, 2019).

In addition, a large number of studies have indicated that physical activity may be useful in improving degenerative processes and symptoms in people with Parkinson's disease (Fernández-del-Olmo et al., 2018). In this population, it has been observed that the regular practice of physical activity throughout life could protect against the emergence of the disease, and that greater quantity and intensity have protective effects against Parkinson's disease (Paillard et al., 2015). Specifically, several authors have highlighted that aerobic exercise and cardiorespiratory capacity are positively related to brain processes, which again moderate the impact of Parkinson's disease (Ahlskog, 2018).

Limitations and Prospects for Future Research

Although many studies in recent years confirm the relationship between physical activity and cognitive functioning, there remains much to be understood. In addition, not all observed findings are supported by other studies, or they are based on small sample sizes with low statistical power. Thus, continued research is needed (Frederiksen et al., 2018). For greater precision in understanding the observed relationship between physical exercise and cognitive functioning and the possibilities for practical application, integration of knowledge from a range of scientific fields is recommended; these fields include sports science, neurobiology, neurophysiology, or neuropsychology as well as data from clinical and epidemiological studies. Furthermore, the transfer of findings from animal research to humans is required (Tari et al., 2019). According to recent research, there is some agreement on accepting the positive links observed between exercise and the brain, but the biological mechanisms underlying them require further examination (Fernández-del-Olmo et al., 2018).

Among the limitations of research to date is the heterogeneity of the studies and interventions, the lack of controls for strange variables, and small sample sizes. This has generated a collection of studies supporting the benefits of exercise on cognitive functioning, despite their moderate clinical value (Brasure et al., 2018). In addition, the exact amount and intensity of physical activity to meet individual needs has not yet been determined (Paillard et al., 2015). As an example, Frederiksen et al. (2018), studying a group of elderly Alzheimer's patients, concluded that a 16-week (60 min/3 days per week) aerobic exercise program had no positive impact on cortical gray matter atrophy. However, disease symptoms improved and there were positive correlations in the intervention group between frontal cortical volume, exercise load, measures of attention, and cognitive processing speed. Thus, the authors suggested that longer interventions and a larger sample could generate more convincing results. The challenge therefore remains to find the most appropriate formulas for each case and thereby determine the optimal exercise program.

An attempt has been made to explain the benefits of physical activity for the brain and its functioning in multiple populations, both healthy and with some pathology. However, presumably the requirements for each age or disease are specific, in addition to the differential impact on each person

(Phillips et al., 2015; Carson et al., 2016; Donnelly et al., 2016; Fernandes et al., 2017). For example, correlational or intervention studies in childhood and adolescence are conditioned by the natural development of these age groups and subject to various confounding factors, both intrapersonal and environmental, which impede the interpretation of the observed results (Chen et al., 2016; Chaddock-Heyman et al., 2018). Thus, one of the greatest challenges in coming years is to identify the appropriate load, intensity, volume, frequency, duration, and type of physical activity so that the effects on the development of the brain of the relevant population group will achieve the desired objectives. Therefore, extensive control of confounding variables is necessary to minimize their bias. This goal achieved, not only can physical exercise for health be recommended in general terms, but it can also be implemented in multiple specific educational and clinical programs to complement the actions recommended by other disciplines.

COGNITIVE FUNCTIONING AND HIGH-PERFORMANCE SPORTS

In the field of high-performance sports, the study of cognitive functioning has caught the attention of researchers. Vestberg et al. (2017) and Policastro et al. (2018) have shown that improved brain functioning in male and female athletes may enhance performance and predict success in competition. In general, it is assumed that this cognitive functioning may be more relevant in open sports requiring constant attention, management of multiple variables, or adaption to changing situations (Williams et al., 2011; Verburgh et al., 2014). Furthermore, good cognitive functioning may be a competitive advantage in disciplines with less variability but requiring high levels of concentration or attentional control (Memmert, 2009).

Studies have observed that better scores in executive functioning are related to greater expertise and success in football players (Verburgh et al., 2014; Huijgen et al., 2015). In turn, Roca et al. (2018) suggested that the creativity shown by adult football players in decision-making could be conditioned by their attentional capacity. In addition, Voss et al. (2010) pointed out that elite athletes tend to show better measures in aspects such as cognitive processing speed or various attentional tasks. Similarly, Wagner et al. (2014) concluded that cognitive aspects such as attentional capacity and executive functioning influence sports performance in handball. Moreover, Hänggi et al. (2015) pointed out that the brain structure can indicate the athlete's functioning, making brain plasticity an interesting predictor of player behavior on the playing field.

Recently, following these findings and the need to find variables to explain athletes' behaviors and success, the amount of research on how their brains work is increasing. Moreover, some researchers have attempted to train the athletes' brains with the objective of modifying the way athletes respond to stimuli during games and improve their decisions (Calmels et al., 2004; Seo et al., 2012). Some of these studies have sought to modify the capacity of the athletes' brains and have tried to improve their attention, processing speed, or different aspects of cognitive functioning in sports such as tennis, football, handball, basketball, badminton, rugby, or archery (Hagemann et al., 2006; Ducrocq et al., 2016; Romeas et al., 2016).

For cognitive assessment and training in sports, multiple strategies have been used, both classical paper and pencil or computerized tests (Memmert, 2009; Hernández-Mendo et al., 2012; Verburgh et al., 2014; Huijgen et al., 2015; Reigal et al., 2019b) as well as other more technologically advanced procedures (Memmert, 2009; Hernández-Mendo et al., 2012; Verburgh et al., 2014; Huijgen et al., 2015). In recent years, new electromechanical, digital, and combined devices have been developed, such as Fitlight Trainer^{TM}, Dynavision D2^{TM}, NeuroTracker^{TM}, eye-tracking in sports, Vision Trainer^{TM}, Senaptec Sensory Station, and Sports Vision Performance (M&S). Additionally, other products are based on technologies such as augmented or virtual reality. Overall, this new technology enabled notable progress in the assessment and cognitive preparation of athletes (Schack et al., 2014; Romeas et al., 2016; Appelbaum and Erickson, 2018). The rapid development of new technical measurement and training tools continuously increases the ecological validity of the measures by bringing the athlete's training experience closer to an authentic game context. Therefore, the technology development opens up a very promising path for this line of research by offering possibilities that were previously unexplored.

Limitations and Prospects for Future Research

Studies of the relationship between brain functioning and sports performance have evolved rapidly in recent decades following technological advances that have enabled the development of increasingly powerful instruments (Appelbaum and Erickson, 2018). This has created a series of opportunities for professionals as well as researchers to advance our understanding of the relationship between brain functioning and sports performance. Similarly, current limitations are likely to be reduced by the coming technologies. Among them are many laboratory-based procedures used to study how the brain works in sport contexts (Verburgh et al., 2014; Fink et al., 2018). This involves assessing the athletes' behavior in artificial situations, which limits the ecological validity of these procedures. Although possibly quite accurate inferences may be drawn, there are variables inherent in the competitive context that are currently difficult to reproduce.

Therefore, to increase the usefulness of cognitive assessments and training in performance sports, it will be necessary to improve the transference of laboratory knowledge to real-life contexts. The available technology allows experiences to approach reality, but such strategies are limited by technologies that are still very invasive and difficult to use on the playing field (Romeas et al., 2016; Appelbaum and Erickson, 2018). As technical evolution makes it possible to evaluate and train brain function in sports environments, it will help to determine more precisely the most appropriate way to stimulate the brain to optimize sports performance.

Similarly, cognitive assessments of athletes must be adjusted to the requirements of their specific tasks. In other words, the needs of a defender in football are not the same as those of a striker, nor are the needs of a basketball player the same as those of a tennis player. Therefore, another challenge to be addressed more clearly is finding the right type of training for each athlete considering his/her sporting characteristics and goals (Vestberg et al., 2017). In this way, the usefulness of this type of training, as well as the demand from athletes and technical coaches, will be increased. Much progress has been made in recent decades in areas such as physical or technical–tactical training. Nevertheless, a core question remains: how should the brain be trained to optimize sports performance so that it benefits physical and psychological health? Hopefully this question will be clearly answered in the future.

AUTHOR CONTRIBUTIONS

AH-M, RR, JL-W, SS, OS, VM-S, RJ-R, JT-R, and CF participated in the design of the work and the bibliographic review, drafted the manuscript, and approved the final manuscript as submitted. All authors made substantial contributions to the final manuscript.

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Teacher Autonomy Support in Physical Education Classes as a Predictor of Motivation and Concentration in Mexican Students

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There is a strong belief that physical education can affect an individual's physical activity, healthy habits, and behaviors through pleasant, positive, and significant exercise experiences, a practical knowledge base, and comprehensive teaching strategies. However, a crucial cognitive aspect for the effective and significant learning of the activities offered in the educational environment is the concentration of students. This study aims to test a hypothetical model based on self-determination theory to assess the degree of support prediction provided by the teacher for student autonomy in the various types of motivation and on student concentration in physical education classes in high schools within the Mexican context and test invariance across gender groups. This study included 859 students between 11 and 16 years from different high schools in the city of San Nicolás de los Garza, Nuevo León (México). The Learning Climate Questionnaire, the Perceived Locus of Causality, and the Concentration scale adapted to physical education and translated into Mexican Spanish were used. Results showed good internal consistency for all instruments. Both the measurement model and the structural equation modeling showed satisfactory adjustment indexes. The results revealed that the autonomy support positively predicted autonomous motivation, controlled motivation to a lesser extent, and amotivation negatively. Furthermore, the students' concentration was highly and positively predicted by autonomous motivation, by controlled motivation to a lesser extent, and by amotivation negatively. The model predicted 39% of variance of autonomous motivation with large effect size ($f^2 = 0.64$), 2% of controlled motivation with small effect size ($f^2 = 0.02$), 8% of amotivation with small effect size ($f^2 = 0.09$), and 49% of concentration with large effect size ($f^2 = 0.96$). Finally, the invariance analysis revealed that the model fit was invariant across gender groups. The results of this study emphasize how important it is for teachers to adopt an interpersonal style of autonomy support to generate a motivational climate that influences the concentration of students. This could contribute to the achievement of the purposes and educational objectives of the physical education class, which, in turn, might be conducive to students adopting healthy lifestyles in adolescence and beyond.

Keywords: self-determination theory, autonomy support, motivation, concentration, physical education, Mexico, invariance, gender

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INTRODUCTION

Physical education (PE) is regarded as one of the most viable vehicles to promote an active and healthy lifestyle, as it is able to reach a large number of children, adolescents, and youth (Pate et al., 1995; Sallis and Owen, 1999; McKenzie, 2001).

There is a strong belief that PE can affect an individual's leisure time physical activity through pleasant, positive, and significant exercise experiences, a practical knowledge base, and comprehensive teaching strategies (Vilhjalmsson and Thorlindsson, 1998; Fox and Harris, 2003). Moreover, in theory, it has been established that individuals who went through the stage of adolescence adopting healthy habits and behaviors in a successful manner are more likely to have a longer and healthier life (Williams et al., 2000). However, to promote engagement in physical activity among diverse individuals participating in PE classes successfully, the content offered therein must be learned in a significant manner.

Concentration is a crucial cognitive aspect for the effective and significant learning of the activities offered in the educational environment. According to the American Psychological Association (2009), concentration is the act of bringing together or focusing, as, for example, bringing one's thought processes to bear on a central problem or subject. It refers to the ability of drawing attention to a single object, and this skill may be difficult to acquire since the mind tends to shift focus every time a new stimulus is presented (Murray, 2002).

For some years, teachers and researchers have sought to maximize the time during which students focus on class activities for the purposes of optimizing learning (Berliner, 1990). Unfortunately, students do not always turn their attention to the contents of a class, as their interests, skills, and efforts differ from each other. Thus, it is interesting to understand the role of PE teachers in motivational processes and the impact they have on student concentration.

A theoretical approach that has contributed to understanding how these motivational processes occur in different contexts is the self-determination theory (SDT; Deci and Ryan, 1985, 2002; Ryan and Deci, 2017). This theory explains that motivation is multidimensional as individuals are generally motivated by a combination of diverse factors. It postulates that a person's behavior may be intrinsically or extrinsically motivated or amotivated. These three types of motivation vary in their level of self-determination (i.e., sense of freedom to do whatever you want to do). Moreover, these types can be placed on a continuum of self-determination where the behavior would fluctuate from high levels of autonomy (i.e., intrinsic motivation), going through the mid-levels (i.e., extrinsic motivation), and on to the lowest levels (i.e., amotivation; Deci and Ryan, 1985, 2002).

Intrinsic motivation is the most self-determined type of motivation. It involves behaving in a certain manner simply for the pleasure and satisfaction of doing so. This type of motivation is an important construct that reflects the natural human interest in learning and assimilating (Ryan and Deci, 2000a). It is characterized by a high level of autonomy, and it represents the prototype of self-determined behaviors (Ryan and Deci, 2000b).

Extrinsic motivation refers to performing an activity because of the incentives or consequences associated with it. The least self-determined regulation is the external one and involves the specific manner in which someone behaves to receive a reward or avoid punishment. Introjected regulation takes place when an activity is carried out to avoid blame or to boost the ego. Identified regulation is a bit more self-determined than the introjected regulation, as it is produced when the behavior is regarded as important for the subject's purposes. Finally, integrated regulation is the most self-determined type of extrinsic motivation, occurring when the result of the behavior is consistent with the individual's values and needs.

The use of these regulations has also been proposed, grouping them in a broader sense to form *autonomous motivation*, derived from combining intrinsic, integrated, and identified regulations, and *controlled motivation*, resulting from the combination of introjected and external regulations (Deci and Ryan, 2000).

The last self-determined dimension is amotivation, which is present when individuals fail to perceive the contingencies between actions and their results, that is, they do not perceive the basis of their reasons. Therefore, they doubt their actions, creating a feeling of incompetence, which will likely make them give up in the future (Pelletier et al., 1999).

Due to the aforementioned points, motivation is a well-known concept for all individuals taking on leading roles such as teachers, which involves mobilizing others to act (Deci and Ryan, 1985). In PE classes, the teacher's role is a key element that must be considered, given that students' willingness and motivation to gain knowledge, and the possibility of acting on this basis, may result in an involvement that leads to the successful pursuit of healthy lifestyles (Johnson et al., 2011).

Students need help shifting from their dependence on the teacher to their independence in class, developing the understanding, competence, and trust required to be active in an autonomous way. This is something that must be taught, rather than waiting for it to happen *per se* (Harris, 2000).

Within SDT, autonomy support from teachers represents acts or instructions to identify, encourage, and develop internal motivational resources such as their interests, preferences, goals, and psychological needs (Assor et al., 2002; Reeve, 2006). According to Deci and Ryan (1985), individuals will improve their learning quality if they are intrinsically motivated to learn. Similarly, the conditions or contexts that provide information and autonomy support foster student learning.

In the context of PE, different studies have examined the predictive role of autonomy support on the various types of motivation through diverse cultures. According to the results obtained in these studies, autonomy support predicts the most autonomous regulations (i.e., intrinsic and identified) in a positive manner. On the other hand, autonomy support predicts the least autonomous ones (i.e., introjected external regulations and amotivation) in a negative manner (Standage et al., 2005, 2006, 2012; Standage and Gillison, 2007; Zamarripa et al., 2016; Behzadnia et al., 2018; Fin et al., 2019).

However, studies that have examined the background on student concentration during PE classes are still limited. In England, Standage et al. (2005) conducted a study to examine the model of motivation as a mediator between autonomy and concentration, among other resultants based on the SDT; the participants included 950 high school students (boys = 443; girls = 490; M_{age} = 12.14). They used the Learning Climate Questionnaire (LCQ) by Williams and Deci (1996), which is composed of 15 items suited to the PE class to measure autonomy support. The Perceived Locus of Causality Scale (PLOC), designed by Goudas et al. (1994), was used to assess the motivational regulations, and six items were designed to evaluate the level at which students remain focused during class activities. The instrument's reliability analysis to measure autonomy support yielded a result of 0.96. As regards the sub-scales to measure the various motivation types, the alpha values ranged from 0.69 to 0.88. For the concentration scale, the alpha value was 0.84. The predictive character of autonomy support can be observed in its results, positively in meeting requirements (i.e., autonomy, relationships, and competence) and in intrinsic motivation. On the other hand, it showed negative results regarding external regulation and amotivation. Finally, a significant and positive connection between intrinsic motivation and concentration can be observed, as well as a significant and negative link between amotivation and concentration.

For their part, Zhang et al. (2012) examined the correlations among autonomy support, competence, beliefs associated with expectations, homework's subjective values, concentration, and persistence/effort in 273 high school students from the southeastern United States. Autonomy support was measured using six items from the Health Care Climate Questionnaire by Williams and Deci (1996), which obtained an alpha value of 0.91, whereas the concentration level during the class was measured using the six items developed in the study conducted by Standage et al. (2005), achieving an alpha value of 0.80. The results showed correlations between the PE teacher's autonomy support and concentration (r = 0.43, p < 0.05). Moreover, a hierarchical regression analysis was conducted, including expectancy and value constructs in the first stage, which accounted for 32.5% of concentration variance. Subsequently, when the constructs of teacher support—competence support and autonomy support—were included in the second stage, the variance percentage increased by 5.0%. These findings provide evidence with respect to the teacher's role in building motivational constructs (i.e., beliefs related to expectation and subjective values of homework) and predicting a student's concentration and effort.

In line with Ntoumanis and Standage (2009), physical ability, interest levels, and efforts invested by students in PE classes may be quite different depending on the subjects and cultures. Therefore, it is interesting to understand how the motivational processes are produced and the impact they have on student concentration.

This study aims to test a hypothetical model (see **Figure 1**) based on SDT (Deci and Ryan, 1985, 2002; Ryan and Deci, 2017) to assess the degree of support prediction provided by the teacher for student autonomy in the various types of motivation and on student concentration in PE classes in high schools within the Mexican context and test invariance across gender groups.

MATERIALS AND METHODS

Design and Type of Study

The present study is an empirical research of associative strategy with explicative aim (purpose), cross-sectional with latent variables (Ato et al., 2013).

Participants

This study involved students from 84 high schools that are part of the municipality of San Nicolás de los Garza, Nuevo León (México). The data were obtained through the Department of Public Education for the state of Nuevo León, corresponding to the 2012–2013 school year. The sample size was determined to obtain a sampling error of ±3% and a 95% confidence interval. This was a probabilistic, multi-phased cluster, and stratified sampling procedure with proportional allocation, considered by the various strata of grade, type of center, age, school shift, and sex.

The sample composed of 859 students (51% boys and 49% girls; M_{age} = 13.69 years old; SD = 0.98; range = 11–16) from different public (81.6%) and private (18.4%) high schools in the city of San Nicolás de los Garza, Nuevo León (México). In total, 35% of the students were in first grade, while 31.1% were in second grade and 33.9% in third grade. Most of them attended school during the morning shift (56.6%) compared to the evening (43.3%).

Instruments

A version of the LCQ, originally designed by Williams and Deci (1996), adapted to PE by Standage et al. (2005), translated into Mexican Spanish, and validated by Maldonado et al. (2017), was used. The questionnaire included 15 items that are grouped in a single factor to measure student perception on the autonomy support offered by the teacher. The instrument begins with the following title: "In this physical education class …." An example of an item is: "…we feel that the teacher gives us choices and opportunities." Students use a Likert scale to answer, ranging from 1 (completely disagree) to 7 (completely agree). The results of the reliability of the autonomy support scale adapted to PE (Standage et al., 2005) showed a suitable internal consistency (α = 0.85).

The PLOC (Goudas et al., 1994) was used to measure the different types of regulations, adapted to PE by Standage et al. (2005), and validated for the Mexican context by Zamarripa et al. (2016). The scale comprises 20 items, four for each of the five sub-scales: intrinsic motivation, identified regulation, introjected regulation, external regulation, and amotivation. Students answered the scale items preceded by the phrase: "I take part in this physical education class…." Some examples of this scale include: "because it is funny" (intrinsic motivation), "because it is important for me to do it correctly" (identified regulation), "because I will feel bad about myself if I do not do it" (introjected regulation), "because I will get into trouble if I do not do it" (external regulation), and "but I am really not sure why I do it" (amotivation). Students used a 7-point Likert scale to answer, ranging from 1 (completely disagree) to 7 (completely agree). To create the autonomous motivation variable, the items corresponding to intrinsic motivation and

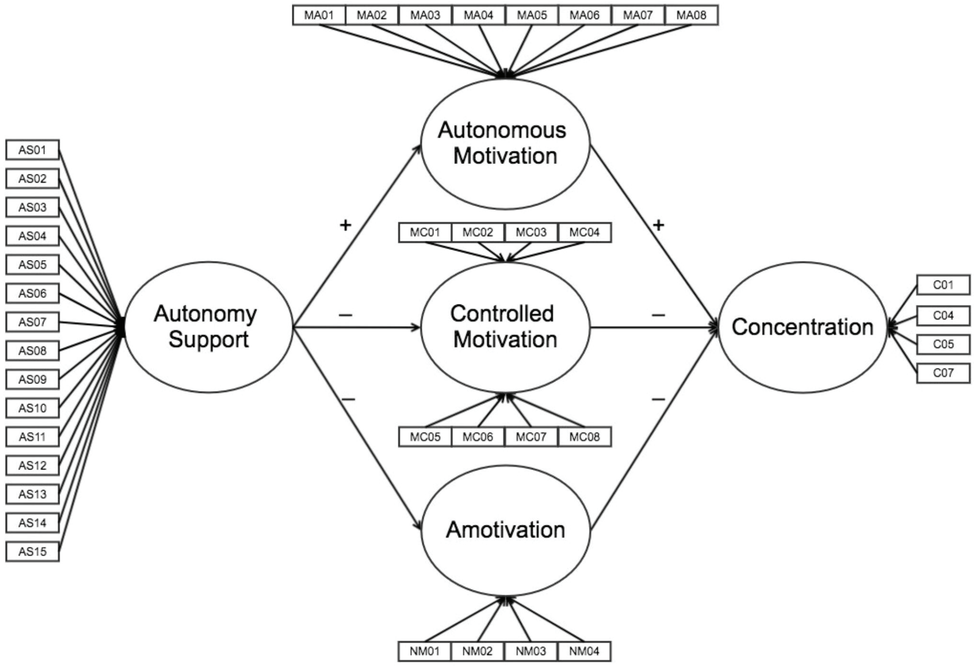

FIGURE 1 | Structural model hypothesized of the relationships between autonomy support, types of motivation, and concentration.

the identified regulation scale were combined. On the other hand, to form the controlled motivation, the items corresponding to introjected and external regulation scales were combined. The results of the reliability of the intrinsic motivation ($\alpha = 0.88$), identified regulation ($\alpha = 0.86$), introjected regulation ($\alpha = 0.69$), external regulation ($\alpha = 0.81$), and amotivation ($\alpha = 0.84$) adapted to PE (Standage et al., 2005) showed a suitable internal consistency. Likewise, the reliability of the autonomous motivation ($\alpha = 0.88$), controlled motivation ($\alpha = 0.86$), and amotivation ($\alpha = 0.84$) in the Mexican context (Zamarripa et al., 2016) showed a suitable internal consistency.

The concentration scale developed for PE by Standage et al. (2005) and validated for the Mexican context by Maldonado et al. (2014) was used to measure students' concentration levels. The questionnaire includes four items assessing the level at which students perceive their concentration during the PE class. These four items are grouped in a single factor to measure the students' concentration level. The instrument begins with the following title: "For the following items, please indicate the frequency with which you feel like this during your PE class." An example of an item is as follows: "I pay attention during the class." Students use a Likert scale to answer, ranging from 1 (Never) to 5 (Always). The results of the reliability of the concentration scale adapted to PE (Standage et al., 2005) showed a suitable internal consistency ($\alpha = 0.84$).

Procedure

Authorization was requested through official letters sent to school district authorities and to each educational center principal, explaining the research objectives and the procedure that would be carried out together with the instrument's model. This was followed by the request for authorization for implementation of the group teachers for the selected students, considering the main inclusion criteria: being regular students attending the corresponding grade, attending regular PE classes (at least twice a week), knowing or identifying their PE teacher, and being willing to complete the questionnaire. Students were informed of the study's aim, its voluntary nature, the absolute confidentiality of the responses, and the handling of data. Moreover, they were told that there were no correct or incorrect answers and that it was mandatory to provide truthful and honest answers. The questionnaire was answered in an anonymous fashion, self-administered, and implemented collectively in the classroom during school hours. To unify the data collection conditions, the survey-takers received preparatory training. All subjects gave their parents and guardians' written and informed consent in accordance with the Helsinki Declaration. This research was conducted in compliance with international ethical standards, which are consistent with the recommendations outlined by the APA. Ethical approval for the study was obtained from the Universidad Autónoma de Nuevo León (Mexico) ethics review committee (No. 16CI19039021).

Statistical Analysis

First, confirmatory factor analyses (CFA) were carried out in each instrument separately. A single-factor model (autonomy support) was tested for the Learning Climate Questionnaire adapted for physical education (LCQ-PE), whereas the PLOC tested a three-factor model (i.e., autonomous motivation, controlled motivation, and amotivation) and a single-factor model (i.e., concentration) was tested for concentration. Considering the number of response categories of the observable variables ($k \geq 5$) and the value range of skewness and kurtosis (from −1.77 to 0.95 and from −2.13 to 2.58, respectively), the maximum likelihood (ML) method was implemented, using a polychoric correlation matrix and asymptotic covariances as input (Finney and DiStefano, 2006). The fit of models was assessed through different adjustment indexes: the non-normed fit index (NNFI), which allows for the adjustment of the model's parsimony; the comparative fit index (CFI), which estimates the relative population decrease obtained; and the root mean square error of approximation (RMSEA). CFI and NNFI values above 0.90 indicate an acceptable adjustment (Hu and Bentler, 1995). Values ranging from 0.05 to 0.10 are considered acceptable for RMSEA, and values of 0.08 or lower are considered satisfactory (Cole and Maxwell, 1985).

Second, descriptive, normality, and reliability analyses of the scales were conducted using Cronbach's α, Composite Reliability (CR), and the Average Variance Extracted (AVE). Third, the hypothesized structural equation modeling (**Figure 1**) was tested, following the suggested step approximation by Anderson and Gerbing (1988). The first step consists of examining a measurement model to determine whether the indicators (i.e., the latent variable items) correlate with their factors in a satisfactory manner. It is vital for the measurement model to show satisfactory adjustment indexes to conduct the hypothesized structural equation model successfully. In the second step, the structural model is assessed, analyzing the general adjustment using the goodness-of-fit indexes. The maximum likelihood (ML) method was implemented, using a polychoric correlation matrix and asymptotic covariances as input, using the LISREL 8.80 program (Jöreskog and Sörbom, 2006). The effect size was calculated following the guide developed by Selya et al. (2012). Finally, the invariance of the proposed model across gender groups was tested using multi-sample invariance analysis. In order to test differences between models, a modeling rationale was considered. Differences not larger than 0.01 between NNFI and CFI values (ΔNNFI and ΔCFI) and differences not larger than 0.015 between RMSEA values (ΔRMSEA) are considered as an indication of negligible practical differences (Widaman, 1985; Cheung and Rensvold, 2002; Chen, 2007).

RESULTS

Confirmatory Factorial Analysis

The CFA results showed satisfactory goodness-of-fit indexes for the single-factor model of the LCQ-PE (SBχ^2 = 363.83; gl = 90; p < 0.001; NNFI = 0.985; CFI = 0.987; and RMSEA = 0.060), for the PLOC-PE three-factor model (SBχ^2 = 982.01; gl = 165; p < 0.001; NNFI = 0.964; CFI = 0.969; and RMSEA = 0.076), and for the concentration questionnaire's single-factor model (SBχ^2 = 13.23; gl = 2; p < 0.01; NNFI = 0.980; CFI = 0.993; and RMSEA = 0.080).

Descriptive Statistics, Normality Tests, Reliability Analyses, Convergent, and Discriminant Validity

The results of K-S with Lilliefors (1967) correction normality tests were significant for all variables excepted controlling motivation, which indicated non-normal distribution of data. However, the skewness and kurtosis values for all variables of study (see **Table 1**) and the items that compose them (the skewness values ranged from −1.77 to 0.95, and the kurtosis values ranged from −2.13 to 2.58) showed a moderately non-normal distribution (skew <2, kurtosis <7; Finney and DiStefano, 2006).

The reliability analyses showed good internal consistency for all instruments used in this study, which ranged from 0.92 to 0.79. The composite reliabilities for all instruments ranged from 0.84 to 0.94, which are considered satisfactory. In general, the AVEs for all instruments of this study were above the recommended threshold of 0.50, ranged from 0.57 to 0.73, except for the value of 0.49 for autonomous support and 0.44 for the controlled motivation dimension. These results support adequate convergent validity of the instruments.

Table 1 shows that students perceive high autonomy support from their teacher and that the activities in PE classes are mostly carried out with autonomous motivation, followed by moderate controlled motivation and low amotivation. Moreover, students show a high level of concentration during class.

Structural Equation Modeling

First, the measurement model was tested, considering autonomy support, autonomous motivation, controlled motivation, amotivation, and concentration in PE classes as latent variables. All of them have their items as indicators, previously mentioned in the section "Instruments." The model showed satisfactory goodness-of-fit indexes (SBχ^2 = 2376.42; gl = 692; p < 0.001; NNFI = 0.98; CFI = 0.98; and RMSEA = 0.05), thus confirming the diverging validity of the latent variables.

Later, the structural equation modeling proposed was tested (**Figure 1**). The goodness-of-fit indexes were satisfactory (SBχ^2 = 2575.45; gl = 696; p < 0.01; NNFI = 0.97; CFI = 0.98; and RMSEA = 0.06). The autonomy support's interpersonal style predicted positively the autonomous motivation, and this, in turn, predicted the concentration in PE classes in a positive manner. For its part, autonomy support also predicted the student's controlled motivation, although to a lesser degree, which was also the case between controlled motivation and student concentration. Finally, autonomy support negatively predicted the amotivation, which was also predicted the concentration in the class in a negative manner (see **Figure 2**).

Besides the direct effects mentioned in **Figure 2**, the model also showed the indirect effects of autonomy support on concentration (β = 0.45, p < 0.01) through different types of motivation. As a whole, the model predicted 39% of variance of autonomous motivation with large effect size (f^2 = 0.64), 2% of variance of controlled motivation with small effect size (f^2 = 0.02), 8% of variance of amotivation with small effect size (f^2 = 0.09), and 49% of variance of concentration with large effect size (f^2 = 0.96) according to Cohen's (1988) guidelines.

TABLE 1 | Descriptive statistics, alpha, test of normality, and correlations between autonomy support, motivational types, and concentration.

Study variables	*M*	SD	*S*	*K*	K-S *Z*	Range	α	1	2	3	4
1. Autonomy support	5.19	1.22	−0.92	0.30	3.37**	1–7	0.92	1			
2. Autonomous motivation	5.80	1.24	−1.57	2.26	5.06**	1–7	0.93	0.55**	1		
3. Controlled motivation	4.04	1.49	−0.12	−0.84	1.26	1–7	0.84	0.15**	0.23**	1	
4. Amotivation	2.68	1.79	0.87	−0.49	5.12**	1–7	0.87	−0.17**	−0.28**	0.38**	1
5. Concentration	3.99	0.76	−0.67	0.22	3.21**	1–5	0.79	0.42**	0.58**	0.17**	−0.22**

*M = mean; SD = standard deviation; S = skewness; K = kurtosis; K-S Z = Kolmogorov-Smirnov Z score with Lilliefors correction. *p < 0.05; **p < 0.01.*

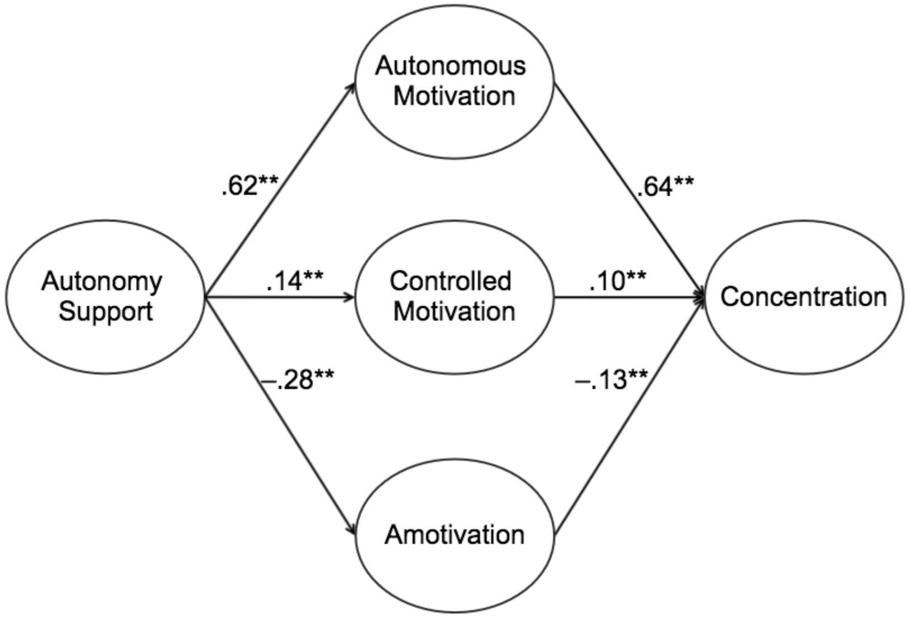

FIGURE 2 | Standardized solution of the relationships between autonomy support, types of motivation, and concentration. ***p* < 0.01.

Multi-sample Invariance Analysis

First, the model (**Figure 2**) was tested independently for boys (M0a) and girls (M0b) students (see **Table 2**). Then, a baseline multi-sample structural equation model testing for the structural invariance of the relationships among gender groups (M1) was run. Finally, a multi-sample total invariance model (M2) was run. In M2, the parameters of the structural model (i.e., those parameters that specify the relationships between the latent variables of the model) were constrained to be equal across gender groups.

As can be seen in **Table 2**, the fit indices for the boy (M0a) and girl (M0b) groups were closer to or better than the values suggested by Hu and Bentler (1995).

Regarding the model that tested the structural invariance (M1), the goodness-of-fit indices were satisfactory: $\chi^2(6) = 27.57$, $p < 0.01$; NNFI = 0.917; CFI = 0.975; and RMSEA = 0.092 (90% CI = 0.059–0.128). This indicates that the pattern of relationships among the variables in the study appeared to be invariant across male and female students.

Finally, the model that tests the total invariance (M2) also showed satisfactory goodness-of-fit indices $\chi^2(15) = 72.36$, $p < 0.01$; NNFI = 0.911; CFI = 0.933; and RMSEA = 0.095 (90% CI = 0.073–0.117). When comparing the baseline model (M1) with the total invariance model (M2), the incremental fit indices indicated negligible practical differences based on ΔNNFI and ΔRMSEA values. Additionally, the modification fit indices did not indicate any structural parameter that should be set free in order to improve the fit of M2 model. Then, we considered reasonable to conclude that the parameters of the structural model were equal across gender groups. Thus, the invariance of the proposed model across gender groups was supported.

DISCUSSION

This study aimed to test a hypothetical model (**Figure 1**), based on the SDT (Deci and Ryan, 1985, 2002; Ryan and Deci, 2017), to examine the level of prediction of the support provided by teachers to student autonomy on the various motivation types, and the latter on student concentration in PE classes in high schools in the Mexican context and test invariance across gender groups.

TABLE 2 | Results of the SEM multi-sample invariance analysis across gender.

Model	Model description	df	χ^2	RMSEA	90% CI	NNFI	CFI	ΔNNFI	ΔCFI	ΔRMSEA
M0a	Boys model	1	4.65*	0.092	0.022–0.182	0.885	0.989			
M0b	Girls model	1	2.56	0.061	0.000–0.158	0.972	0.997			
M1	Structural invariance (baseline model)	6	27.57**	0.092	0.059–0.128	0.917	0.975			
M2	Total invariance model	15	72.36**	0.095	0.073–0.117	0.911	0.933	0.006	0.042	0.003

*$p < 0.05$; **$p < 0.01$.*

The results of Kolmogorov-Smirnov tests indicate non-normal distribution of data, and this could be a limitation of our study; however, some authors have argued that with large sample sizes, the tests will be significant even if there are only mild deviations from normality (Ntoumanis, 2001, p. 52). Therefore, the analysis on the distribution of the data was complemented with the values of skewness and kurtosis. Unfortunately, there is no clear consensus regarding an "acceptable" degree of non-normality. Studies examining the impact of univariate normality on ML-based results suggest that problems may occur when the values of skewness are grater to 2 and univariate kurtosis are grater to 7, respectively (e.g., Chou and Bentler, 1995; Curran et al., 1996). In the present study, the skewness and kurtosis values for all observables variables showed a moderately non-normal distribution (skew <2, kurtosis <7; Finney and DiStefano, 2006); moreover, the number of response categories for all the variables was ≥5. For this reason, the maximum likelihood (ML) method was implemented, since it has been proven that if the observed data have many categories (e.g., at least five ordered categories) and are approximately normal, use of ML estimation techniques does not result in severe levels of bias in fit indices, parameter estimates, or standard errors. Problems begin to emerge as the number of response options decreases or the observed item distributions diverge widely from a normal distribution (Finney and DiStefano, 2006).

The results of the structural equation model showed that when teachers develop activities that facilitate autonomy support, that is, when they allow students to ask for things in their interest during class and even give their opinions and make decisions, where appropriate, it results in a positive relation with autonomous motivation. This, at the same time, allows the autonomous motivation to cause positive effects such as concentration during class. This result is consistent with the results obtained for other populations, such as British (Standage et al., 2005) and American (Zhang et al., 2012). A positive relationship between autonomy support and autonomous motivation was observed in both studies. At the same time, they were found to be positively associated with student concentration. Similarly, the predictive effect of autonomy support as social context in PE classes was also reviewed by Standage et al. (2006). This study focused on the satisfaction of needs and self-determined behaviors, including an assessment by teachers regarding the behavior of each student in their class. The results also showed positive relationships, consistent with the findings in the Mexican context, where this model has been developed.

In our study, contrary to what had been expected in the hypothetical model, autonomy support turned out to have a positive association with controlled motivation that, in turn, is positively associated with student concentration. Although the strength of the association was extremely low, it achieved significant levels. These results are consistent with those presented by Black and Deci (2000) and Standage et al. (2005), who state that the highest level of student concentration in class activities occurs when teachers design activities for students to perceive autonomy. They also state the support provided by teachers to student autonomy who may not reduce external pressures experienced by students to conduct activities in the academic field (e.g., guilt, obligation, and punishment).

In our study, autonomy support was negatively associated with amotivation, which was negatively associated with concentration. This suggests that when teachers provide autonomy support, that is, when students ask about things of their interest during class, give their opinions, and make decisions, the lack of intent to participate and the incompetence perceived decrease. In other words, amotivation is avoided, which in turn increases student concentration. Similar results have been found in the literature (Standage et al., 2005), even at low levels of amotivation, in line with this study.

In general, the goodness-of-fit indexes obtained from the structural equation modeling show a satisfactory adjustment of data to the hypothetical model. The results support the hypothesis that claims that the autonomy support style predicts autonomous motivation and amotivation in a positive and negative manner, respectively. The latter is widely supported and documented in various studies (Standage et al., 2005, 2006, 2012; Standage and Gillison, 2007; Zamarripa et al., 2016; Behzadnia et al., 2018; Fin et al., 2019). For their part, autonomous motivation and amotivation predicted concentration in a positive and negative manner, respectively. Although this variable has not been widely studied in the PE context, our results are consistent with the limited literature that exists (Standage et al., 2005).

Finally, the invariance analysis revealed that the model fit was invariant across gender groups. These results are consistent with those presented by Standage et al. (2005) and support the self-determination theory hypothesis that claims that the need for autonomy be equally important for males and females across cultural (Deci and Ryan, 1985, 2002; Ryan and Deci, 2017).

CONCLUSIONS

In conclusion, presently, the content of the PE subject for Mexican basic education is being extensively discussed. The results of this study highlight the importance of knowing and adopting the autonomy support style through teacher training and education, which would facilitate the creation of learning environments that promote autonomous motivation and concentration to learn PE content, as well as avoiding amotivation, in other words, the loss of interest and motivation in class.

The main limitations of this study focus mainly on the sample's specific characteristics as it involves high school students and is a cross-sectional study. Nevertheless, these limitations suggest possible directions for future research, as it would be interesting to extend the study with elementary school students and conduct a longitudinal collection of data to strengthen conclusions on the prediction relationships of variables included in this study.

Furthermore, the practical implications of this work focus on the design of training and education programs that guide physical educators to plan, structure, and develop classes using an autonomy support style for students to participate in class activities through the most autonomous regulations. This will ensure that students achieve positive experiences, leading to their genuine interest in and focus on learning the content of PE classes, and adopt healthy lifestyles outside the school.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical approval for the study was obtained from the Universidad Autónoma de Nuevo León (Mexico) ethics review committee (No. 16CI19039021). Written informed consent was obtained from the parents of all participants.

AUTHOR CONTRIBUTIONS

JZ, EM, and FR-J conceived the hypothesis of this study. EM and RP participated in data collection. JZ and MD analyzed the data. All authors contributed to data interpretation of statistical analysis. JZ and EM wrote the paper with significant input from JZ. All authors read and approved the final manuscript.

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The Effects of a Multidimensional Exercise Program on Health Behavior and Biopsychological Factors in Mexican Older Adults

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Background: The population of older adults is increasing worldwide, which brings attention to the importance of healthy aging. Adoption of healthy lifestyle activities such as participating in physical activity on a daily basis is key to maintaining physical and mental health. The aim of this study was to investigate the effects of participation in a 12-week multidimensional exercise program on health behavior and biopsychological factors of older adults living in Northeastern Mexico.

Methods: A quasi-experimental study was conducted with 45 older adults (35 females and 10 males; $M = 67.24 \pm 5.73$ years). The participants were assigned to an experimental group (EG; $n = 23$) that participated in a 12-week exercise program and a control group (CG; $n = 22$). Pre- and post-analyses of the exercise intervention data were carried out to investigate the participants' health-related variables including physical activity levels, blood pressure, self-esteem, depressive symptoms, and blood lipids profiles.

Results: The results indicated that the exercise intervention contributed to significant improvements in the older adults' health-related variables for the EG when contrasted with the control group. For instance, the EG significantly improved systolic ($p < 0.001$) and diastolic ($p < 0.027$) blood pressure, blood lipids [e.g., cholesterol ($p < 0.05$)], triglycerides ($p < 0.05$), self-esteem ($p < 0.005$), and depressive symptoms ($p < 0.002$) as well as physical activity ($p < 0.001$) levels. The results also demonstrated that only those individuals in the EG diagnosed with disease benefited from improved self-esteem and physical activity levels when contrasted with their healthy counterparts.

Keywords: older adults, multidimensional exercise programs, healthy aging, physical and psychological well-being, depression

INTRODUCTION

As the global population of older adults continues to increase, activities such as participation in physical activity have been found to be essential to promote healthy aging and quality of life. In fact, a lack of physical activity may result in severe health and social problems (World Health Organization, 2010). Health problems may include suffering from chronic diseases (Dunlop et al., 2015; Mama et al., 2015) or depression, which can increase morbidity and mortality (Voinov et al., 2013). Social problems may include concerns about raising social and economic costs due to increases in medical expenses for older adults with health problems (Unsar and Sut, 2010) and/or development of negative stereotypes toward the older population in society (Lamont et al., 2015). These health and social impacts may result in older populations' negative self-perception and low self-esteem that may cause loss of function and decreases in the quality of life (Unsar and Sut, 2010).

Although physical activity participation has been found to be a critical option to achieve healthy aging, the level of physical activity among older adults, in general, is low (McPhee et al., 2016). In Mexico, only 12.2% of older adults engage in a recommended amount of physical activity (Ramos, 2016). Such a low level of physical activity can be correlated easily with physical and psychological health issues for this age group. Specifically, a lack of physical activity tends to increase risk of cardiovascular diseases, cancer, and metabolic syndrome (Murrock and Graor, 2014; Pérez, 2014; McPhee et al., 2016). For psychological issues, approximately 30% of older adults who live independently suffer from depression (Murrock and Graor, 2014). It should be noted that physical and psychological health are interrelated and affect one another. As one example, being diagnosed with depression can be associated with decline in physical health such as chronic diseases (Bordon, 2012), loss of function (Unsar and Sut, 2010), and disability (Wight et al., 2011).

Since physical and psychological well-being play a significant role in maintaining and improving older adults' health, integrating multidimensional factors into a health promotion program offers a clear path to improving and protecting the health and general well-being of older adults. In particular, including holistic approaches in an exercise program can improve opportunities for older adults to initiate and continue exercise compared with programs that do not consider biological (age, sex, and others); social (such as ethnicity, and socioeconomic status); psychological well-being, social support, motivational readiness, self-efficacy, and others factors (Pender et al., 2011; Mama et al., 2015, 2017). Research has found that it is important that an exercise program places emphasis on satisfying interpersonal, organizational, and environmental factors (Glanz and Bishop, 2010; De Silva et al., 2014) such as promoting enjoyment and interaction among exercise participants while increasing accessibility and safety at exercise facilities (Sowle et al., 2017).

Integrating multidimensional factors (e.g., biopsychosocial factors) into health promotion programs helps participants successfully enhance health-related behavior (e.g., participating in exercise; Pender et al., 2011; Mama et al., 2017). Theories and models focusing on such integrative approaches have been established and utilized to design, implement, and evaluate health promotion programs (Lippke and Ziegelmann, 2008; Bartholomew et al., 2011). As one example, the Health Promotion Model (HPM; Pender et al., 2011) claims that each individual tries to regulate his or her own behavior based on his or her characteristics, experiences, and behavior-specific knowledge and affect. Health-promoting behavior – which is considered the desired behavioral outcome and the end point in this model – should contribute to obtaining health benefits such as improved health, enhanced functional ability, and better quality of life. The HPM considers compliance with multidimensional factors such as age, gender, physical abilities, perceived competence or self-efficacy are crucial for people who register a change in behavior that promotes health, such as participating in the exercise activities.

In another model established by Bouchard et al. (1994), physical activity levels play a significant role in health-related fitness (e.g., cardiorespiratory level, muscular strength) and the overall health status. Other variables that would affect these factors include the individuals' heredity and lifestyle (e.g., diet patterns, smoking) and physical and social environments. For example, sociocultural and economic factors could influence an individuals' participation in physical activity, thus affecting their fitness and health status. As noted previously, there is strong evidence that regular participation in physical activity is beneficial for physical and psychological health, including factors such as improvements in hypertension, type 2 diabetes mellitus, depression, and anxiety (Shephard, 1995; Carek et al., 2011; Gil et al., 2017; Alomoto et al., 2018; Solórzano and Vargas, 2019).

Sometimes the programs that reach citizens are far from having the required planning and structuring, or they are not supported by clear scientific support. In relation to this point, the differences and benefits between the "Structured-Unstructured" programs are that the former can be based and evaluated from theories or theoretical models that emphasize the adequacy of facilitating environments to enhance the adherence of the people to an active lifestyle and explain the processes that mediate or condition the causal relationship between the program and the desired results (Frieden, 2010; Glanz and Bishop, 2010; Bartholomew et al., 2011). Although the aging of the population occurs worldwide, the difference between countries lies in the planning and preparation to face this change. It is here that the implementation of specific physical activity programs for older adults becomes essential to improve current health conditions (Riekert et al., 2013).

Based on the information previously mentioned, the aim of this study was to investigate the effects of the participation in a 12-week multidimensional exercise program on health

Abbreviations: HPM, Health promotion model; BMI, Body mass index; SBP, Systolic blood pressure; DBP, Diastolic blood pressure; GDS-15, Geriatric depression scale 15 items; RSES, Rosenberg self-esteem scale; SEL, Socioeconomic level; AMAI, Mexican Association of Marketing and Opinion Intelligence Agencies; CAFAM, Physical activity questionnaire for the elderly adult; METs, Metabolic equivalents.

behavior considering as the physical activity levels and the biological factors of blood profiles (glucose, glycosylated hemoglobin, cholesterol, triglycerides, high-density lipoproteins, low-density lipoproteins, and very low-density lipoproteins), body weight, body mass index, blood pressure, and nutritional status; psychological factors of depression and self-esteem; and the social factors of sociodemographic characteristics and socioeconomic level of older adults living in northeastern Mexico. We considered, for the design of the exercise program, the healthy fitness factors mentioned in the model of Bouchard et al. (1994) and social factors of HPM. To evaluate its effectiveness, the biological and psychological personal factors as the health promoting behavior of the HPM were considered (HPM: Pender et al., 2011).

MATERIALS AND METHODS

Sample and Inclusion/Exclusion/ Elimination Criteria

A convenience sampling was utilized based on accessibility to a sports and recreation center in the state of Sonora that is part of the facilities of Public Health Institution of Mexico. Seventy older adults who lived independently in the urban community were registered for geriatric care programs (e.g., crafts, embroidery, dance, and recreational activities) provided by the center. The STATS 2.0 software was used to estimate an appropriate sample size considering the following factors: 95% confidence interval, 5% error and 10% losses to follow-up.

Initial interviews were conducted with 50 older adults to examine if these individuals met the following inclusion criteria: able to walk 2.44 meters independently, receipt of permission from their primary doctors, and assessment for exclusionary risk factors. In order to check the participants' risk factors, the research team utilized two approaches: collecting general information about the participants such as demographics (e.g., age, education level), brief history of disease, and use of medicine; and the completion of a more detailed health history and current health issues using the AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire. All 50 older adults met the criteria and were invited to participate in the study and received details of the study protocol. Forty-five older adults (35 females and 10 males; $M = 67.24 \pm 5.73$) ended up accepting the invitation, signed a written informed consent, and passed medical evaluation conducted by medical doctors prior to the study. The participants included healthy individuals and those who were under medical supervision or needed treatment for the following health conditions: hypertension, type 2 diabetes mellitus, and obesity. Participants were excluded if they had cognitive impairment, had physical limitations such as pain or discomfort in the chest by increasing the level of physical exercise, angina pectoris, those who had a cardiac implant, suffered complications that affect the musculoskeletal system, had chronic diseases different from those indicated in the inclusion criteria or chronic diseases indicated in the inclusion criteria but without medical control. Older adults were eliminated from the study if they decided to leave the study and if they did not comply with 80% attendance at the exercise program. In relation to the criteria considered for the study, nine people were excluded because they had diseases other than those indicated in the inclusion criteria.

Study Design

A quasi-experimental design was employed for this study where all of 45 participants were assigned to either experimental or control group based on activities they had engaged in at the center prior to participating in this study. As a result, 23 individuals who were enrolled in physical activity sessions offered by the center before the study were assigned to the experimental group (EG) and 22 individuals who were registered in embroidery, weaving, and handicraft activities offered by the institution were assigned to the control group (CG). The participants selected for both groups met the inclusion criteria and agreed to be part of the study. To control the effect of the program, as part of the informed consent, the GE agreed not to participate in other types of programs or physical activity other than the activities they already performed regularly and the GC agreed to continue performing the activities of the center in which they were registered; the data was confirmed at the beginning, after two months and at the end of the program through open questions stipulated in the sociodemographic survey.

The research considered the criteria for carrying out human research projects established by the Official Mexican Standard NOM-012-SSA3-2012 (Diario Oficial de la Federación [DOF], 2013) and was approved by the Comité Institucional de Bioética (Institutional Committee of Bioethics) of the Instituto Técnico de Sonora, México (Technical Institute of Sonora Mexico).

Exercise Program Intervention

Prior to the implementation of the program, researchers designed the sessions corresponding to each module according to the recommendations for the prescription of physical activity in older adults with and without chronic disease of the experts (American College of Sports Medicine, 2013; World Health Organization, 2015), previous research (Jiménez, 2007; García, 2013; Keller et al., 2014; Loprinzi et al., 2015; Mama et al., 2015), and the theoretical background mentioned in the introduction (Bouchard et al., 1994; Pender et al., 2011). Subsequently, the sessions were modified according to the physical characteristics of the participants detected in the evaluation carried out with the Senior Fitness Test Battery (Rikli and Jones, 2001). In addition, some interpersonal factors of the participants were considered in the design of the program, including team activities and promoting communication between instructors.

Some sociocultural factors of the participants in the choice of a specific type of music that was popular in the region and culturally popular team activities such as cachibol are also considered. The popular music of the region was used to stimulate movement and accompany the exercise (Clark et al., 2016), in addition to using it to regulate the intensity of physiological arousal (Karageorghis and Priest, 2012), promote participation, enjoy exercise (Murrock and Higgins, 2009), and increase physical activity levels (Altenmüller and Schlaug, 2013).

The work team responsible for data collection and implementation of the exercise program is described below: undergraduate and master's students in physical activity and sport, who are responsible for collecting health behavior data, imparting the sessions, and monitoring participants during them through the observation and Borg rating of perceived effort (RPE; Borg, 1982); undergraduate students in nutrition responsible for assessing nutritional status; a nurse in charge of the evaluation of blood pressure, the psychological and social factor; and a chemist in charge of taking blood tests.

The primary goal of the multidimensional exercise program was to help the participants improve aerobic capacity while aiming to assist them in improving muscular strength, speed, agility, flexibility, and coordination. Cognitive function activities also were included at least twice a week with aims to improve their memory, through group dynamics with cognitive stimulation activities. The exercise class was offered 5 days a week for 12 weeks with a total of 60 sessions. Each session lasted for 60 min, including a 10-min warm-up, a variety of exercises for 40 min, and cool-down for 10 min. The 12-weeks exercise sessions were divided in to six modules identified with letters according to the increase in the intensity of the exercise for every 2 weeks (Porter et al., 2011). In each module, a goal was established, and the exercises developed in it focused mainly on achieving it (**Supplementary Table S1**).

During the implementation of the program, the sessions were monitored by the researchers, responsible for evaluating the development of the program through observation and a checklist of the duration of the sessions, the time of each part of the session, the intensity, the music, material and explanation of the exercises by the instructors according to schedule. The exercise protocols and intensity were changed if instructors confirmed participants' progress through observation and/or communication. In each session, three to four exercise instructors took care of 23 participants where they took turns leading exercise instruction while other instructors observed the participants to provide feedback or make corrections whenever necessary. The instructors constantly monitored the participants' perception of exercise intensity by RPE four times and inquiring about their physical conditions during a 60-min class. In each session, a variety of exercise modalities were used such as dancing, team activities (e.g., throwing or kicking a ball as a team), and resistance (like light walk, rhythmic activities, and ball game) and circuit training [e.g., upper train strengthening exercises (biceps, triceps, shoulder, back, pectorals, and abdomen) and lower (thigh and leg), **Figure 1**]. The main materials used for cognitive stimulation exercises were ribbons of different colors, scarves, hats and balloons.

Measures

After the initial health screening was conducted, the research team carried out measurements including anthropometry, nutritional status, blood profiles, depressive symptoms, self-esteem, and physical activity levels as well as surveys for sociodemographic and socioeconomic levels. Pre- and post-intervention assessments were carried out to both groups 1 week before the beginning of the exercise program (pre) and 1 week after the conclusion (post) as follows: a blood test was provided on the first day while anthropometric psychological and socioeconomic measurements and the blood pressure and physical activity assessments were conducted on the second day. The following section includes detailed descriptions of these measurements and surveys.

Anthropometry

A Seca 634 scale and a Seca 274 stadiometer (Seca Mexico, Mexico City) were utilized to measure body weight and height, respectively. BMI was calculated by dividing body weight by height squared (BMI = kg/m^2).

Nutritional Status

The Mini Nutritional Assessment (MNA) was used to identify the nutritional status of the older adults. The MNA is composed of 18 questions in two parts: the screening and the assessment sections. The overall score resulting from the sum of the two parts reveals nutrition status (Nestle Nutrition Institute, 2016a): normal nutrition status from 24 to 30 points, risk of malnutrition from 17 to 23.5 points, and malnutrition with less than 17 points. MNA has been shown to have a sensitivity of 96%, a specificity of 98%, and a positive predictive value of 97% compared to clinical status (Nestle Nutrition Institute, 2016b).

Blood Profiles

A fasting blood test was conducted at the sports and recreation center to measure blood glucose levels and lipid profiles including total cholesterol, high-density lipoprotein (HDL), low-density lipoprotein (LDL), very low-density lipoprotein (VLDL), triglycerides, atherogenic index of plasma, and glycosylated hemoglobin (HbA1c). The blood sample was extracted through the Vacutainer system and later analyzed with the Analyzer of Differentiated Chemistry, Automated, Vital Scientific, Vitalab Selectra 2® through the wet chemistry method.

Blood Pressure

A Riester nova-presameter® mercury sphygmomanometer (Rudolf Riester GmbH, Jungingen, Germany) was used to measure blood pressure while following the protocol described in the Official Mexican Standard, NOM-030-SSA2-1999 (Secretaría de Salud, 2000).

Depressive Symptoms

The 15-item Geriatric Depression Scale (GDS-15) was used to assess if the older adults had depressive symptoms (Salguero et al., 2011; Raudsepp and Riso, 2017). This scale is composed of 15 items that require a yes or no answer and scores 0 or 1 point for each question. The total scores from 0 to 4 are considered

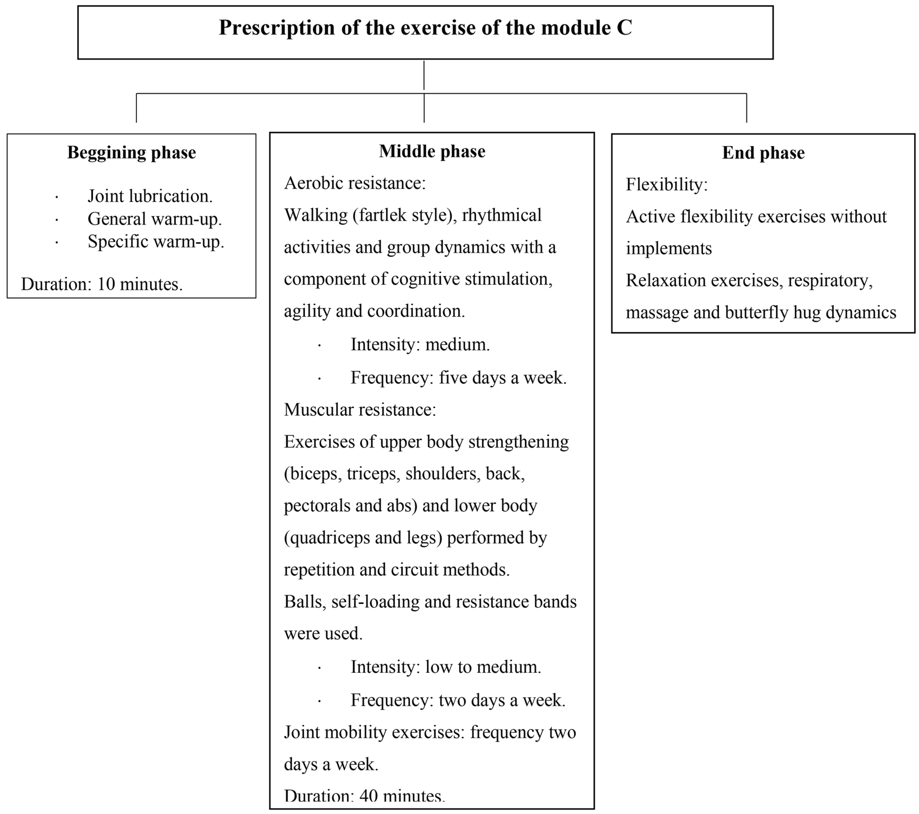

FIGURE 1 | Example of prescription of exercise protocols in one of the modules of the exercise program.

normal, and 5 or more points are considered the presence of depression. The GDS-15 has a sensitivity of 92% and a specificity of 81% in the detection of major depression (Yesavage et al., 1982).

Self-Esteem

The Rosenberg Self-Esteem Scale (RSES: Rosenberg, 1965) was used to evaluate general self-esteem. This 10-item scale is considered uni-dimensional by measuring positive and negative feelings about the self, using a 4-point Likert scale that ranges from strongly agree to strongly disagree. This scale has been used to measure self-esteem in diverse populations (Zabala et al., 2016), validated in several languages including Spanish with a Cronbach's alpha between 0.80 and 0.85 (Martín-Albo et al., 2007), and culturally adapted to the Latin context (Schmitt and Allik, 2005; Rojas-Barahona et al., 2009).

Physical Activity Level

The physical activity questionnaire for the older adult (CAFAM) was used to assess the participants' physical activity level achieved at home, through participation in sport or exercise, and during free time. The questionnaire shows a reliability of 0.89 determined by the test-retest method in the older population of both genders with ages between 63 and 80 years (Voorrips et al., 1991). The participants' physical activity level was classified using Metabolic Equivalent (METs) as follows: high >16.5 METs, moderate from 9.4 to 16.5 METs, and low <9.4 METs (Kalapotharakos et al., 2004).

Sociodemographic Survey

A survey was used to collect each participant's personal data and medical history: name, sex, age, marital status, education, illnesses, medications, and affiliation to health services.

Socioeconomic Level

The socioeconomic level (SEL) index proposed by the Mexican Association of Marketing and Opinion Intelligence Agencies (AMAI) was used to identify the participants' socioeconomic level by assessing their ability to satisfy their needs such as habitation, utility, technology, and education.

Analysis

Data were analyzed using Statistica 8.0 software. Descriptive statistics were applied using central tendency and dispersion measures; the Shapiro-Wilk test was used to identify the distribution of the variables. An inferential analysis was carried out with Student's t-test for independent samples and a paired t-test for dependent samples, only for data with normal distribution. For non-normal data distributions, nonparametric statistics were used: the Mann-Whitney U test for independent samples and the Wilcoxon signed-rank test for dependent samples. After the inferential analysis, an analysis was carried out to evaluate the magnitude of the change produced after the intervention with Cohen's *d* in variables with normal distribution, considering a small effect (0.20), a medium effect (0.50), a large effect (0.80), and a very large effect (>0.80) size. The effect size analysis was complemented, with a regression analysis to see the strength of the relationship between the variables *y*.

RESULTS

Of the total sample (n = 45), 77.77% (f = 35) were women and 22.22% (f = 10) were men. Within the experimental group (EG; n = 23), 40% (f = 18) were women whereas 11.1% (f = 5) were men; in the control group (CG; n = 22), 37.7% (f = 17) were women, whereas 11.1% (f = 5) were men. The mean age was 67.78 ± 6.66 years for the EG and 66.68 ± 4.67 for the CG.

Descriptive Statistics Regarding Biological and Social Factors

In terms of health conditions, 47.82% (f = 11) of the participants in the EG and 36.36% (f = 8) in the CG reported having two or more diseases, including high blood pressure, type 2 diabetes mellitus, and obesity. In addition, about half of the participants (EG: f = 13; 56.52% and CG: f = 8; 36.36%) reported taking two or more medications in order to control hypertension or type 2 diabetes mellitus. For social factors, there were no differences between these two groups in frequencies of using health services, types of health services used, and marital status. However, the participants in the EG tend to have higher education levels and socioeconomic status (**Supplementary Table S2**).

Differences Between the Groups in the Biopsychological Factors and Health-Promoting Behavior

In terms of biological factors, only the EG showed significant improvements between pre- and post-tests in cholesterol ($p < 0.05$), triglycerides ($p < 0.05$), VLDL ($p < 0.01$), SBP (p = 0.001), and DBP (p = 0.027; **Supplementary Table S3**). For nutritional status, the results showed significant differences between groups ($p < 0.01$; **Supplementary Table S4**) such that the EG demonstrated better nutritional status compared with the CG: normal nutritional status (f = 19; 82.60% versus f = 15; 68.18%), risk of malnutrition (f = 04; 17.39% versus f = 06; 27.27%), and malnutrition (f = 0; 0.0% versus f = 1; 04.54%).

The results of the analysis of the effect size for the biological factors in the EG showed that the intervention produced a small effect in the variable of LDL (d = 0.48; r = 0.23). For the glucose (d = −0.46; r = 0.22) and nutritional status (d = −0.45; r = −0.22) variables, the effect size was small and negative, which indicates a higher than average score in the post-test. For total cholesterol (d = 0.63; r = 0.30), triglycerides (d = 0.70; r = 0.33), and VLDL (d = 0.78; r = 0.36) variables, the intervention had a medium effect on the differences found by evaluation. For diastolic blood pressure (d = 0.93; r = 0.42) effect size was large (**Supplementary Table S3**).

In **Supplementary Table S3**, the coefficient of determination confirms that in the EG for the biological factors of glucose, LDL, and nutritional status, the relationship is small (R^2 = 0.048; R^2 = 0.052; R^2 = 0.048, respectively) for TG and VLDL the relationship it is medium (R^2 = 0.108; R^2 = 0.129, respectively) and for SBP (R^2 = 0.409) the relationship it is large. The proportion of variance shared by the multidimensional exercise program and the SBP is 40.9% (**Supplementary Table S3**).

Data analysis revealed that there were statistically significant differences regarding the psychological factors. For depressive symptoms, the results showed significant differences between groups both in pre (p = 0.01) and post (p = 0.001) assessments. Depression decreased only in the EG (p = 0.002). For self-esteem, significant differences between the groups in the posttest were observed (p = 0.005); the EG demonstrated a significant increase (p = 0.005) between pretest and posttest (**Supplementary Table S4**).

In relation to the size of the difference, the scores obtained with Cohen's d for self-esteem (d = −0.89; r = −0.40) is large size, which indicates that the scores obtained by the EG in the posttest are higher tha the scores obtained in the pretest. The negative value of the effect size confirms the result, that is, the average of the pretest is less than the average of the posttest. The regression analysis through the coefficient of determination for the self-esteem in the EG showed that for self-esteem the proportion of variance that is explained by the effect of the exercise program is small (R^2 = 0.16; **Supplementary Table S4**).

The results regarding physical activity levels in METs revealed statistically significant differences between the groups at the post-intervention evaluation ($p < 0.001$), but not at the pre-intervention evaluation. Only the EG demonstrated a significant increase between pre and post assessments ($p < 0.001$). The results indicate that participating in the 12-week exercise program contributed to the participants' engaging in more physical activities compared with those who did not participate. The scores obtained with Cohen's d for the health behavior was very high and had a negative effect size (d = −4.24; r = −0.90), which indicates the average of the pretest is less than the average of the posttest. The regression analysis through the coefficient of determination for health behavior in the EG allowed to correct the negative values and showed that for the health behavior the proportion of variance that is explained by the effect of the exercise program is medium (R^2 = 0.81) (**Supplementary Table S4**).

Differences in Biological and Psychological Factors and Health-Promoting Behavior Between Healthy Older Adults With Disease in the Experimental Group

Supplementary Table S5 shows the results of pre and post measurements in the biological and psychological factors and health-promoting behavior between healthy older adults and those with disease within the experimental group. Both healthy older adults and those with disease improved SBP, whereas only those with disease improved self-esteem and physical activity levels.

DISCUSSION

The aim of this study was to evaluate the effect of the 12-week multidimensional exercise program on health behavior, the biological factors of blood profiles, body weight, body mass index, blood pressure, and nutritional status and the psychological factors of depression and self-esteem of older adults who resided in Northeastern Mexico. The results of this study showed that the older adult participants showed improved physical activity levels as well as various biopsychosocial factors such as blood lipids profiles, blood pressure, and depressive symptoms. The results are consistent with the previous research, which indicated that health promotion programs designed for the purpose of modifying behaviors allow people to adopt health behaviors (e.g., increasing physical activity levels after the exercise participation; Keller et al., 2014; Mama et al., 2015).

Regarding sociodemographic variables, the experimental group in this study tended to have higher levels of education and socioeconomic status and demonstrated higher levels of physical activity compared with the control group. Although the current study did not conduct inferential analysis on this matter, the results somewhat supported those of the previous studies that older adults with higher levels of education and socioeconomic status tended to have higher physical activity levels (Eronen et al., 2016; Zainol et al., 2016). For instance, education levels were associated with an average increase of 50% in hours of accelerometer use among older adults compared to counterparts with lower education levels (Zainol et al., 2016). The results of the present and previous studies consistently show that the sociodemographic factors influence physical activity levels in older adults, which also affect physical and health conditions.

The results of the blood lipids profile showed significant improvements after the exercise intervention in total cholesterol, triglycerides, and VLDL, which is consistent with the previous studies. For instance, Martins et al. (2010) found that physical activity participation contributed to older adults' improvements in levels of triglycerides, total cholesterol, HDL, and LDL. In another study, Ho et al. (2012) found that obese older adults who participated in a 12-week aerobic exercise program improved in HDL, whereas counterparts who did not showed no changes. A result found in the present study and which was not reported in the results of the mentioned studies was the significant effect on VLDL. This finding is important because it reinforces the usefulness of physical exercise to increase the catabolism of VLDLs that help to transport mainly triglycerides to the tissues, that is, at higher levels greater risk of accumulation of fat in the arteries limiting the flow of blood rich in oxygen to the body and as a consequence an increase in the risk of heart disease (Carvajal, 2014).

The present study revealed that the 12-week exercise participation resulted in improvements in systolic and diastolic blood pressure. However, the results do not necessarily support the previous studies. For instance, Martins et al. (2010) found that a 16-week multicomponent exercise program (e.g., using aerobic and strength exercise) affected decreases in older adults' diastolic but not systolic blood pressure. Also, (Finucane et al., 2010) found that a 12-week aerobic exercise program with 36 sessions utilizing cycle ergometers was not effective for both systolic and diastolic blood pressure. The results may be because the type of exercise used was low impact and involved fewer muscle groups, whereas in the present study, most exercises used, such as walking, jogging, and dancing, involved larger muscle groups.

The exercise program had a positive effect on the nutritional status of the AM however there were no significant differences between the initial evaluation and final evaluation in the EG, this may be due to the fact that among the parameters contemplated in the state of nutrition, those referring to anthropometric measurements also did not show significant improvements. In terms of anthropometric variables, the older adults in this study reduced body weight and BMI through exercise participation but not to a statistically significant degree. These results are consistent with previous studies (Martins et al., 2010; Villareal et al., 2011). For instance, Villarreal et al. (2011) provided 12-month interventions to older adults with obesity while assigning them to one of four groups: a diet, an exercise, a diet-exercise, or a control group. The results revealed that the participants in the diet and the diet-exercise groups significantly decreased in body weight; however, those who were in the exercise and the control groups did not. Martins et al. (2010) found that 16-week interventions using either aerobic or strength training were not effective for improvements in older participants' BMI and body weight. Based on the results of the present and previous studies, it seems that interventions using both exercise and nutrition programs are more effective than an exercise-only intervention for older adults' weight management. However, research may need to be continued to find if an exercise-only intervention is effective for older adults' weight management and they will have to be strengthened with periodic dietary controls because physical activity alone is not enough to reduce fat levels and increase muscle mass in older adults.

The current study revealed that 12-week exercise participation was effective for improvements in depressive symptoms and self-esteem. These results are consistent with the previous studies, which demonstrated that exercise participation contributed to the reduction of depressive symptoms and anxiety (Carek et al., 2011; Dinas et al., 2011). Also, with the results of Salguero et al. (2011) who studied the relationship between physical activity and health-related quality of life and depressive symptoms in older community residents and institutionalized older adults in northern Spain. The results of the level of physical activity were related to different domains of the physical and mental components of health-related quality of life and the decrease in depressive symptoms. In the present study, only older adults with disease improved self-esteem and spent longer on physical activity, which is consistent with the findings from the previous studies that older adults continued to be physically active when they had better self-esteem (Bergland et al., 2010; García and Troyano, 2013).

The older adults of the present study who participated in the exercise program increased their physical activity levels. The group participating in the physical activity intervention spent 40 more minutes per week on physical activity than the other group. The results are consistent with the previous study (Pahor et al., 2014) that older adults who were provided with a physical activity intervention increase physical activity levels compared with those who were provided with health education. Mama et al. (2015) also carried out a systematic review of physical activity interventions with an emphasis placed on psychosocial factors provided for African Americans and Hispanics older adults. The results showed that the interventions that included psychosocial factors such as using strategies to increase motivation or self-efficacy tended to contribute to participants' increase in physical activity and achievement of a higher attendance record in the physical activity.

One of the limitations of the study was the small sample size, it is necessary to expand it and have a homogeneous distribution by sex, also by the duration of the program: interventions of longer duration that allow observing changes in other anthropometric variables and physiological. In addition, the calculation of the magnitude of the effect would be more accurate with larger populations. Another limitation was that in this study the use of music was limited only as a structural resource in the physical activity session and as an accompaniment during the development of the exercises, so the effect on the study variables was not measured. However, research in neuropsychology has used music for other purposes such as controlling emotions, improving quality of life, self-care, and behavior, through the reactions to specific musical signals such as melody, harmony, tempo, doorbell music, among others (Costa et al., 2012; Castillo et al., 2014; Fernández-Sotos et al., 2016). Therefore, it is recommended for future research to consider determining the influence of music on physical and psychological variables.

CONCLUSIONS

The current study supports that older adults who participate in multidimensional exercise programs (e.g., theory-based integrative biopsychosocial factors) improve their cardiovascular function, their self-esteem and depress the depressive symptoms. The increase in physical activity levels can contribute to older adults' improvement in physical and mental health and making health-related behavioral change. Therefore, it is recommended that integrating exercise and physical activity into daily life can be a proactive, economical approach for older adults with various health conditions to maintain and improve their physical and psychological health and well-being. Moreover, it evaluates the adherence of the elderly to the practice of physical activity to strengthen the psychosocial factors that influence health behaviors and monitor the participants after finishing their participation in the program to verify the specific moment in which the stopping training produces significant changes in the factors of healthy physical condition.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the research that was authorized by the Comité Institucional de Bioética of the Instituto Técnico de Sonora and complied with the Official Mexican Standard NOM-012-SSA3-2012, which establishes the criteria for performing human research projects in health. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

NB-C is responsible for the study design and supervision of the exercise program application. AC-Z collaborated on the survey and analysis of the data. RC-C collaborated in the design of the study, supervised the data collection and the writing of the manuscript. NB-S and MD-O collaborated in the study design and the manuscript review.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2019.02668/full#supplementary-material

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Physical Fitness Level Is Related to Attention and Concentration in Adolescents

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The main goal of this study was to analyze the relationships among physical fitness, selective attention and concentration in a group of 210 teenagers (43.81% male, 56.19% female) from the city of Málaga (Spain), aged between 11 and 15 years old (M = 13.27, SD = 1.80) that participated in the study. D2 attention test was used in order to analyze selective attention and concentration. Physical fitness was evaluated using the horizontal jump test, the Course Navette test and the 5 × 10 meters speed test. The analysis taken indicated a significant relationship among the physical fitness level, the attention and the concentration, as in the general sample as looking at gender. Linear regression tests performed showed that oxygen consumption is the best predictor of attentional parameters. Cluster analysis shows two groups characterized by a greater or lower physical fitness level. So, the highest physical fitness level group scores better in the attention (e.g., boys: $p < 0.001$, d' Cohen = 1.01, 95% CI [0.57, 1.44]; girls: $p < 0.01$, d' Cohen = 0.61, 95% CI [0.24, 0.98]) and the concentration tests (e.g., boys: $p < 0.001$, d' Cohen = 0.89, 95% CI [0.46, 1.32]; girls: $p < 0.01$, d' Cohen = 0.58, 95% CI [0.21, 0.95]). Results indicate that physical fitness analysis can be used as a tool for observing differences in the attention and concentration level of the analyzed adolescents, suggesting that a physical performance improvement could be an adequate procedure to develop some cognitive functions during adolescence.

Keywords: attention, concentration, adolescents, physical fitness, sports activity

INTRODUCTION

Brain functioning study has increased in the field of physical activity and sports sciences in recent years (Northey et al., 2018; Xue et al., 2018; Reigal et al., 2019b). There is a large number of studies analyzing the practice of physical activity and cognitive functioning in children and adolescents showing links between these variables (Donnelly et al., 2016; Chaddock et al., 2018). For example, positive relationships have been observed at early ages between regular or acute physical activity with cognitive abilities such as attention, concentration, memory, working memory, cognitive flexibility, inhibitory control or processing speed (Best, 2010; Tomporowski et al., 2011; Scudder et al., 2014; Li et al., 2017). These findings are especially relevant in stages such as childhood or adolescence, because an appropriate cognitive development would help to a better psychosocial adjustment and adaptation to the environment, as well as good mental health and a higher quality of life (Costigan et al., 2016; Santana et al., 2017; Zmyj et al., 2017).

However, while physical activity is considered to be positively related to cognitive functioning, researching has shown that it is necessary to assess the level of physical fitness for a better understanding of these links (Hillman et al., 2009; Herting et al., 2014; Pérez-Lobato et al., 2016). Physical fitness would refer to a set of physical characteristics that people have or could achieve through an adaptation process. In general, good physical fitness allows physical exertion without fatigue and vigorousness. Among others, some of the factors that are often measured for evaluation are cardiorespiratory fitness, muscle strength or body composition (Caspersen et al., 1985). Authors such as Hillman et al. (2009) have shown that physical condition is an essential element to explain the relationships between physical activity and cognitive functioning. Previous research has shown that brain development in childhood and adolescence is conditioned by factors linked to health, and the level of physical condition can be an indicator of brain health (Hötting and Röder, 2013; Reloba-Martínez et al., 2017).

What it means that physical activity taken should be done with a certain level of exigency in order to have a significant impact on the participants. Physical fitness development is a sign of the impact that physical activity has on human body, which it also corresponds with better effects in the brain. Working on that researching line, authors such as Pontifex et al. (2011), Kao et al. (2017), Reloba-Martínez et al. (2017) or Westfall et al. (2018) have pointed out positive associations between physical fitness and cognitive functioning in children and adolescents, with aerobic capacity being the best predictor of these relationships. However, other manifestations of physical condition such as motor control or strength are being explored in recent years, and it has been observed that they can have a positive influence on brain development (Esteban-Cornejo et al., 2019).

In the set of cognitive functions, attention has been one of the most attentions received in adolescence stage (Kim-Spoon et al., 2015; Bauer and Manning, 2016). This is a basic cognitive capacity involved in a broad set of tasks, conditioning the probability of success of behavior in areas such as academic, sports or social (Perlman et al., 2014; Rabiner et al., 2016). In addition, attention is not a univocal construction, but presents different manifestations as arousal, focal, selective, divided, alternating or sustained (Manly et al., 2001; Tamm et al., 2013). Selective attention refers to the ability to attend to objective stimuli while ignoring other distracting stimuli (Estévez-González et al., 1997; Giuliano et al., 2014). Likewise, the ability to maintain attention accurately and to a high degree on a given stimulus is called concentration (Buehner et al., 2006). Performing a task with high levels of concentration and for a long time is called sustained attention, which is necessary to succeed in a broad set of tasks (Blotenberg and Schmidt-Atzert, 2019).

Several studies have shown that physical activity in childhood and adolescence is positively related to improved attention and concentration (Budde et al., 2008; Trudeau and Shephard, 2008; Verret et al., 2012; Vanhelst et al., 2016). Specifically, previous studies have indicated the positive effects of physical activity on selective attention in children and adolescents (Janssen et al., 2014; Tine, 2014; Altenburg et al., 2016). Other works have related physical fitness level in children and adolescents with selective attention and concentration, observing that cardiorespiratory aptitude is one of the variables that explains better these associations (Pérez-Lobato et al., 2016; Reloba-Martínez et al., 2017; Reigal et al., 2019a).

Although there are previous studies that have explored this phenomenon, some of them have evaluated only isolated physical capacities, others have not taken a differentiated gender analysis, and a few have grouped different manifestations of physical fitness into profiles. In addition, we would like to evaluate the predictive capacity of fitness on cognitive functioning. For all this, aiming to go in depth into the relationships between physical fitness, selective attention and concentration, this paper focus on: (1) Analyzing the correlations among these variables according to gender; (2) assess the predictive capacity of fitness on selective attention and concentration; (3) measuring differences in selective attention and concentration based on fitness and gender.

MATERIALS AND METHODS

Participants

A total of 210 adolescents (43.81% male, 56.19% female) from the city of Málaga (Spain), aged between 11 and 15 years old (M = 13.27, SD = 1.80) participated in this research. Sample was selected through a suitable sampling group from several schools in Malaga. The exclusion criteria were: (a) not between 11 and 15 years old, (b) have a health problem that could bias any result or prevent you from taking a test of the study, and (c) not have parental authorization.

Measures and Instruments

Attention Test d2 (Brickenkamp, 2002)

This test is used to analyze the ability to visually scan for target items quickly and accurately, ignoring irrelevant ones, which is considered a manifestation of selective attention and concentration. In this test it is necessary to discriminate among 47 characters in 14 rows, with a total of 658 elements. You have 20 s to complete each row. Stimuli contain the letters “d” or “p,” which may be accompanied by one or two lines on the top of the item, on the bottom, or both. The “d” must be crossed out with two stripes (regardless of position). The test is always completed from left to right and from top to bottom. The scores you get are: TR (processed elements), TA (successes), O (omissions), C (commissions or errors), TOT [effectiveness in the task = TR−(O + C)], CON (concentration = TA−C), TR+ (last stimulus analyzed in the row with the most attempted elements), TR− (last stimulus analyzed in the row with the least attempted elements) and VAR [index of variation between the last stimulus analyzed between different rows = (TR+)−(TR−)]. This test has a test–retest reliability in the original study up to 0.90.

Physical Fitness

Three tests, which are included in the Eurofit (1993), were used to analyze the physical fitness of the participants: the horizontal Jump test (to evaluate the explosive strength in the lower limbs), the 5 × 10 meters speed test (to analyze the speed and the agility) and the Course Navette test (Léger et al., 1988) (to assess cardiorespiratory fitness). The latter test allows to calculate indirectly the maximum oxygen consumption (VO_{2max}). To calculate the maximum oxygen consumption the formula $VO_{2\text{max}} = 31.025+3.238\text{S}-3.248\text{A}+0.1536\text{SA}$ was used (S = speed reached in the last completed stage; A = age).

Procedure

Sample set was obtained from schools. Every school management was contacted in order to request them to participate. In addition, written and informed consent was obtained from the parent/guardian of each adolescent who wanted to participate. Authorization was also obtained from the Ethics Committee of the University of Malaga (CEUMA, n° 243, 18-2015-H) and the principles of the Declaration of Helsinki were complied with throughout the phases of the study (World Medical Association [WHO], 2013). Evaluations were taken along 2 days with a 3 days difference between them. Attention and concentration were evaluated in the first day, and physical fitness in the second day. The evaluation schedules were from 9:00 to 12:00 in the morning.

The D2 test was taken following the protocol established in the test. Instructions were carefully explained to the students and previous questions were solved in order to avoid any doubts. The test was conducted in groups in a classroom at the school.

For the physical tests, a 15-min warm-up was carried out. Activation, joint mobility and explosive exercises were developed, as well as specific tests of the horizontal jump and speed tests. Subsequently, the tests were taken, with a 15-min break between them and following the same order: horizontal jump test, 5 × 10-meter speed test and Course Navette test, following the protocols established by the Eurofit (1993).

Data Analysis

Descriptive and inferential analysis were performed. Data normality was checked with the Kolmogorov–Smirnov test. Correlation analyses were performed with the Pearson and Spearman test (±0.01 to ±0.19 = very weak correlation; ±0.20 to ±0.39 = weak correlation; ±0.40 to ±0.59 = moderate correlation). The predictive capacity of fitness on selective attention and concentration was assessed by linear regression analysis (successive steps). Different clusters were established according to fitness level and gender by k-mean clustering analysis. Also, comparisons between groups were made with t-student and U-Mann Whitney tests. The IBM SPSS Statistics 24.0 statistical analysis package was used to process the data.

RESULTS

Table 1 shows the descriptive statistics and normality test (Kolmogorov–Smirnov) of the variables under study. Only the variable commissions (C) of test d2 showed problems of normality.

Correlation analyses (**Table 2**) indicated significant and positive relationships between the variables horizontal jump and maximum oxygen consumption with various measures of the D2 attention test. Also, the speed test was significantly and negatively associated with some of the attention test measures. However, the omissions, commissions and index of variation (D2 test) were not related to any of the physical fitness variables. In the general sample, the correlations among horizontal jump and speed test with the main measures of D2 test are weak. However, the correlation level between maximum oxygen consumption with TOT and CON are moderate ($r \geq 0.40$). On the other hand, correlations in boys are greater than in girls. Children have moderate or near-moderate correlations between the main measures of the D2 test and physical fitness variables (horizontal jump and maximum oxygen consumption, r = 0.49–0.54; speed test, $r \leq -0.36$ to -0.37). However, in girls the correlations are weaker (horizontal jump and maximum oxygen consumption, r = 0.28–0.38; speed test, $r = -0.16$ to -0.20).

The linear regression analysis (successive steps) can be seen in **Table 3**. The latest models generated for the whole sample and differentiating by gender are shown. Some variables were excluded as predictors due to the lack of significance ($p > 0.05$). The linearity assumptions were met in the relationship between predictor variables and criteria, homoscedasticity and normal waste distribution. The value of Durbin–Watson was between 1.69 and 2.34, so it can be assumed that the waste is independent and the assumption of independence of the independent variables with respect to the dependent one is fulfilled (Pardo and Ruiz, 2005). Tolerance Index (ranged from 0.66 to 0.99) and Variance Inflation Factor (VIF) (ranged from 1.01 to 1.52) did not reveal issues of multicollinearity.

K-means clustering was used to generate two groups. The groups constituted were characterized by lower level of physical fitness (group 1) (boys, n = 45; girls, n = 57) and higher level of physical fitness (group 2) (boys, n = 47; girls, n = 61) (**Figure 1**). The clusters were generated depending on the following variables: horizontal jump test, speed test 5 × 10 and $VO_{2\text{max}}$. Each data was correctly classified, because the maximum distance of each one from the center of its group was less than the distance between the centers of the clusters.

Tables 4, **5** show descriptive and normal measures (Kolmogorov–Smirnov) of the different clusters for each gender. In addition, **Table 4** shows the significant differences calculated with the *t-student* statistic. Differences for the commissions (C) measure of the D2 attention test were calculated with the U-Mann Whitney test but they were not significant. As can be seen, there were differences for boys between clusters in the measures TR ($p < 0.001$, d' Cohen = 1.05, 95% CI [0.62, 1.49]), TA ($p < 0.001$, d' Cohen = 0.90, 95% CI [0.47, 1.33]), TOT ($p < 0.001$, d' Cohen = 1.01, 95% CI [0.57, 1.44]), CON ($p < 0.001$, d' Cohen = 0.89, 95% CI [0.46, 1.32]) and TR− ($p < 0.001$, d' Cohen = 1.16, 95% CI [0.72, 1.60]) of the D2 attention test, as well as in the horizontal jump test ($p < 0.001$, d' Cohen = 3.29, 95% CI [2.67, 3.93]), 5 × 10 speed test ($p < 0.001$, d' Cohen = −1.15, 95% CI [−1.59, −0.71]) and

TABLE 1 | Descriptive statistics of study variables and Kolmogorov–Smirnov test.

	Total (n = 210)					Boys (n = 92)					Girls (n = 118)				
	M	*SD*	*S*	*K*	*K–S*	*M*	*SD*	*S*	*K*	*K–S*	*M*	*SD*	*S*	*K*	*K–S*
HJT	158.06	33.08	0.44	−0.34	1.08	176.16	35.06	−0.11	−0.86	0.85	143.94	23.23	0.04	−0.24	1.11
5 × 10	19.17	1.97	0.61	0.16	1.16	18.23	1.77	0.98	0.99	0.97	19.90	1.82	0.69	0.26	1.22
VO_{2max}	43.05	7.72	0.34	0.98	1.10	45.52	8.96	0.11	0.57	0.98	41.13	5.97	−0.19	0.02	0.92
D2-TR	59.26	19.56	0.08	−0.70	1.03	56.02	20.40	0.31	−0.49	0.91	61.79	18.58	−0.07	−0.75	1.17
D2-TA	58.90	19.74	0.07	−0.73	1.08	57.38	21.01	0.21	−0.78	0.76	60.09	18.69	−0.04	−0.65	0.81
D2-O	53.18	21.05	0.00	−0.37	0.98	56.22	22.67	−0.16	−0.75	0.85	49.55	19.00	−0.03	0.16	0.86
D2-C	52.65	17.06	−0.40	−0.45	[a]2.83	53.62	17.51	−0.17	−0.50	[a]2.04	51.90	16.74	−0.61	−0.46	[a]1.96
D2-TOT	60.14	19.23	0.02	−0.76	1.27	57.85	20.49	0.23	−0.64	0.87	61.93	18.08	−0.12	−0.83	1.12
D2-CON	59.28	19.65	0.14	−0.81	1.20	57.95	21.45	0.23	−0.91	0.94	60.31	18.15	0.10	−0.74	0.88
D2-VAR	52.40	21.06	−0.21	−0.52	1.04	50.92	21.08	−0.20	−0.67	0.65	52.19	21.13	−0.22	−0.37	0.90
D2-TR+	60.94	16.68	0.01	−0.24	1.08	59.32	17.82	0.02	−0.43	0.97	62.20	15.69	0.08	−0.08	0.98
D2-TR−	62.68	20.05	0.31	−0.80	1.23	61.87	20.62	0.48	−0.99	1.27	63.31	19.65	0.17	−0.55	1.21

M = Mean; SD = standard deviation; S = Skewness; K = Kurtosis; K–S = Kolmogorov–Smirnov test; HJT = Horizontal jump (cm); 5 × 10 = Speed test 5 × 10 meters (sec.); VO_{2max} = Maximum oxygen consumption (ml/kg/min); D2 = d2 test; TR = Total number of attempts; TA = Total successes; O = Omissions; C = Commissions; TOT = Total effectiveness in the test; CON = Concentration index; VAR = Variation index; TR+ = Line with the greatest number of elements attempted; TR− = Line with the least number of elements attempted. [a]$p < 0.001$.

TABLE 2 | Correlation analysis among D2 test and physical fitness factors by gender and total sample.

	Total			Boys			Girls		
	HJT	5 × 10	VO_{2max}	SH	5 × 10	VO_{2max}	SH	5 × 10	VO_{2max}
D2-TR	0.30***	−0.20**	0.39***	0.52***	−0.37***	0.54***	0.33***	−0.23*	0.35***
D2-TA	0.33***	−0.20**	0.40***	0.50***	−0.36**	0.49***	0.32***	−0.16	0.39***
D2-O	−0.04	0.01	−0.02	−0.14	0.01	−0.15	−0.14	0.14	0.05
D2-C	−0.10	0.08	0.04	−0.16	0.14	−0.03	−0.12	0.10	0.09
D2-TOT	0.32***	−0.21**	0.41***	0.51***	−0.37**	0.54***	0.32**	−0.20*	0.36***
D2-CON	0.33***	−0.20**	0.40***	0.50***	−0.36**	0.49***	0.28**	−0.16	0.38***
D2-VAR	−0.07	0.06	0.08	−0.18	0.07	0.08	0.11	0.03	0.10
D2-TR+	0.04	0.02	0.29***	0.04	0.05	0.34***	0.17	−0.07	0.33***
D2-TR−	0.32***	−0.19**	0.24***	0.54***	−0.32**	0.37***	0.21*	−0.16	0.15

*HJT = Horizontal jump (cm); 5 × 10 = Speed test 5 × 10 meters (sec.); VO_{2max} = Maximum oxygen consumption (ml/kg/min); D2 = d2 test; TR = Total number of attempts; TA = Total number of hits; O = Omissions; C = Commissions; TOT = Total effectiveness in the test; CON = Concentration index; VAR = Variation index; TR+ = Line with the greatest number of attempted elements; TR− = Line with the least number of attempted elements. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.*

VO_{2max} ($p < 0.001$, *d*' Cohen = 1.27, 95% CI [0.82, 1.72]). Also, there were differences for girls between clusters in the measures TR ($p < 0.01$, *d*' Cohen = 0.58, 95% CI [0.21, 0.95]), TA ($p < 0.01$, *d*' Cohen = 0.61, 95% CI [0.24, 0.98]), TOT ($p < 0.01$, *d*' Cohen = 0.61, 95% CI [0.24, 0.98]), CON ($p < 0.01$, *d*' Cohen = 0.58, 95% CI [0.21, 0.95]) and TR− ($p < 0.05$, *d*' Cohen = 0.42, 95% CI [0.05, 0.78]) of the D2 attention test, as well as in the horizontal jump test ($p < 0.001$, *d*' Cohen = 2.59, 95% CI [2.10, 3.08]) and VO_{2max} ($p < 0.001$, *d*' Cohen = 1.06, 95% CI [0.68, 1.45]).

DISCUSSION

The purpose of present investigation was triple. On the one hand, it was to analyze the relations between physical condition, selective attention and concentration in a sample of adolescents according to gender. On the other hand, determine the predictive capacity of fitness on selective attention and concentration. Finally, it was intended to generate two groups based on the level of fitness and gender to assess differences in cognitive functioning measures. For the first and second objectives, correlation and linear regression tests have been carried out, observing that there were significant relationships in total sample as well as for each gender in the analyzed variables. It has also been observed that maximum oxygen consumption has been the main predictor of attention and concentration measures, although in boys strength is also a significant predictor. For the third objective, participants were classified into groups characterized by a higher and lower level of physical fitness and gender, getting better scores in selective attention and concentration those groups with a better level of physical fitness. Looking at data together, these data are in the same line with previous studies that had linked the level of physical fitness with improved cognitive functioning at these ages (Pontifex et al., 2011; Kao et al., 2017; Westfall et al., 2018) and specifically, those which had observed this phenomenon in

TABLE 3 | Linear regression analysis of D2 test factors regressed on physical fitness predictors by gender and total sample.

		Total sample			Boys			Girls		
		B	*SE B*	β	*B*	*SE B*	β	*B*	*SE B*	β
D2-TR	VO_{2max}	1.04	0.15	0.43***	0.85	0.23	0.37***	0.76	0.32	0.24*
	5 × 10	–	–	–	–	–	–	–	–	–
	HJT	–	–	–	0.19	0.06	0.32**	0.16	0.08	0.20*
		(R^2 = 0.19; F = 46.95***)			(R^2 = 0.35; F = 25.88***)			(R^2 = 0.14; F = 10.43***)		
D2-TA	VO_{2max}	0.84	0.19	0.35***	0.73	0.24	0.31**	1.22	0.27	0.39***
	5 × 10	–	–	–	–	–	–	–	–	–
	HJT	0.09	0.04	0.17*	0.20	0.06	0.34**	–	–	–
		(R^2 = 0.22; F = 28.34***)			(R^2 = 0.31; F = 21.28***)			(R^2 = 0.14; F = 20.61***)		
D2-TOT	VO_{2max}	1.01	0.15	0.42***	0.84	0.23	0.37***	1.10	0.26	0.36***
	5 × 10	–	–	–	–	–	–	–	–	–
	HJT	–	–	–	0.19	0.06	0.32**	–	–	–
		(R^2 = 0.18; F = 44.59***)			(R^2 = 0.35; F = 25.09***)			(R^2 = 0.13; F = 17.74***)		
D2-CON	VO_{2max}	1.09	0.16	0.45***	0.75	0.25	0.31**	1.16	0.26	0.38***
	5 × 10	–	–	–	–	–	–	–	–	–
	HJT	–	–	–	0.20	0.06	0.33**	–	–	–
		(R^2 = 0.19; F = 50.11***)			(R^2 = 0.31; F = 21.11***)			(R^2 = 0.14; F = 19.52***)		
D2-TR+	VO_{2max}	0.58	0.13	0.31***	0.68	0.20	0.34***	0.86	0.23	0.33***
	5 × 10	–	–	–	–	–	–	–	–	–
	HJT	–	–	–	–	–	–	–	–	–
		(R^2 = 0.09; F = 21.41***)			(R^2 = 0.11; F = 11.90***)			(R^2 = 0.10; F = 13.90***)		
D2-TR–	VO_{2max}	–	–	–	–	–	–	–	–	–
	5 × 10	–	–	–	–	–	–	–	–	–
	HJT	0.25	0.04	0.42***	0.36	0.05	0.64***	0.18	0.08	0.21*
		(R^2 = 0.17; F = 43.47***)			(R^2 = 0.39; F = 57.93***)			(R^2 = 0.04; F = 5.46*)		

*B = Unstandardized beta coefficient; SE B = Standard error on beta; β = Standardized coefficient Beta; VO_{2max} = Maximum oxygen consumption; 5 × 10 = Speed test 5 × 10 meters; HJT = Horizontal jump test; D2 = d2 test; TR = Total Number of Attempts; TA = Total Hit; TOT = Total Test Effectiveness; CON = Concentration Index; TR+ = Line with the greatest number of attempted elements; TR– = Line with the least number of attempted elements. *p < 0.05; **p < 0.01; ***p < 0.001.*

selective attention and concentration (Trudeau and Shephard, 2008; Pérez-Lobato et al., 2016; Reloba-Martínez et al., 2017).

Correlation and linear regression analyses have highlighted that maximum oxygen consumption is an essential variable to explain the relationship between physical confidence and cognitive functioning. This is consistent with others studies that had observed this previously (Chaddock et al., 2010, 2016; Kao et al., 2017; Westfall et al., 2018). However, the explosive strength, which has been evaluated by the horizontal jump test, has also obtained adequate levels of correlation with selective attention measures and concentration. Although the relationship between aerobic capacity and cognitive functioning has been better established in previous research, the complexity of this phenomenon is so broad that more data on the underlying processes that accompany the improvement of other physical capacities and the mechanisms that allow it to be related it to brain development will probably be known in the future.

In fact, there are studies that have already highlighted the relationships between aspects such as strength or coordination skills and cognitive functioning in children and adolescents (Haapala et al., 2015; Mierau et al., 2016). For example, Esteban-Cornejo et al. (2017) consider that it is necessary to assess how the interaction of different physical qualities could modulate the brain development. Landrigan et al. (2019) performed a meta-analysis and observed the effects of strength training on cognitive functioning, highlighting the importance in the development of this physical quality. These authors consider that both the cognitive demands of the exercise itself and other physiological effects derived from physical exertion would explain this phenomenon. For example, some current hypotheses consider that physical exercise promotes the activity of biomolecules such as the brain-derived neurotrophic factor (BDNF) or the insulin-like growth factor-1 (IGF-1), which promote changes in brain (Tari et al., 2019).

Thus, the structural and functional changes in the brain were previously caused by improvements in fitness levels. In previous studies such as Esteban-Cornejo et al. (2017), it was observed that several factors of physical fitness, and similar to those analyzed in this research (oxygen consumption, speed-agility and strength), were related to the gray matter volume of some brain

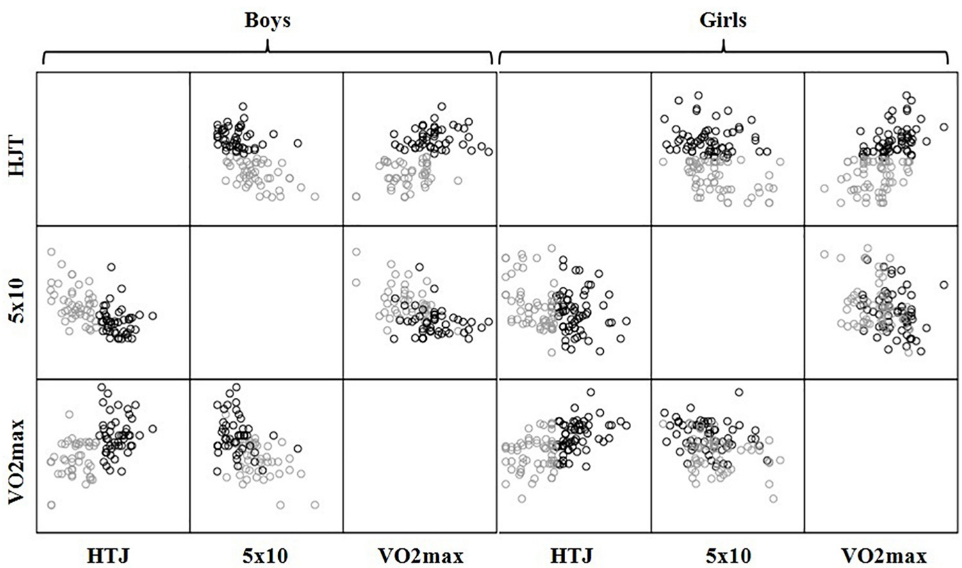

FIGURE 1 | Clusters generated from physical fitness variables. HJT = Horizontal jump test; 5 × 10 = Speed test 5 × 10 meters; VO_{2max} = Maximum oxygen consumption.

TABLE 4 | Descriptive statistics of study variables analyzed by cluster and differences among groups (*t*-student).

	Boys					Girls				
	Low PF (45)		High PF (47)			Low PF (57)		High PF (61)		
	M	*SD*	*M*	*SD*	*t*	*M*	*SD*	*M*	*SD*	*t*
HJT	145.60	19.33	205.43	16.91	15.82***	124.93	14.36	161.70	14.00	14.08***
5 × 10	19.14	1.72	17.37	1.34	−5.34***	20.22	1.91	19.60	1.69	−1.86
VO_{2max}	40.61	7.37	50.22	7.78	6.08***	38.22	5.58	43.85	4.99	5.78***
D2-TR	46.29	17.45	65.34	18.73	5.04***	56.44	18.19	66.79	17.66	3.14**
D2-TA	48.51	18.07	65.87	20.24	4.33***	54.40	17.93	65.41	17.94	3.33**
D2-O	59.33	21.26	53.23	23.78	−1.30	50.65	18.28	48.52	19.74	−0.61
D2-C	56.64	16.69	50.72	17.97	−1.64	52.05	16.35	51.75	17.23	−0.09
D2-TOT	48.40	17.69	66.89	18.98	4.83***	56.49	16.98	67.02	17.71	3.29**
D2-CON	48.98	18.17	66.53	20.99	4.28***	55.07	17.37	65.21	17.62	3.15**
D2-VAR	54.29	19.80	47.70	20.71	−1.55	52.81	21.33	51.62	21.09	−0.30
D2-TR+	58.93	19.69	59.68	16.04	0.20	60.82	15.47	63.49	15.92	0.92
D2-TR−	51.27	15.56	72.02	19.87	5.56***	59.14	20.21	67.20	18.44	2.27*

HJT = Horizontal jump (cm); 5 × 10 = Speed test 5 × 10 meters (sec.); VO_{2max} = Maximum oxygen consumption (ml/kg/min); PF = Physical fitness; D2 = d2 test; TR = Total number of attempts; TA = Total successes; O = Omissions; C = Commissions; TOT = Total effectiveness in the test; CON = Concentration index; VAR = Variation index; TR+ = Line with the greatest number of attempted elements; TR− = Line with the least number of attempted elements. * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$.

regions. This could be one of the reasons for the relationship between the physical condition and the cognitive functioning. By affecting the structural development of the brain, it would be conditioning its functioning. Specifically, these authors observed that cardiorespiratory fitness was best associated with the gray matter volume of cortical and subcortical brain areas. In this work, although the other measures of physical condition are also related to the levels of attention and concentration, it is observed that oxygen consumption is the variable that best explains the results in general terms. There are also other reasons that would explain the results. For example, physical training generates cognitive demands that have an impact on the brain. In addition, physiological processes are implemented as increased levels of neurotrophic or hormonal factors that facilitate brain plasticity processes (Landrigan et al., 2019).

These analyses have shown that there are differences among boys and girls in the level of correlation and in the predictive capacity of the variables. Data indicate that boys have better levels of correlation between the variables and the percentage of explained variance in the regression models are higher, which is consistent with previous studies (Drollette et al., 2015; Jaakkola et al., 2015). In addition, in boys strength is a more decisive

TABLE 5 | Skewness, Kurtosis and Kolmogorov–Smirnov by cluster and gender.

	Boys						Girls					
	Low PF			High PF			Low PF			High PF		
	S	*K*	*K–S*	*S*	*K*	*K–S*	*S*	*K*	*K–S*	*S*	*K*	*K–S*
HJT	−0.34	−0.87	0.86	0.72	0.30	0.94	−0.34	−1.31	1.27	1.23	1.24	1.08
5 × 10	0.79	0.70	0.67	1.64	0.94	0.92	0.84	0.10	1.07	0.42	−0.01	0.71
VO_{2max}	−0.40	0.52	1.08	0.49	0.17	0.94	−0.19	−0.25	0.92	0.04	0.09	0.77
D2-TR	0.68	0.58	0.86	0.10	−0.56	0.64	0.41	−0.29	1.32	−0.52	−0.31	1.18
D2-TA	0.52	−0.02	0.75	−0.14	−0.80	0.53	0.26	−0.06	0.93	−0.33	−0.64	0.91
D2-O	−0.55	−0.25	0.88	0.38	−0.76	0.69	−0.33	0.99	0.79	0.21	−0.23	0.74
D2-C	−0.99	0.01	1.64*	0.50	0.04	1.23	−0.56	−0.66	1.28	−0.66	−0.27	1.47*
D2-TOT	0.56	0.41	1.02	−0.04	−0.83	0.75	0.16	−0.44	0.85	−0.45	−0.67	1.20
D2-CON	0.59	−0.01	0.97	−0.19	−0.95	0.71	0.43	0.01	0.86	−0.20	−0.87	0.96
D2-VAR	−0.22	−0.57	0.73	−0.10	−0.93	0.65	−0.27	−0.38	0.77	−0.18	−0.28	0.99
D2-TR+	0.15	−0.67	1.19	−0.17	−0.08	0.69	0.28	−0.05	1.15	−0.11	0.11	0.79
D2-TR−	1.45	2.10	1.23	−0.19	−1.11	0.93	0.55	−0.42	1.04	−0.13	−0.07	0.99

*S = Skewness; K = Kurtosis; K–S = Kolmogorov–Smirnov; HJT = Horizontal jump test; 5 × 10 = Speed test 5 × 10 meters; VO_{2max} = Maximum oxygen consumption; PF = Physical fitness; D2 = d2 test; TR = Total number of attempts; TA = Total number of hits; O = Omissions; C = Commissions; TOT = Total effectiveness in the test; CON = Concentration index; VAR = Variation index; TR+ = Line with the greatest number of attempted elements; TR− = Line with the least number of attempted elements. *$p < 0.05$.*

factor. These differences could be conditioned by a higher level of regular physical activity in boys, which could lead to greater intra-group variability (Telford et al., 2016). In addition, other elements such as differences in brain structure, plasticity or the impact of environmental factors among genders may be influencing these results (Cosgrove et al., 2007; Isaacs et al., 2008). However, these are hypothesis that cannot be tested, but it would be interesting to integrate it into future work to check if gender could be subtly modulating the results.

On the other hand, this work has analyzed intragender differences based on the level of physical condition. This is interesting, as previously discussed, since it allows to observe whether this phenomenon reproduces similarly in both genres. In many previous studies, no analysis has been carried out on boys and girls to facilitate their comparison, which is an interesting aspect of this work. Based on the results obtained in this study, it can be observed that the size of the effect on intra-group differences in boys is greater than girls, although in both girls and boys the group with higher kevel f physical fitness had better scores in attentional and concentration measures. This raises the question of whether other variables such as study habits, rest and eating could also contribute to qualify the results found (Cosgrove et al., 2007; Isaacs et al., 2008). These suggestions should be addressed in future work, which will help to set a better description of the relationships between the variables analyzed. In any case, and despite the differences, these data are relevant because it would suggest that this phenomenon is fairly stable and can benefit a wide range of adolescents.

This research presents limitations such as the type of design, which does not allow to set causal relationships. In addition, assessments of other measures of physical fitness or cognitive functioning may provide more information about the findings. However, it provides an adequate sample size and gender analysis, which allows for selective in-depth analysis of boys and girls. Therefore, it is considered that the results found contribute as valuable information to the existing literature set that contributes to consolidate these relationships and increase the available evidence on this subject.

Results highlight that physical fitness in children and adolescents could help to improve their cognitive functioning, with the benefits this would bring to their developmental and psychosocial adjustment processes (Hillman et al., 2009; Pontifex et al., 2011; Herting et al., 2014; Kao et al., 2017). These data joined to previous ones, allow us to emphasize that the practice of physical activity alone is not enough for the impact on the brain to be noticeable. Physical activity must have specific qualities that allow it to overcome a minimum threshold of adaptation that facilitates changes in the organism (Chaddock et al., 2010; Esteban-Cornejo et al., 2017; Reloba-Martínez et al., 2017).

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

AUTHOR CONTRIBUTIONS

AH-M, VM-S, JP, RR, JM-B, RJ-R, and LM-C participated in the study design and data collection, performed the statistical analyses, contributed to the interpretation of the results, wrote the manuscript, approved the final manuscript as presented, reviewed and provided feedback to the manuscript, and made substantial contributions to the final manuscript. RR, AH-M, and LM-C conceived the study and participated in its design and coordination.

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Association Between Preschoolers' Specific Fine (But Not Gross) Motor Skills and Later Academic Competencies: Educational Implications

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Motor development is an inseparable component of cognitive development. So, to develop the mind, it is necessary to work the body. Therefore, Early Childhood Education curricula and the scientific literature emphasize the need to promote the development of motor skills during the 1st years of life. These skills are necessary for learning and subsequent academic performance. However, studies frequently offer only a partial view of these relationships. Few works have analyzed the specific relationships between different components of preschool gross and fine motor skills and subsequent performance on different academic competencies. Further, they present discrepant results. The aim of this study was to determinate which specific components of gross and fine motor skills assessed in Spanish students during the final year of Early Childhood Education (5 to 6-year-olds) were associated with different academic competencies assessed in the following academic year, when the students were in their 1st year of Primary Education. The final sample consisted of 38 Spanish students, aged 5. A mixed methods approach was used. It consisted of systematic observation to assess specific components of gross and fine motor skills when children were in the Early Childhood Education period, and selective methodology to evaluate their academic competencies (specifically in literacy and mathematics and overall), 1 year later, once in Primary Education. Multiple linear regression models were constructed using the computing language R to examine the association between motor skills and academic competencies. The results indicated that only the components of fine motor skills showed associations with academic competencies. The pattern of association varied when literacy and mathematics competencies were specifically and individually assessed and when overall academic competency was considered. The two assessed fine motor skills (Coordination and Integration) were associated with literacy competency ($\beta = 0.344$, $p = 0.025$; $\beta = 0.349$, $p = 0.024$, respectively) and overall academic competency ($\beta = 0.267$, $p = 0.065$; $\beta = 0.493$, $p = 0.001$, respectively). However, only

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Integration was associated with mathematics competency (β = 0.476, p = 0.002). The "Discussion" section focuses on the educational implications of these results and future research. It highlights the importance of early assessment of fine motor skills to identify students likely to present inadequate subsequent academic performance and the need to apply instruction and interventions tailored to the specific needs of each child.

Keywords: motor skills, academic competencies, systematic observation, early childhood assessment, child development, learning, preschoolers, educational practice

INTRODUCTION

Diverse development theories and numerous authors have highlighted the relationship existing between motor and cognitive development (Frick and Möhring, 2016). Decades ago, Wallon (1977) declared that children develop through movement. This development takes place "from the act to the thought" (Wallon, 1942), from the concrete to the abstract, from the action to the representation, from the physical to the cognitive. Piaget (1936, 1970, 1973) also suggested that bodily action prepares logical operations, since logic is based on the coordination of actions, prior to being formulated on the language plane. Thus, he established sensory-motor or practical intelligence as the base of verbal or reflexive intelligence. Pelicier et al. (1996) stated that motor and psychological functions are the two fundamental elements of human behavior. Initially, they develop together, later being specialized and differentiated, although they continue to be subject to reciprocal interactions (Adolph and Franchak, 2017; Kim et al., 2018).

The relationships between motor and cognitive aspects have been corroborated by empirical data based on different types of studies: (a) neuro-functional and neuro-anatomical studies: data resulting from functional magnetic resonance techniques reveal that motor and cognitive development follow a common extended development pattern, sharing anatomical areas that were previously considered to be specific to only one of the development types (Schmahmann, 2019). So currently, it is known that there is a clear connection between the brain areas involved in motor skills (mainly, the cerebellum) and those involved in cognitive skills (mainly, the pre-frontal cortex); and the development of both takes place simultaneously and is especially rapid over the 1st years of life, with a developmental peak occurring between 5 and 10 years of age (Ahnert et al., 2009; Haartsen et al., 2016; Leisman et al., 2016). Thus, both brain structures are active when carrying out certain motor or cognitive tasks. Other structures, such as basal ganglia, and certain neurotransmitters, such as dopamine, also appear to be involved in certain complex components of motor and cognitive performance (Diamond, 2000, 2007; Leisman et al., 2016; Jung et al., 2017). (b) Studies carried out on patients suffering from cerebral lesions and developmental disorders: individuals having cerebral lesions in the primary motor area or in the primary cognitive area often reveal deficits in both types of skills (Diamond, 2000, 2007; Rooijen et al., 2012). Likewise, many disorders exist in which motor problems are accompanied by learning difficulties or cognitive deficits, as is the case with the Developmental Coordination Disorder (DCD), Attention-Deficit and Hyperactivity Disorder (ADHD), or Autism Spectrum Disorder (ASD) (Blank, 2018; Lange, 2018; Scandurra et al., 2019). (c) Longitudinal studies carried out on normal populations: many longitudinal studies have found that the relationship between motor skills and cognitive development continues over the short, medium, and long term. So, motor skills acquired at a very early age may relate to cognitive abilities during childhood (Son and Meisels, 2006; Michel et al., 2016), adolescence (Cantell et al., 2003), and even adulthood (Kuh et al., 2006; Murray et al., 2006). This suggests that performing early motor development assessments may help to identify children having a probability of demonstrating poor academic performance and even adults who may have difficulties in entering the work force (Son and Meisels, 2006; Cameron et al., 2012, 2016; Roebers et al., 2014; Pitchford et al., 2016; Schmidt et al., 2017; Goodway et al., 2019).

In the field of Early Childhood Education (ECE), numerous studies have defended the idea that motor skills are associated with academic competencies and achievement (Grissmer et al., 2010; Cameron et al., 2012, 2016; Pitchford et al., 2016). However, upon analyzing their results, it may be found that the association between motor and academic achievement has yet to be well established in childhood. One of the issues that may explain this situation is based on the fact that motor skills and academic achievement are broad concepts. Most studies only focus on some of their components, offering a partial view of motor development and academic performance as well as their associations.

In motor development, two main types of skills have been traditionally considered: (1) Gross motor skills and (2) Fine motor skills (Grissmer et al., 2010; Bjorklund and Hernández, 2012; Gentier et al., 2013; Raisbeck and Diekfuss, 2015; van der Fels et al., 2015; Oberer et al., 2017; Haywood and Getchell, 2019). (1) Gross motor skills refer to actions of large muscle and postural groups; movements of the entire body or large body segments. They include specific skills: (1a) Locomotor skills: involving the coordination of the entire body, allowing for the movement of the body from one point in space to another, using body movement to achieve this. Locomotor skills include running, galloping, hopping, leaping, jumping, and sliding. (1b) Balance: this refers to the ability to hold a controlled position or posture during a specific task or activity. There are two types of balance: (i) Dynamic Balance refers to the ability to maintain a position during activities that require movement, such as walking. It is obtained when stability of the body is held during movement performance. (ii) Static Balance refers to the ability to maintain position during stationary tasks, such as standing or sitting. A task that is commonly used to assess this balance type is the ability to remain standing on only one leg. (1c) Object Control skills: movements in which the main action focuses on the handling of objects. It includes all tasks that involve the handling of objects (such as, for example, throwing, catching, hitting, absorbing, etc.), be it with the hands, feet or other objects. These skills may be separated into two sub-types: (i) Propulsive skills are those that involve sending an object away from the body (overhand throw and underhand roll, hitting a ball with a tennis racket, kick, etc.); (ii) Receptive skills involve receiving an object. They involve an absorption movement, that is, they serve to slow down a movement in order to handle it (stationary bounce, match) (Ulrich, 2000; Grissmer et al., 2010; Lopes et al., 2013; D'Hondt et al., 2014; Magistro et al., 2015; Rudd et al., 2015; Chang and Gu, 2018; Haywood and Getchell, 2019). (2) Fine motor skills involve the action of small muscle groups; precise movements of the hands, face and feet, such as, for example, the ability to use hands. Within this type of skills, two specific skill types may be differentiated: (2a) Fine Motor Coordination or Visual Motor Coordination: it refers to small muscle movements, but not to the integration of these muscle movements with other input, such as visual-spatial information, from the environment. It includes certain abilities such as finger dexterity, motor sequencing, and fine motor speed and accuracy. Some of the tasks that are commonly used to assess it are: tracing, finger tapping, imitative hand movements, building with blocks, threading beads, replacing pegs, moving coins from one place to another or inserting them in a slot (Davis and Matthews, 2010); (2b) Fine Motor Integration: it involves the organization of small muscle movements in the hand and fingers through the processing of visual stimuli. Visual information from the environment must be processed and integrated with fine motor movements (Sortor and Kulp, 2003). It relies more on synchronized hand-eye movements than Fine Motor Coordination. For its assessment, writing and copying tasks are carried out on shapes, letters or other stimuli (Grissmer et al., 2010; Cameron et al., 2012; Roebers et al., 2014; Jansen et al., 2015; van der Fels et al., 2015; Oberer et al., 2017; Chang and Gu, 2018). The development of gross and fine motor skills does not take place independently. For example, biped walking leaves the hands free, permitting new possibilities of action and representation (Oberer et al., 2017).

As described above, various components or specific skills are involved in each of the two main motor skills (gross and fine). However, the majority of studies analyze only one type of these main motor skills (gross or fine); and very few have considered their distinct specific components. Therefore, these may be considered partial studies. Other works have assessed the distinct specific gross and fine motor skills, but they are quite scarce (Oberer et al., 2017). And paradoxically, some of these later consider the specific gross and fine motor skills in a global sense, offering a sole score for each main type of motor skill (gross or fine) or even one single overall indicator for all of them. This implies a confused perspective and a lack of depth to the topic. In accordance with many other authors (Oberer et al., 2017; Schmidt et al., 2017), we highlight the need to operationalize the childhood motor skills through distinct specific gross and fine motor skills that suitably represent their multidimensional nature.

The same occurs with academic performance. As previously mentioned, this is also a very broad concept. However, some studies offer only one overall score for academic performance. This is a limitation, since, according to the scholastic curriculum, the academic competencies that are studied in schools and that should therefore be assessed, belong to diverse domains (Organization for Economic Co-Operation and Development, 2005; Education, Culture and Sports Ministry of the Spanish Government, 2015). Traditionally, studies considering various curricular aspects distinguish between literacy and mathematics achievement (Fernandes et al., 2016; Abdelkarim et al., 2017; Ribner et al., 2017). Literacy and mathematics are considered to be the core academic domains since well-developed competencies in these areas are critical for performance in other scholastic fields such as geography and history, and for success in the child's subsequent studies. Children need these academic competencies in order to reach their full potential, thereby paving the road to a successful professional life (Organization for Economic Co-Operation and Development [OECD], 2016).

Since, generally speaking, studies have failed to collectively consider the distinct specific motor skills and the distinct academic competencies, there is a lack of conclusive data to affirm the extent to which each specific motor skill can be associated with academic performance in the distinct areas (Magistro et al., 2015; Veldman et al., 2019). Furthermore, of the few studies that have analyzed the different specific motor skills and academic competencies, it is difficult to reach conclusions as to the associations between them, since each study analyzes different motor skills and academic competencies, or operationalizes them in different ways; and they have been assessed in populations with distinct characteristics. All of these aspects contribute to the disparity of results in this area. Therefore, this is a complex area of study, filled with partial results and contradictory situations, making it difficult to reach consensual conclusions.

Ultimately, it is necessary to thoroughly and profoundly consider the potential existence of specific associations between the distinct components of motor skills and academic competencies in order to contribute to the children's success. To do so, as mentioned previously and in accordance with other authors (York et al., 2015), it is necessary to collectively examine the specific gross and fine motor skills, as well as literacy and mathematics competencies (in addition to overall ones) in one study. However, this type of study is scarce and the results of the few that have been conducted are quite disparate.

This study has been carried out in an attempt to eliminate this gap. Its objective was to determinate which specific gross and fine motor skills, assessed in Spanish students in the last year of ECE (5–6 years), were associated with later academic competencies (specifically in both literacy and mathematics and overall competencies) assessed during the following academic year, when the students were in the first quarter of Primary Education.

Determining these associations in preschool children may help with the design and implementation of effective teaching and interventions to improve the specific motor skills that are most relevant for the subsequent academic competencies. This would promote the future academic success of students from a young age, helping to strengthen the country by ensuring the educational success of all of its inhabitants (Organization for Economic Co-Operation and Development [OECD], 2016).

MATERIALS AND METHODS

Methodology and Design

We applied a mixed methods approach (Anguera et al., 2017, 2018b; Escolano-Pérez et al., 2019a,b) consisting of systematic observation to observe preschoolers' motor skills and selective methodology to assess their academic competencies the following year.

We employed systematic observation to observe preschooler motor skills for several reasons: (1) The study was carried out in the school context of the participants, specifically, in their regular motor development sessions within their scholastic program. These motor development sessions make up a regular and necessary part of ECE (the educational stage at which the participants were), since some of the purposes of the same include the discovery of body and movement possibilities, the development of more voluntary motor activity in the children and the acquisition of progressive body control (Education and Science Ministry of Spanish Government, 2008). (2) Spanish education regulations (in addition to those of distinct international institutions and the scientific literature) indicate that during this scholastic phase, the assessment of student learning and development should be carried out mainly via direct and systematic observation (Education and Science Ministry of Spanish Government, 2008; Early Head Start National Resource Center, 2013; Otsuka and Jay, 2017). (3) This is coherent with the methodological requirements of systematic observation: having perceivable and regular behaviors in a natural setting (Shaughnessy et al., 2012; Portell et al., 2015a,b; Anguera et al., 2018a,b).

According to the observational designs described by Anguera (2001) and Anguera et al. (2011, 2018a), the study was carried out using a Nomothetic/Punctual/Multidimensional (N/P/M) design. Nomothetic refers to the observation of several different children, each of whom was observed individually. Punctual refers to the recording of the motor execution of each child in each activity of interest, in a single observation session. Multidimensional refers to the fact that more than one dimension of the participant's response is taken into account; more precisely, different aspects of the child's motor execution were observed with reference to specific gross and fine motor skills, in accordance with the theoretical proposal of several authors (Ulrich, 2000; Grissmer et al., 2010; Bjorklund and Hernández, 2012; Gentier et al., 2013; Lopes et al., 2013; D'Hondt et al., 2014; Jansen et al., 2015; Magistro et al., 2015; Raisbeck and Diekfuss, 2015; Rudd et al., 2015; van der Fels et al., 2015; Oberer et al., 2017; Chang and Gu, 2018; Haywood and Getchell, 2019). These dimensions of the participant's response led to the *ad hoc* observation instrument that was designed.

Observation was non-participative and active, based on scientific criteria and characterized by total perceptibility. Direct observation of the film recorded was carried out (Bakeman and Quera, 2011; Shaughnessy et al., 2012; Anguera et al., 2018a,b).

For the assessment of the academic competencies 1 year later (during the first school year of Primary Education), a selective methodology was used. Specifically, the standardized PAIB-1 (*Test of basic instrumental aspects: Reading, writing and numeric concepts*; Galve-Manzano et al., 2009) instrument was administered. The assessment of academic competencies through a standardized instrument such as the PAIB-1 guaranteed a more objective, reliable, and valid assessment, as compared to the use of scores given by the teachers. These have been found to be less reliable, also leading to other problems such as a lack of comparability with other teachers or schools (Marzano, 2000; Organization for Economic Co-Operation and Development [OECD], 2012; Castejón et al., 2016).

Participants

The study participants were selected intentionally. They were enrolled in a school that declared its interest in participating in a study that was directed by the first author of this manuscript. Thus, the studied sample was part of a larger research project.

The school was located in the center of a Spanish city. The students attending this school came from middle to upper socio-economic level families.

Inclusion criteria for the sample were: (1) being a student in the 3rd year of ECE (in Spain, this course year corresponds to an age of 5–6 years and is the last year in this non-mandatory school phase); (2) attendance at the targeted school since the 1st year of ECE (that is, since 3 years of age); (3) anticipating the continued study in this same school the following year (that is, intent to enroll in the first course year of Primary Education in the same school); (4) absence of the following disorders or risk factors: (a) birth weight < 2,000 g and/or gestational age <36 weeks or significant pre, peri-, or postnatal events; (b) medical/neurological conditions affecting growth, development, or cognition (e.g., seizure) and sensory deficits (e.g., vision or hearing loss); (c) neurodevelopmental disorders (e.g., ASD, ADHD, and language disorder); (d) genetic conditions or syndromes; and (e) a first-degree relative with schizophrenia, bipolar disorder, or related disorders; and (5) an adequate IQ for their chronological age.

The assessed information to ensure compliance with criteria 1 (being a student in the 3rd year of ECE) was provided by teachers. The information to be assessed for compliance with the criteria 2 (attendance at the targeted school since the 1st year of ECE), along with criteria 3 (anticipating continued studies in the same school over the following year) and criteria 4 (absence of disorders or risk factors) was provided by the children's parents. Information related to inclusion criteria 5 (an adequate IQ for their chronological age) was tested using the BADyG-I (*Battery of Differential and General Abilities I*; Yuste and Yuste Peña, 2001).

The initial sample consisted of 44 children who, in addition to complying with the inclusion criteria, presented informed consent forms signed by their parents, authorizing their participation in the study. Six of these children were eliminated from the final sample, since they did not complete all of the activities related to the observation of motor skills and, therefore, had missing data (see the section "Data Analysis"). So, the final sample consisted of 38 children. Of these, 12 participants (31.6%) were male and 26 (68.4%) were female. Their mean age was 5.72 years (*SD* = 0.30). They represented 82.61% of all of the children enrolled in the last year of ECE at the school.

All of the participants were treated in accordance with international ethical principles.

Natural Setting

Natural setting is one of the requirements for making use of systematic observation (Anguera et al., 2018a,b). In accordance with it, the ECE curriculum (Education and Science Ministry of Spanish Government, 2008; Early Head Start National Resource Center, 2013) has established that the assessment of preschool skills should be carried out in the very educational situations and via direct and systematic observation. Therefore, in our study, the observation sessions intended for assessment of the preschool motor skills took place during the motor development sessions that were carried out regularly in the school (in the motor development classroom) and within their regular scholastic programming.

According to the methodological principles determined by the Spanish government for the learning-teaching process of motor skills in ECE (Health, Social Services and Equality Ministry and Education, Culture and Sports Ministry of Spanish Government, 2017), and, therefore, following the same methodology used by the teachers with their students to prevent any alterations of the regular scholastic context of the study participants, five motor circuits were designed. These circuits were designed to be executed by the participants, in order to observe the specific motor skills of interest for our study. The motor circuit is a methodological proposal in which a set of motor activities are used so that the children could assimilate and improve their motor possibilities through specific and overall work on certain motor patterns, adapted to their level of performance. The activities to be carried out must be explained in advance by the teacher, who acts as a model for the students so that they can visualize the motor patterns to be carried out. The motor circuit must be made up of distinct activities, and its completion requires the execution of a combination of motor skills, which may vary in type: Locomotor skills, Balance, Fine Motor Coordination, etc. (Health, Social Services and Equality Ministry and Education, Culture and Sports Ministry of Spanish Government, 2017).

In accordance with our study's objective and in line with our initial theoretical framework, the completion of the motor activities forming part of the circuits allowed for the observation of the following specific motor skills: (1) Those belonging to Gross motor skills: (1a) Locomotor skills; (1b) Balance: (i) Dynamic Balance and (ii) Static Balance; (1c) Object Control skills: (i) Propulsive skills and (ii) Receptive skills. (2) Those belonging to Fine motor skills: (2a) Fine Motor Coordination; (2b) Fine Motor Integration.

In order to design the motor activities that allowed for the observation of these specific motor skills, the following aspects were considered: (1) ECE curriculum that specifies the motor skills that should be promoted in children at this age; (2) recommendations and examples of the motor activities proposed by the Health, Social Services and Equality Ministry and Education, Culture and Sports Ministry of Spanish Government (2017) to be carried out in schools in order to improve student motor skills during the period of ECE; (3) existing empirical studies in the scientific literature on the topic that describe activities to be used for the assessment of these childhood motor skills (Franjoine et al., 2010; Grissmer et al., 2010; Pfeiffer et al., 2015; Frick and Möhring, 2016; Gu, 2016; Hestbaek et al., 2017; Oberer et al., 2017; Stein et al., 2017; Cadoret et al., 2018; Chang and Gu, 2018); (4) existing instruments for use in the assessment of motor skills in preschoolers, specifically: the Early Screening Inventory-Revised, 2008 Edition (ESI-R; Meisels et al., 2008); McCarthy Scales of Children's Abilities (MSCA; McCarthy, 1972); Bruininks–Oseretsky Test of Motor Proficiency-2nd Edition (BOT-2; Bruininks and Bruininks, 2005); Movement Assessment Battery for Children-Second Edition (MABC-2; Henderson et al., 2012); Battelle Developmental Inventory (Newborg et al., 1996); Childhood Neuropsychological Maturity Questionnaire (CUMANIN; Portellano et al., 2000); Pediatric Balance Scale (PBS; Franjoine et al., 2003); and The Beery–Buktenica Developmental Test of Visual-Motor Integration (Beery VMI; Beery et al., 2010).

All of the designed motor activities are playful and fantasy-like. Play is an essential methodological tool of ECE and it should not be separated from a child's life. Therefore, it is an indispensable tool for the teaching-learning process of children and the observation and analysis of their progress and development (Fasulo et al., 2017; Salcuni et al., 2017; Zosh et al., 2018). But in addition, when play is framed within a world of fantasy, children's intrinsic motivation, and engagement increase (Garris et al., 2002; Paley, 2005).

The motor activities designed to observe each type of specific motor skill are included in **Table 1**. Below, each of these is described.

TABLE 1 | Motor activities designed to observe the distinct specific motor skills.

Principal type of motor skills	Specific motor skills		Motor activities
Gross motor skills	Locomotor skills		Hopping on one leg
			Long jump
	Balance	Dynamic	Walking heel-to-toe
			Jumping in place
		Static	Squatting with arms extended horizontally
			Standing on one leg
	Object Control skills	Propulsive skills	Vertical throwing
			Horizontal throwing
		Receptive skills	Catching a ball
			Catching a bouncing ball
Fine motor skills	Fine Motor Coordination		Tying a pencil
			Touching fingertips
	Fine Motor Integration		Copying shapes
			Copying letters, words, and numbers

(1) Activities to observe Gross motor skills:
(1a) Locomotor skills:

- Hopping on one leg: the child was to hop on one leg down a line, stepping on it without crossing the line. This line was drawn on the ground in a square measuring 1 m per side. Therefore, the child walked on one leg, without stopping, over one of the four sides of the square. On the first two sides, he/she walked with one leg and on the last two sides, with the other.
- Long jump: the participant, situated on a specific point, was to jump forward with both feet together, propelling him/herself forward with his/her arms. The child was to jump as far as possible. Then, he/she was to land on his/her feet, without touching the ground with his/her hands. In the case in which the participant did not comply with these requirements, the jump was considered null and the child was able to repeat the attempt up to a maximum of three times in order to correctly complete the jump.

(1b) Balance:
(i) Dynamic Balance:

- Walking heel-to-toe: the child was to walk down a line with his/her heel next to the toes of the other foot (between the two feet, no space was to be found on the ground). The line that the child was to walk down, without exiting the same and without stopping, was drawn on the ground in a square having 1 m long sides.
- Jumping in place: the participant, situated on a point that is the center of a square measuring 25 cm per side, and looking forward (not at the ground), was to jump up and down 10 times in a row, landing on the same point. While this task was being carried out, an adult counted the jumps, indicating when the participant had completed the 10 jumps so that he/she knew when to stop.

(ii) Static Balance:

- Squatting with arms extended horizontally: the child was to squat over the balls of his/her feet, with feet separated by approximately 30 cm, and with his/her body bent and arms extended horizontally to the sides (that is, their arms extended in the form of a cross). With his/her eyes closed, the child was to remain in this position as long as possible. In the case in which the child remained in this position for less than 5 s, he/she was permitted a second attempt.
- Standing on one leg: the participant, with his/her eyes closed, was to remain standing on one leg on one point. He/she was to remain in this position as long as possible. This exercise was performed on one leg (the leg selected by the participant). In the case in which he/she remained in the position for less than 5 s, the child was permitted a second attempt, with the same leg. Later, the task was carried out using the other leg. Once again, in the case in which the child remains in the position for less than 5 s, he/she was allowed a second chance with this same leg.

(1c) Object Control skills

(i) Propulsive skills:

- Vertical throwing: the child was situated below a hoop measuring 50 cm in diameter and situated 20 cm above his/her head. He/she was to place his/her feet in parallel, slightly separated. From this position, he/she threw a ball (14 cm in diameter) from his/her shoulders upward, sending it through a hoop (once the ball was thrown upward, when falling, it went either inside or outside of the hoop). The child had 4 throws.
- Horizontal throwing: the child was to throw a tennis ball horizontally through a hoop (30 cm in diameter) situated 1.5 m away. He/she had 4 throws with one hand and 4 with the other, beginning with his/her dominant side hand. The ball was thrown from their shoulders, in a straight line and without turning the trunk. The opposite foot (from the throwing hand) was to be placed in front of the other foot.

(ii) Receptive skills:

- Catching a ball: the child was to catch a ball thrown softly by an adult standing in front of him/her at a distance of 1.5 m. The adult had four throws.
- Catching a bouncing ball: the child was to catch a ball after it was bounced from a distance of 0.75 cm. The ball was thrown by an adult standing 1.5 m in front of the child and who threw the ball so that it bounced over a cross that was drawn some 0.75 m from the child, making sure that it bounced directly toward the child. The child was to catch it. The adult had four throws.

(2) Activities to observe the Fine motor skills:
(2a) Fine Motor Coordination:

- Tying a pencil: with a cord measuring 125 cm in length, the child was to form a knot around the pencil so that it was tied by the cord. The child had a maximum of three attempts to successfully complete the task.
- Touching fingertips: the child was to touch his/her thumb to the other fingertips of the same hand, beginning with the pinky finger and going in reverse order (that is from pinky finger, ring finger, middle finger, index finger, middle finger, ring finger, and pinky finger). Once the child completed the exercise with one hand, he/she was to carry it out with the other. The child began with whichever hand he/she wished. He/she had a maximum of three attempts to successfully complete the task.

(2b) Fine Motor Integration:

- Copying shapes: the participant was to copy 6 shapes of distinct complexities (cross, triangle, square, cross made up of an intersection of arrows, rhombus, triangle inscribed inside of another triangle). He/she was given a pencil and sheet of paper with the shapes that were to be copied, having three blank spaces below each shape where he/she could draw his/her copy. The child was not allowed to trace the shape in order to copy it. He/she could use an eraser prior to finishing the shape, but not afterward.

- Copying letters, words and numbers: the participant was to copy 3 letters of distinct complexities (V, H, and T); 3 words of distinct complexities (*TÍO, BOLA*, and *MANO*); and numbers from 1 to 5. The child was given sheets of paper with the letters, words and numbers that he/she was to copy. Under each letter/word/number to be copied, there were three blank spaces where the child could make the copies. The child was not allowed to trace the letter/word/number to be copied. He/she could use an eraser before finishing the letter/word/number, but not afterward.

As previously indicated, the motor circuit, as a methodological proposal, is characterized by different activities that demonstrate distinct motor skills, which may be of different typologies. The circuits intended for ECE students should include a maximum of 4 activities requiring distinct motor skills (Miraflores and Rabadán, 2007). In line with this recommendation, the previously described activities were organized to form five circuits. Each circuit consisted of three distinct activities (see **Table 2**). (The last activity of circuit 5 –free play– was not considered for this study, and therefore it has not been described).

Instruments

Given that a mixed methods approach was used, combining observational and selective methodology, distinct types of instruments were used for data collection in this study. First, we present the instruments used in observational data collection and then, those related to the selective methodology. Finally, the data analysis software is indicated.

Instruments Used for Observational Data Collection

Systematic observation demands the differentiation and use of distinct types of instruments. Therefore, it is necessary to differentiate between the observation instrument (built *ad hoc* to determine the behaviors of interest, based on the study objective) and recording instruments (used to record and code data).

Observation instrument

According to the demands of the observational methodology and taking into account the objective of our study, an *ad hoc* observation instrument was built to observe the motor skills used in each of the activities carried out by the children. Of the distinct types of observational instruments, an instrument that combined a field format and systems of categories was built. A system of exhaustive and mutually exclusive categories was hung from each of the criteria making up the field format. The choice of this type of instrument was justified by the multidimensionality of our observational design.

The instrument was built based on: (a) preliminary recordings of the real object of study; (b) theoretical and empirical studies on motor skills, specifically in childhood (Cameron et al., 2012; Gentier et al., 2013; Pitchford et al., 2016; Hestbaek et al., 2017; Oberer et al., 2017). It was necessary to create distinct versions until reaching the definitive version. The definitive version of the observation instrument is included in the **Supplementary Material**.

TABLE 2 | Motor activities making up each motor circuit.

Motor circuit	Motor activity 1	Motor activity 2	Motor activity 3
1	Hopping on one leg	Tying a pencil	Squatting with arms extended horizontally
2	Catching a ball	Walking heel-to-toe	Long jump
3	Touching fingertips	Vertical throwing	Jumping in place
4	Catching a bouncing ball	Standing on one leg	Copying shapes
5	Horizontal throwing	Copying letters, words and numbers	*Free play*

Free play = This activity was not considered in this study.

Recording instruments

The activity of each participant was recorded using a digital video camera.

Lince (v.1.2.1) (Gabin et al., 2012) free software was used to code observational data from each participant. It may be downloaded from http://lom.observesport.com/.

Instrument for Data Collection via Selective Methodology

The BADyG-I (*Battery of Differential and General Abilities I*; Yuste and Yuste Peña, 2001) was used to measure IQ of children and ensure that it was adequate for their chronological age (inclusion criteria 5). It is an instrument that was built, validated, and typified for a Spanish children and with adequate psychometric properties. It is composed by nine subscales. Each subscale has 18 items with five response options (five pictures). The test administrator reads a statement and the child must mark the picture that matches with it. BADyG-I allows to know Verbal, Non-verbal and General Intelligence.

For the evaluation of academic competencies, the PAIB-1 (*Test of basic instrumental aspects: Reading, writing and numeric concepts*; Galve-Manzano et al., 2009) was used in its pencil and paper version. This test allowed for the assessment of literacy and mathematics competencies, obtaining the following: (1) one score referred to Basic Aspects of Reading and Writing; (2) another score referred to Basic Aspects of Mathematics; (3) a total score for all academic competencies (Global Basic Aspects), sum of the 2 previous scores. Therefore, the PAIB-1 permitted the assessment of the most important academic competencies for academic success (Organization for Economic Co-Operation and Development [OECD], 2016), justifying its use as opposed to the use of other standardized instruments that only offer a global score. (Although PAIB-1 also permits the obtaining of other scores, they were not used in this study, given the objective of the same). The reliability of the PAIB-1 has been demonstrated (Galve-Manzano et al., 2009).

Data Analysis Software

To control the quality of the observational data, an essential aspect in observational methodology, intra and inter observer reliabilities were calculated using SAS 9.1.3 software (Schlotzhauer and Littell, 1997; SAS Institute Inc, 2004).

To carry out data preprocessing (precisely, to check our dataset for missing data) the 'VIM' package (Kowarik and Templ, 2016) of R computing language version 3.6.1 (R Core Team, 2019) was used.

To carry out an analysis that would respond to our study objective (determining which specific preschool motor skills was associated with academic competencies), the R computing language version 3.6.1. (R Core Team, 2019) was used. Specifically, the following packages were used: 'Stats' (R Core Team, 2019), 'QuantPsyc' (Fletcher, 2012), 'GGally' (Schloerke et al., 2020), 'ggplot2' (Wickham, 2016), 'gridExtra' (Auguie, 2017), 'lmtest' (Zeileis and Hothorn, 2002), 'car' (Fox and Weisberg, 2019), 'corrplot' (Wei and Simko, 2017), and 'base' (R Core Team, 2019).

Procedure

The school management team was informed of the broader research work, of which this study was part, and they agreed to participate in the same. Parents of children enrolled in the 3rd year of the ECE program at this school were also informed. Those wishing to do so (96.4%), authorized the participation of their child in the study. Thus, they signed a consent form, also indicating the required information on their child with regard to sample inclusion criteria 2, 3, and 4 (that is: school attendance at the targeted school since the 1st year of ECE; the intent to continue attending the same school over the following year; absence of disorders or risk factors). All of the children whose parents provided the signed informed consent complied with these inclusion criteria. Later, in order to determine compliance with the sample inclusion criteria 5 (having a suitable IQ for their chronological age), they were assessed using the BADyG-I. Administration of the BADyG-I was collectively carried out in two groups (natural groups of students attending the same class) in two 30-min sessions on non-consecutive days, following the instructions of the test manual. All children presented adequate IQs for their chronological ages. Therefore, they all formed part of the initial study sample.

The first two authors of this manuscript collectively designed each of the motor activities and circuits with the teachers, considering motor skills, educational resources and assessment methodology as determined by the Spanish government for the ECE period. They also considered the spatial conditions of the school's motor development classroom (where the circuits would be set up) and the temporal organization of each class group (that is, they considered the duration and periodicity of the motor development sessions for each group).

Each class group visited the motor development classroom according to their regular schedule. Each day, one circuit was completed. Before completing the circuit, the teacher explained and demonstrated each of the activities that formed part of a fantasy story to each child. All of the participants performed the activities in the same order (**Table 2**). Performance of each child on each activity was recorded with a video camera for its subsequent coding and analysis.

Video recordings were imported into the Lince software and were coded using the *ad hoc* observation instrument (available in the **Supplementary Material**) by two observers who are experts in observational methodology and preschool motor skills (the first two authors of this manuscript). The recorded data were converted into a matrix of codes that was subsequently tested for reliability.

Observational data quality was assured based on two guidelines (Portell et al., 2015a; Anguera et al., 2018a): (a) Qualitative: consensual agreement was used in the first 3 sessions to be codified for each activity (therefore, a total of 42 sessions) by the 2 expert observers; (b) Quantitative: calculating (b1) intra-observer reliability and (b2) inter-observer reliability. (b1) To calculate intra-observer reliability, observer 1, using the unused observation sessions for the calculation of consensual concordance, randomly selected 28 distinct observation sessions (2 sessions of each activity type). (b2) To calculate inter-observer reliability, observer 2 selected another 28 observation sessions, distinct from those used to calculate the consensual concordance and intra-observer reliability, but corresponding to 2 observation sessions for each activity type. Thus, a total of 98 different sessions were used for data quality control. Intra- and inter-observer reliability were calculated through an intra-class correlation coefficient, using SAS 9.1.3 software. In all cases, the intra-class correlation coefficient was ≥ 0.91. Therefore, the quality of the observational data obtained was excellent.

The following year, when the participants were in the 1st year of primary school education (specifically, at the end of the first quarter), they were administered (in group) the PAIB-1 in order to evaluate their academic competencies. The test was administered in two groups (maintaining children from the same class together for both groups). Test administration was carried out in accordance with the norms indicated in the test manual. So, for each group of children, two sessions were conducted (over non-consecutive days) of 45 and 40 min, respectively. Both the content of the PAIB-1 as well as its format and structure of application were quite similar to the assessment tests carried out by participants on a regular basis in the school.

Test correction was carried out online. Of all of the scores offered by the PAIB-1, in accordance with the study objective, the following three were considered: the score referring to Basic Aspects of Reading and Writing; that referring to Basic Aspects of Mathematics and the score referring to Global Basic Aspects.

Data Analysis

First, it was necessary to transform the observational data into an appropriate format in order to carry out data analysis. Each category observed in each activity was transformed into a score based on the degree of suitability involved for the execution of said activity (taking the current literature on the topic into consideration: Payne and Isaacs, 2017; Goodway et al., 2019; Haywood and Getchell, 2019). For each participant and activity, the scores corresponding to the observed categories in each activity were added together. Thus, each participant obtained a score for each activity (that is, 14 scores). Later, for each participant, the scores obtained for the two activities referring to each specific motor skills were added together (this relationship between activities and specific motor skills appears in **Table 1**). In this way, each participant obtained 7 scores, referring to the following specific motor skills: Locomotor skills, Dynamic

Balance, Static Balance, Propulsive skills, Receptive skills, Fine Motor Coordination, and Fine Motor Integration.

Data referring to academic competencies did not require transformation.

For both data types, referring to specific motor skills and academic competencies, Multiple Linear Regression analysis was carried out (see the next section). Before carrying out the analysis, the data preprocessing procedure was conducted. We check our dataset for missing data using the R computing language version 3.6.1. More specifically, the aggr() function from the R language package 'VIM' was used to visualize the number and proportion of missing values. Schafer (1999) asserted that a missing rate of 5% or less is inconsequential. So, deleting the missing values is a solution when the missing rate is lower than 5% for each variable. We used this solution in our study, given the low missing rate: missing-data rates of 7 variables (4 referring to motor skills and 3 referring to academic competencies) was 0. The rest of the variables (referring to motor skills: Dynamic Balance, Propulsive skills, and Receptive skills) had missing-data rates of 0.046.

Multiple Linear Regression Analysis

Multiple Linear Regression (MLR) analysis examines how multiple independent variables are related to a dependent variable (Pedhazur, 1997; Montgomery et al., 2012). The MLR model can accurately reflect correlations between variables, can indicate the degree of fit can improve the effect of the regression equation (Holmes and Rinaman, 2015). In educational research, MLR analysis is commonly used to measure the effects of the explanatory variables on performance (Fariña et al., 2015).

Taking this into account and given our study objective, MLR analysis was used to study the effects of multiple specific preschool motor skills on later childhood academic competencies. MLR modeling was performed using R computing language version 3.6.1. The data analysis procedure for MLR modeling was as follows.

First, the lm() function from the 'Stats' core package was used to calculate the MLR models. In line with the aim of our study, 3 MLR models were applied to investigate the effects of multiple preschool motor skills on different childhood academic competencies. More precisely, a model was calculated for each of the 3 dependent variables of interest related to academic competencies: (1) Basic Aspects of Reading and Writing; (2) Basic Aspects of Mathematics, and (3) Global Basic Aspects. Also taking into account our objective, the independent variables included in each of this models were the 7 specific motor skills: Locomotor skills, Dynamic Balance, Static Balance, Propulsive skills, Receptive skills, Fine Motor Coordination, and Fine Motor Integration.

Second, to select the most explanatory variables, we used a mixed stepwise strategy (Osborne, 2017). The mathematical value used to determine the quality of the model was the Akaike Information Criterion (AIC; Akaike, 1973). It helped to make decisions regarding which model was the most appropriate. The model with the lowest AIC value was considered the best at explaining the data. The step() function from the 'Stats' package was used for this.

Third, to compare the independent variables included in each model and to determine which one had the strongest relationship with the dependent variable, we generated standardized regression coefficients (β) with the lm.beta() function from the 'QuantPsyc' package.

Fourth, analyses were carried out to ensure that there was no violation of the MLR assumption: (a) linearity in the parameters; (b) normal error distribution; (c) homoscedasticity of errors; (d) independence of errors; (e) multicollinearity, and (f) no influential cases (Nimon, 2012; Williams et al., 2013). Different indicators were used to verify these assumptions. They are explained below.

(a) *Linearity*. We examined whether or not the relationship between the independent variables and the dependent variable was linear by looking at: (1) the scatter plot between the dependent variable and each of the independent variables: the points should be distributed around a diagonal line. We used a ggpairs() function from the 'GGally' package. (2) The scatter plots between each of the independent variables and the model residuals. If the relationship was linear, the residuals should be distributed randomly around 0 with a constant variability along the X-axis. ggplot() function from the 'ggplot2' package and grid.arrange() function from the 'gridExtra' package were used.

(b) *Normality of distributed errors*. For the MLR analysis, the normality assumption applies to the error distributions (residuals), rather than to predictors and the outcome variables (Williams et al., 2013). This assumption had been verified using: (1) The quantile–quantile plots (Q–Q plot): good alignment to the line should be identified, with no dramatic deviations from it, implying no drastic deviations in error distribution. qqnorm() and qqline functions were used from the 'Stats' package. (2) Shapiro–Wilk normality test: It should reveal high p-values ($p > 0.05$) to the null hypothesis of the residual being normally distributed. We used the shapiro.test() function from the 'Stats' package.

(c) *Homoscedasticity*. Two indicators were used to check homoscedasticity: (1) Scatter plots of residuals: the data points should be distributed above and below zero on the X-axis, and above and below zero on the Y-axis. When this occurs, it implies a homogeneous distribution of residuals, i.e., the data were homoscedastic. ggplot() function from the 'ggplot2' package was used. (2) Breusch–Pagan test: when the Breusch–Pagan test revealed high p-values ($p > 0.05$), the null hypothesis of homoscedasticity may be assumed. We used the bptest() function from the 'lmtest' package.

(d) *Independent errors*. The Durbin–Watson test was carried out to check for autocorrelation between the investigated variables. This value should lie between the critical cutoff of $1.5 < d < 2.5$ to assume that there was no first order linear auto-correlation in the multiple linear regression data; that is, the independent errors could be assumed. We used dwt() function from the 'car' package.

(e) *Multicollinearity*. Two indicators were used to consider multicollinearity: (1) The correlation matrix between the independent variables: the correlation between the independent variables should be low. When this occurs, it indicates that the independent variables in the model were not correlated and did not provide redundant information about the dependent variable. We used the corrplot() function from the 'corrplot' package. (2) The variance inflation factor (VIF): if the VIF values for each independent variable were <10 and even <4 [a more demanding value, defended by other authors such as Hair et al. (2010)], there was no problem with multicollinearity. We used the VIM() function from the 'car' package.
(f) *No influential cases*. Cook's Distance was used to check for no influential cases. Cook's Distance >1 indicates an influential case (Cook, 1977). Consequently, Cook's Distance <1 was desirable, suggesting that individual cases were not unduly influencing the model. We used the cooks.distance() function from the 'base' package.

RESULTS

The summary statistics of variables for each MLR model are presented in **Table 3**. More precisely, the unstandardized beta (*B*), standard error for the unstandardized beta (*SE*), standardized beta or standardized regression coefficients (β), confidence intervals (CI), *t*-statistic values and its *p*-values, multiple *R*-squared (R^2), adjusted *R*-squared (R^2adj) and *F*-statistic are shown.

The MLR model that examined the relationship of Basic Aspects of Reading and Writing to motor skills was significant [$F(2,35) = 5.5$, $p = 0.008$]. Basic Aspects of Reading and Writing was positively associated with Coordination ($p = 0.025$) and Integration ($p = 0.024$), explaining 20–24% of its variance ($R^2 = 0.239$; R^2adj = 0.196). A one-point increase in Coordination score (holding Integration constant) was associated with an increase of 0.165 points in Basic Aspects of Reading and Writing score; a one-point increase in Integration score (holding Coordination constant) was associated with an increase of 1.373 points in Basic Aspects of Reading and Writing score. The magnitude of the β coefficients of Coordination (β = 0.344) and Integration (β = 0.349) was almost equal, thus the weight of each of these specific motor skills in Basic Aspects of Reading and Writing was similar. All of the assumptions of MLR (linearity, normality of distributed errors, homoscedasticity, independent errors, multicollinearity, and no influential case) were met.

In the case of Basic Aspects of Mathematics, the optimal MLR model only included Integration [$F(1,36) = 10.55$, $p = 0.002$]. The association between these two variables was positive. For every additional point on Integration, the Basic Aspects of Mathematics score was 2.009 points higher. Integration explained 21–23% of the variance in Basic Aspects of Mathematics ($R^2 = 0.227$, R^2adj = 0.205). All of the MLR assumptions were met.

The MLR model testing Global Basic Aspects was significant [$F(2,35) = 7.981$, $p = 0.001$]. Coordination ($p = 0.065$) and Integration ($p = 0.001$) were positively associated with Global Basic Aspects, accounting for 27–31% of its variance ($R^2 = 0.313$, R^2adj = 0.274). For every additional point in Coordination (holding constant Integration), Global Basic Aspects increased by 0.223 points; for every additional point in Integration (holding constant Coordination), Global Basic Aspects increased by 3.385 points. According to β coefficients, Integration (β = 0.493) had a greater weight on Global Basic Aspects than Coordination (β = 0.267). All of the assumptions of MLR were met.

In summary, the 3 calculated MLR models were significant. In each of these, only one or two independent variables were included, with these always being specific fine motor skills

TABLE 3 | Summary of statistics of variables of each MLR model calculated.

Dependent variables	Independent variables	*B*	*SE*	β	95% CI	*t*	*p*	Multiple R^2	Adj. R^2	*F*
Basic aspects of reading and writing										
	Intercept	15.000	9.050		-3.372, 33.373	1.657	0.106			
	Coordination	0.165	0.071	0.344	0.021, 0.309	2.334	0.025*	0.239	0.196	5.5**
	Integration	1.373	0.580	0.349	0.196, 2.551	2.367	0.024*			
Basic aspects of mathematics										
	Intercept	−14.107	9.003		-32.366, 4.152	−1.567	0.126	0.227	0.205	10.55**
	Integration	2.009	0.619	0.476	0.754, 3.264	3.248	0.002**			
Global basic aspects model										
	Intercept	−1.785	14.996		-32.228, 28.658	−0.119	0.906			
	Coordination	0.223	0.117	0.267	-0.016, 0.461	1.904	0.065	0.313	0.274	7.981**
	Integration	3.385	0.961	0.493	1.433, 5.337	3.521	0.001**			

*p < 0.1, *p < 0.05, **p < 0.01. B, unstandardized beta; SE, standard error for the unstandardized beta; β, standardized beta or standardized regression coefficient; CI, confidence interval; t, t-statistic value; p, p-value of t-statistic; R^2, multiple R-squared; R^2adj, adjusted R-squared; F, F-statistic value.*

(never specific gross motor skills). The 2 specific fine motor skills (Coordination and Integration) had an association with Basic Aspects of Reading and Writing and Global Basic Aspects. However, only one of them (Integration) revealed an association with Basic Aspects of Mathematics.

DISCUSSION

The main goal of this study was to determine which specific preschool gross and fine motor skills assessed in Spanish students enrolled in the last year of ECE (5–6 years) were associated with later academic competencies (specifically, in literacy and mathematics and overall) assessed over the following academic year, when students were in their 1st year of Primary Education.

Some of the results obtained are congruent with past findings while others are contradictory. There is no consensus on this topic in the scientific literature and the results are quite disparate. Furthermore, it should be noted that comparison between the results of the diverse studies is complex and should be made with caution, given the distinct sample characteristics from these studies, as well as the variety of motor skills and academic competencies assessed using diverse instruments. In our case, we are unaware of any other studies that have examined the same specific children's motor skills and academic competencies as those analyzed in our study, using samples of the same age and characteristics, and using the same tasks and assessment tools. All of these variables differ in the studies that have been consulted and this may contribute to the distinct results obtained in each of these (Veldman et al., 2019).

However, and with the previously mentioned caution, we have found our results to be coherent with the literature in terms of the different associations between specific motor skills and academic competencies when this variable (academic competence) was considered globally or specifically, for each main academic domain (literacy and mathematics) (Zhang et al., 2019). Our results are also coherent with other studies in that specific fine motor skills have been found to be more closely linked to academic competencies than specific gross motor skills (Grissmer et al., 2010; Pagani et al., 2010; Pagani and Messier, 2012; Gandhi et al., 2013; Cameron et al., 2016; Pitchford et al., 2016; Zhang et al., 2019). In fact, in our study, specific gross motor skills were not found to be associated with academic competencies, also in accordance with the results of other authors (Grissmer et al., 2010; Pagani et al., 2010; Pagani and Messier, 2012; Gandhi et al., 2013; Pitchford et al., 2016; Macdonald et al., 2020). However, in the literature, certain results contradict this finding: some authors suggest significant associations between gross motor skills and academic competencies both in the literacy and mathematical domains (Son and Meisels, 2006; Pagani et al., 2010; Abdelkarim et al., 2017; de Waal, 2019).

Our results suggest specific associations between the components of fine motor skills (Coordination and Integration) and the academic competencies. Once again, these results are coherent with some past findings, although they disagree with others. And there is a clear lack of consensus in the literature with regard to these relationships, particularly with regard to Coordination. Our results suggest that Coordination is associated with literacy competencies and global academic competency, but not with mathematics competencies. This lack of association between Coordination and mathematical aspects was also supported by Kim et al. (2018). Our results are also congruent with those of other authors who have suggested that Coordination is associated with the literacy domain (Pagani et al., 2010; Dinehart and Manfra, 2013; Manfra et al., 2016; Doyen et al., 2017; Oberer et al., 2018). But unlike our study and that of Kim et al. (2018), these authors have suggested that Coordination is also associated with mathematical competencies. The results of Pitchford et al. (2016) were in partial agreement with those of this series of authors, but they contrasted ours and those of Kim et al. (2018). They found that Coordination was only associated with mathematical aspects, but not with literacy. As for Integration, our results, like those of the literature, revealed associations with both literacy and mathematics competencies (Grissmer et al., 2010; Dinehart and Manfra, 2013; Manfra et al., 2016; Pitchford et al., 2016; Duran et al., 2018; Macdonald et al., 2020).

In summary, our results contribute to the knowledge on the specific relationships existing between the components of gross and fine motor skills in preschoolers and their later academic competencies. However, more research on this topic is necessary, given the disparity of the results found in the literature. Although, as mentioned in the Introduction section, evidence suggests that certain brain structures are responsible for motor and cognitive functions (Diamond, 2000, 2007; Grissmer et al., 2010; Pitchford et al., 2016), our findings suggest that this does not guarantee that all specific motor skills scores are significantly associated with all academic competencies score (Chagas et al., 2016).

On the other hand, as shown in all cases, the percentage of variability in academic competencies that is explained by the different specific motor skills varied from R^2adj = 0.196 to R^2adj = 0.274. In the humanities and social sciences, these R^2adj values lie within an acceptable range, with these values being quite typical (and even other lower ones) in many education studies, some of which also focus on the explanation of academic performance (Oliveira et al., 2017; Pires et al., 2017; Cueli et al., 2019; Morales-Rodríguez et al., 2019; Schorr, 2019; Xiao et al., 2019; Tinajero et al., 2020). Social phenomena are complex and multidimensional, so it is not expected that all relevant variables indicating the subject's behavior will be included. Therefore, it is very difficult to explain a very large amount of variation (Neter et al., 2012; Xiao et al., 2019). Also, it should be highlighted that even if the R^2adj values were considered to be low, the low p-values suggest that motor skills included in the models were significantly correlated with academic competencies, meaning that important conclusions could still be drawn from the models (Neter et al., 2012). Ultimately, in explaining human behavior, even small values of R^2adj can be quite meaningful. They can certainly be used to better understand the phenomenon under study (Abelson, 1985; Moksony, 1999). But, of course, it would be interesting for future studies to include other variables that affect the academic competencies, in addition to those studied here, such as additional personal factors of students (birth weight, gestation period, children's emotions, behavior problems, cognitive dimensions, etc.), family characteristics (educational style of parents, socioeconomic status, etc.) and aspects of the school system (teacher expectations of students, pupil-teacher relationships, etc.) (Pires et al., 2017; Zhang et al., 2019). This would permit an increased understanding of the topic and the design of optimal interventions to improve students' academic competencies.

The results of our study have numerous educational implications. Therefore, we believe that it is necessary to clarify the following point: Although our results do not reveal significantly positive associations between gross motor skills and academic competencies, negative associations were not found. So, our results do not suggest that gross motor skills should be discarded by ECE teachers. The goal of this educational period is to contribute to the child's overall development, and since numerous works have affirmed that gross motor skills promote childhood social competencies development (Goodway et al., 2019; Haywood and Getchell, 2019), their inclusion in preschooler educational practices is more than justified.

Our results highlight the importance of fine motor skills in ECE in order to strengthen subsequent academic achievement. However, frequently, the reality of the classroom situation is quite different. Motor skills, in general, are not highly valued, and therefore, they may not be promoted to the extent that is truly necessary. This appears to be due mainly to the common misconception that children develop motor skills in a natural manner, during their maturation process. However, motor skills do not emerge naturally. They must be learned, practiced, and reinforced (Logan et al., 2012; Pic et al., 2018, 2020). But, this is often forgotten, given the pressure existing in the lower education levels toward instrumental learning. As a result, many childcare settings focus exclusively on academic content, making young children's opportunities to advance motor skills in these settings increasingly limited (Cameron et al., 2016; Osborne et al., 2016; Macdonald et al., 2020).

Research on motor skills suggests that these skills are fundamental for early learning and that they are quite malleable during this early childhood period. In fact, preschool years (3–5 years of age) have been called the "golden age" for motor skills development and learning, suggesting possible windows of intervention (Shenouda et al., 2011). In Spain (and also in most of the other European countries), almost all children of these ages attend ECE, even though it is not a mandatory school phase (European Commission/EACEA/Eurydice, 2019; Spanish Ministry of Education and Professional Training, 2019). Therefore, it is an ideal opportunity for all children, regardless of their socioeconomic background, to develop and improve their motor skills. Furthermore, early education teachers form a part of the children's micro context, monitoring these children for longer periods of time and gaining the trust of their families. This makes them the ideal candidate to promote motor skills and identify early motor problems, and to implement planned programs that prevent or mitigate them (Cueto et al., 2017; Tsangaridou, 2017). These planned movement activities should form a routine part of the preschool curriculum and should be based on play, more specifically, guided play (in which an adult selects or arranges a context for learning but the children direct the play; although the adult may provide scaffolding and guidance), since this is the most natural way of learning and developing in children (Weisberg and Zosh, 2018; Yu et al., 2018; Zosh et al., 2018).

However, it is necessary for ECE teachers to increase play-based opportunities to ensure the development of children's motor skills. Environment-initiated practice opportunities greatly influence both the rate and direction of motor development (Ward et al., 2019). Early motor stimulation before the child engages in formal learning helps to create neuronal networks that may facilitate school readiness and academic knowledge acquisition (Thomas et al., 2019).

But in order to plan successful opportunities to promote the development of children's motor skills, adequate prior assessment is necessary. ECE teachers have declared that they lack the skills and knowledge necessary to assess children's motor skills and therefore, may be unable to engage in appropriate motor practices for young children (Gehris et al., 2015; Cueto et al., 2017). This may be one of the reasons why motor skills are not being promoted in ECE to the extent that they should be. The ECE curriculum in Spain and other European countries declares that action and movement are essential principles that must be acquired during this educational period (European Commission/EACEA/Eurydice, 2019). So, ECE teachers are required to assess motor skills. However, the literature indicates that many motor skill assessments carried out by the ECE teachers are based on impressions and personal subjectivity, given a lack of training on the same. Teachers indicate that their limited knowledge, especially of assessment techniques, significantly limits their use of measurement tools which may provide objective and precise information (Cueto et al., 2017). In fact, the literature indicates that only 54.7% of the ECE teachers are capable of correctly assessing their students' motor skills. Of those committing assessment errors (improperly assessing their students' motor skills), 91.5% overestimate their students' abilities. And even more alarmingly, 13.27% of the teachers assess their students' motor skills as being normal when in fact, they suffer from deficits (Cueto et al., 2017). This may have major consequences on the student's development and learning over the short, medium and long term, since they may be denying the possibility of necessary intervention that would improve their motor skills, thus, limiting their later academic achievement. This lack of preparation by ECE teachers on suitable assessment and intervention of motor skills is not limited to Spain, but is a global problem, as reported over and over in the international scientific literature (Robinson et al., 2012; Gehris et al., 2015; Battaglia et al., 2019).

So, one of the clear highlights of our study is that it offers a tool (and even better, a free tool) that permits to objectively assess motor skills in the children's natural educational context (see the *ad hoc* observation instrument, available in the **Supplementary Material**). So, our study responds to the current need to construct practical tools that permit the assessment of motor skills by ECE teachers (Cueto et al., 2017); and more specifically, the need to increase the limited number of observational tools currently available to teachers in order to identify children having motor problems (Figueroa and An, 2017). Based on these assessments, it would be possible to design and implement teaching practices and interventions that are suited to the specific needs of the students. The built tool would also be useful to assess progress and evaluate the efficacy of these practices and interventions, permitting their modification and thus, offering an evidence-based practice. All of this would clearly improve the early motor skills and offer the possibility of improved future academic achievement for the children.

Another highlight of our work is the fine-grained assessment of the distinct components of motor skills. We have assessed all of the specific preschool motor skills, both gross and fine, identified in the reviewed literature, thereby addressing the multidimensional nature of motor skills and their specific relationships with academic competencies. Many authors criticize the fact that many studies report motor outcomes and only include one overall motor skill or, when including various measures, all of them come from one instrument that is used to assess the holistic development of the children instead of specific components of motor child development (Kim and Cameron, 2016; Macdonald et al., 2018). Therefore, our study extends beyond the limited view of motor skills that has been commonly presented in empirical scientific studies.

The same occurs with regard to academic competencies. Studies reporting academic outcomes often offer only one overall academic performance score (i.e., a combination of literacy and mathematics) (Macdonald et al., 2018). However, in our study we have adopted a more multidimensional approach, considering not only an overall academic competency score, but also analyzing the literacy and mathematics competencies separately. And we have used a standardized instrument to do so, therefore offering a more objective, reliable and valid assessment as compared to the use of only qualifications provided by teachers (Marzano, 2000; Organization for Economic Co-Operation and Development [OECD], 2012; Castejón et al., 2016; Meissel et al., 2017).

Thus, all of the aspects considered in our study respond to suggestions made by various authors (Son and Meisels, 2006; Kim and Cameron, 2016; Macdonald et al., 2018) who have proposed that future studies employ in-depth assessment of motor skills and academic achievement, including diverse aspects of motor skills and academic competencies, in order to better determine which specific aspects of motor skills are associated with which specific aspects of academic achievement. However, to extend upon our study, future works should consider an even broader perspective on these academic competencies than that considered here, including more specific scores on diverse aspects of the linguistic domain (e.g., vocabulary and spelling) and mathematics (operations, measurement, etc.). This would provide even more knowledge on the specific relationships between motor skills and academic competencies, offering more support for the inclusion of certain types of activities at school.

We also believe that future works should continue to examine not only which motor and academic aspects are specifically related, but also how and why. The use of other data analysis techniques, in addition to educational neuroscience studies may provide additional knowledge to optimize learning practice (Coch, 2018; Thomas et al., 2019).

So, in our study, we highlight the use of two motor activities to assess each of the specific motor skills, as opposed to only one, as is the case in most studies (Tomac et al., 2012). This is in line with recommendations of other authors, although it implies a major effort (Cameron et al., 2016). Assessing each specific motor skill in two activities provides additional information on the children's level of each specific gross and fine motor skill. However, it is clear that in the analyses of this study, we have not separately considered the motor performance carried out in each of these activities. Future studies should examine whether or not the level of execution differs in each of the two activities in which each specific gross and fine motor skill was assessed. Studying the different demand characteristics across the spectrum of motor activities could help illuminate why and when a particular task and a particular skill contribute to various educational outcomes (Cameron et al., 2016). It may also assist in instruction, assessment, and intervention programs.

It is important to indicate that in this study, we have attempted to describe each of these activities in detail, in response to criticisms of other works that failed to specify the tasks used for motor skills assessment (typically only mentioning the tasks, without providing any additional information). Using a certain activity to assess the same motor skill may result in distinct results. Therefore, failing to offer a detailed explanation of the tasks used may hinder the comparison of results of different studies (Veldman et al., 2019).

In addition, the descriptions of activities and circuits that we have presented in this study may also help the professional practice of ECE teachers as it offers examples of specific motor activities that can be applied to children (specifically, 5–6 year-olds), designed with consideration to the ECE curriculum and recommendations of the Spanish Health, Social Services and Equality Ministry and the Spanish Education, Culture and Sports Ministry. Often, teachers complain of a lack of resources and materials available to implement practices that improve preschool motor skills, as well as their lack of training and time to design the same (Robinson et al., 2012). Therefore, this work may be useful.

On the other hand, this study has examined the motor skills of children during a changing moment, which, despite being of special importance for their development and learning, has barely been considered in research. In general, motor skills tend to be studied at a very young age, based on a clinical perspective, focusing on dysfunctions or inefficient movement behavior, or at later ages, with regard to athletic skills (Altunsöz, 2015). So, despite its importance, research on motor skills in preschool children is scarce and quite fragmentary (Cools et al., 2009). Our study has attempted to contribute to the elimination of this gap. Many authors have defended the potential usefulness of assessing preschool motor skills in a normative sample and in an educational context, as was done in this study (Hyson and Douglass, 2019).

Our results reveal associations between specific fine motor skills of preschoolers and their academic competencies one school year later, in the 1st year of Primary Education. It would be interesting to carry out a follow up study to determine if the relationship between specific preschooler motor skills and academic competencies differ during Primary Education grades and beyond.

Of course, in the future it may be necessary to also increase sample size, given its small size is one of the main limitations of this study. However, difficulties in doing arise when working with minors (Fargas-Malet et al., 2010; Elwick et al., 2014): (1) it is necessary to rely on the cooperation of different "gatekeepers," such as school staff and parents. At times, the school staff is so overworked that, even though the importance of the study is recognized, they do not collaborate. With regard to parents, it is not unusual overprotective attitudes toward their children and consequently, the non-authorization for participation of their children in studies. (2) The evolving characteristics of the children, such as their great degree of distraction even when playing, high fluctuation of motivation and rapid fatigue (Zosh et al., 2018), requiring greater time and effort in data collection.

Other issue that also justifies the smaller sample size is the use of observational methodology. This methodology is distinguished by its intensive nature as compared to the extensive nature of other methodologies; i.e., there is a greater interest in obtaining a large quantity of detailed information on the natural behavior of a small number of participants than in the representativeness with respect to a larger population (Anguera, 2003). In addition, in order to capture the richness of information on participant behavior, this methodology demands the building of a reliable and precise *ad hoc* observation instrument (in this case, it is available in the **Supplementary Material**). This implies arduous and detailed work. Other characteristics of the observational methodology (such as the need to rely on expert observers or to devote time to their training, and the need to carry out rigorous quality control of the data) require much time, effort and cost for the researchers (Portell et al., 2015b; Bardid et al., 2019; Maddox, 2019).

All of this serves to explain and justify why observational studies, and hence, our study, are carried out using a smaller, accessibility-based sample. In fact, the high cost involved in observational studies, even when recognizing their greater suitability in examining child development and learning, has led to a preferred use of other, less costly methodologies (Maddox, 2019). Little value has been placed on the extra effort made in studies involving the direct behavioral observation and the increased effort required when observing the behavior of young participants (Patterson, 2008). Furthermore, it should be noted that observational studies are often "punished," considering them to be undervalued, based on the predominantly scientific-based perspective of the experimental paradigms (Rozin, 2009). So, we advocate a correct and just assessment of observational studies, defending their use, despite the effort that they imply in many aspects, since this methodology is the most appropriate and possibly even the only potential option for the study of spontaneous childhood behavior in an educational setting (Anguera, 2001; Escolano-Pérez et al., 2017, 2019a,b; Bardid et al., 2019; Vitiello et al., 2019). Systematic observation provides rich and contextualized information that cannot be obtained from other methodologies, making it possible to gather relevant data to describe, explain, and understand fundamental aspects of children's development and learning (Federici et al., 2017; Otsuka and Jay, 2017). So, more observational studies are clearly needed in order to better understand childhood development and learning and thereby implement more effective early educational practices.

CONCLUSION

The mixed methods approach used has allowed us to know that only the fine motor skills, and not the gross ones, of preschool children (5 to 6-year-olds) are associated with their academic competencies 1 year later, when the students were in their 1st year of Primary Education. These results highlight the importance of preschool fine motor skills in order to strengthen subsequent academic achievement. Given fine motor skills are quite malleable during this early childhood period, ECE teachers have to increase play-based opportunities to ensure and promote the development of children's fine motor skills. This early educational practices will encourage future academic achievement.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

This study was part of a broader research study that was evaluated and approved by the Research Unit of the University of Zaragoza. Research was also approved by the school management team. In accordance with Organic Law 15/1999 of December on Protection of Personal Data (1999, BOE no. 298 of December 14), all parents of the participants signed the informed consent authorizing the participation of their children in the study and their being recorded. In addition, and following the guidelines of the aforementioned law, observers signed the confidentiality agreement. No special ethical approval was required for this research since the Spanish public education system and national regulations do not require such approval. Each participant received a small reward (two chocolates) in gratitude for their participation.

AUTHOR CONTRIBUTIONS

EE-P was involved in conceptual and methodological structure, literature review, collecting data, systematic observation, manuscript drafting, data analysis, results, and discussion. MH-N was involved in data collection and systematic observation. JL was involved in methodological structure and data analysis. All authors contributed to revising the manuscript and provided final approval of the version to be published.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.01044/full#supplementary-material

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Physical Exercise and Fitness Level Are Related to Cognitive and Psychosocial Functioning in Adolescents

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The purpose of this study was to analyze the relationships among physical exercise and fitness with selective attention, concentration, processing speed, general self-efficacy, self-rated health, and satisfaction with life. 208 adolescents between 14 and 16 years, from the city of Malaga (Spain), participated in the study. A comparative and predictive design was used to carry out this research. The instruments used for the evaluation were the Tanita® BC-601 Body Composition Monitor, the Eurofit Physical Condition Test Battery, the D2 Test of Attention, the WISC-IV Symbol Search and Coding tests, the General Self-Efficacy Scale (GSE), the General Health Questionnaire (GHQ-28), and the Satisfaction with Life Scale (SWLS). Analysis of variance (ANOVA), Kruskal–Wallis test, correlation analysis and linear regression were used to contrast the research objectives. The results indicated that adolescents who practiced more hours of physical exercise per week and were in better physical fitness achieved higher scores in selective attention, concentration, processing speed, general self-efficacy, self-rated health, and satisfaction with life. In addition, cardiorespiratory fitness was the physical fitness variable most closely related to and predictive of cognitive and psychosocial functioning. Cardiorespiratory fitness was predictor of all the variables analyzed, except the factor anxiety and insomnia (self-rated health), and life satisfaction that were predicted by horizontal jump measurements and fat mass, respectively. Thus, the study findings indicate that adolescents who practiced more weekly physical exercise and had a higher level of physical fitness scored better on the cognitive functioning and psychosocial tests evaluated. The data suggest that engaging in physical exercise and fitness in adolescence may be appropriate to improve health and well-being, contributing to better development at this stage.

Keywords: physical exercise, cognitive, psychosocial, quality of life, health

INTRODUCTION

Numerous studies have pointed out the physical, psychological, and social benefits that physical exercise can bring to adolescents (Esteban-Cornejo et al., 2015; Swann et al., 2018). Among them, the relationships between the practice of physical exercise with cognitive, and psychosocial functioning at these ages are relevant (Eime et al., 2013; Lubans et al., 2016; Cooper et al., 2018;

Pontifex et al., 2019). On the one hand, adolescents with adequate cognitive functioning improve their adaptation to the environment, increase the likelihood of success in numerous everyday tasks, and contribute to their future mental health (Lubans et al., 2016; Zmyj et al., 2017). Furthermore, cognitive functioning is related to social cognition, which is essential for effective social interactions (Gil et al., 2012). On the other hand, in adolescence identity is formed, interpersonal bonds are established, and psychosocial skills are developed (Viholainen et al., 2014; Wilson et al., 2014). Physical exercise or sport often takes place in contexts of continuous social interaction and comparison, requiring the acquisition of skills necessary for good psychosocial development (Holt, 2008; Swann et al., 2018). Therefore, practicing physical exercise regularly and in appropriate environments could facilitate better adaptation to the environment, contributing to greater well-being and quality of life (Lubans et al., 2016).

In this context of study, it has been highlighted in recent years that only practicing physical exercise does not ensure health benefits. Some research has pointed to the need to achieve an adequate level of physical fitness to develop improvements in cognitive aspects and optimize psychosocial functioning in people (Herting et al., 2014; Ho et al., 2015; Kantomaa et al., 2015; Fraguela-Vale et al., 2016; Reloba-Martínez et al., 2017). So, various studies have suggested in recent years that cardiorespiratory fitness is the best predictor of optimal cognitive and psychosocial functioning (Becerra-Fernández et al., 2013; Chaddock et al., 2014; Herting et al., 2014; Reigal et al., 2014).

Specifically, in recent years much progress has been made in understanding how physical exercise is related to cognitive functioning. Advances in neuroscientific knowledge (Chaddock et al., 2014), making it possible to resolve questions that were unknown decades ago, are supporting the findings in this area. The use of techniques such as electroencephalography, functional magnetic resonance imaging, and magnetoencephalography, together with the study of proteins such as BDNF (brain-derived neurotrophic factor), IGF-1 (insulin-like growth factor-1), and VEGF (vascular endothelial growth factor), are helping to achieve essential milestones for the development of this field of knowledge (e.g., Tari et al., 2019; Voss et al., 2019). For example, there is evidence of structural changes in the brain associated with increases in physical fitness, and this is a reliable indicator of the impact that physical exercise is thought to have on the brain (Esteban-Cornejo et al., 2017; Chaddock et al., 2018). Also, Chaddock et al. (2010) observed positive relationships among aerobic performance with hippocampal volume and the striated dorsal body. Furthermore, Chaddock et al. (2018) found an increase in the white matter microstructure of the genu of the corpus callosum after a program of physical exercise. In another study, Esteban-Cornejo et al. (2017) noted relationship among cardiorespiratory capacity and speed/agility with the volume of gray matter in various areas of the brain.

Thus, some research has highlighted the relationships among physical exercise and variables such as attention, concentration, working memory, inhibitory control, cognitive flexibility, processing speed, and language (e.g., Liu et al., 2018; Ludyga et al., 2018; Westfall et al., 2018; Xue et al., 2019). Specifically, attention has been an object of interest in a number of studies (Budde et al., 2008; Vanhelst et al., 2016). The ways in which selective attention and concentration are related to physical exercise and physical condition have been analyzed and positive associations have been found between them (Guiney and Machado, 2013; Tine, 2014; Reloba-Martínez et al., 2017). Likewise, cognitive processing speed has been explored, also indicating positive links with physical performance (Hillman et al., 2005; Pontifex et al., 2011). Both selective attention, which is the ability to attend to a particular series of stimuli and ignore others (Giuliano et al., 2014), and concentration or processing speed are factors that affect the efficiency with which multiple tasks are performed, such as academic or social tasks (Perlman et al., 2014; Rabiner et al., 2016).

Also, other studies have pointed out relationships between physical exercise and psychosocial variables such as life satisfaction, self-efficacy, and perception of health. Self-efficacy constitutes the judgments made about one's own abilities and their effectiveness in carrying out a task (Bandura, 1986). Its development is complex and is thought to depend on factors such as previous successes, vicarious experience, verbal persuasion, and physiological states (Bandura, 1986, 1997). Many authors suggest that self-efficacy is specific; others, however, argue for the existence of general self-efficacy (Schwarzer, 1992; Schwarzer and Jerusalem, 1995). Perception of health refers to the judgments people make about the level of physical or mental health they possess, and it can be a predictor of levels of mortality and future disease, even in a young population (Bombak, 2013; Kantomaa et al., 2015). Finally, satisfaction with life involves an overall assessment of what life itself is like, the conditions in which it is developed, whether the expectations created have been fulfilled or are being achieved, etc., and it is one of the indicators that are usually evaluated when analyzing subjective well-being (Diener et al., 1985; Miller et al., 2019).

The analysis of well-being has been carried out from different models (Ryff, 1989; Keyes et al., 2002). The hedonic tradition presents well-being in subjective terms and is linked to aspects such as life satisfaction. From the eudaimonic tradition it is linked to human potential and has been studied under the construct called psychological well-being (Ryff, 1989). Specifically, Keyes's model extends Ryff's to speak of social well-being, and considers that mental health requires positive psychosocial functioning (Keyes et al., 2002). From this point of view, emphasis has been placed on the so-called psychosocial well-being, which would refer to aspects such as perceptions of themselves, the ability to function effectively in the environment or the perception of health (Pinquart and Silbereisen, 2004). For this reason, the analysis of variables such as self-efficacy, perception of health or life satisfaction are relevant to determine the mental health or well-being in people. Therefore, analyze whether physical exercise could be related to these variables becomes very important, due to the repercussion that it can have on the health and quality of life of adolescents.

So, previous research has revealed positive relationships among physical exercise and physical fitness with self-efficacy (Ho et al., 2015), perception of health (Bombak, 2013; Kantomaa et al., 2015), and life satisfaction (Zullig and White, 2011;

Fraguela-Vale et al., 2016). In general, appropriate engagement in physical exercise and sport is considered an effective tool for improving numerous psychological issues in adolescence and other stages of life (Lubans et al., 2016).

The aim of this study was to determine if the weekly physical exercise volumen and physical fitness are related to cognitive and psychpsocial functioning in a sample of adolescents. For this purpose, we first analyzed the differences between various groups divided by hours of weekly physical exercise, and secondly, we evaluated whether there were correlations between the study variables, as well as whether physical fitness could predict measures of cognitive functioning and psychosocial variables studied.

MATERIALS AND METHODS

Study Design

This is a comparative and predictive study (Ato et al., 2013).

Participants

A total of 208 adolescents (boys = 50.96%, girls = 49.04%) aged between 14 and 16 years from the city of Malaga (Spain) were included in the study [mean (M) $\pm$ standard deviation (SD): age = 15.25 $\pm$ 0.74 years; height = 167.65 $\pm$ 9.67 cm; weight = 63.75 $\pm$ 14.76 kg; and body mass index (BMI) = 22.59 $\pm$ 4.29 kg/m^2]. The initial inclusion criteria was to be between 14 and 16 years old. Those who had significant health problems that did not allow them to carry out the evaluation tests following the specified protocol (e.g., physical injury), failed to provide informed consent, or failed to complete the tests correctly were excluded. Out of 224 possible participants, the sample was finally made up of the 208 indicated. Sampling was not probabilistic, it was chosen for convenience.

Instruments and Measures

(a) D2 Test of Attention (Brickenkamp, 2002). This was used to analyze selective attention and concentration. Performing this test requires discriminating among 47 elements in each of the 14 rows that make up the test (658 elements in total). Each row is completed in 20 s, working from left to right and from top to bottom. The stimuli contain the letters *d* or *p* and may be accompanied by one or two dashes located at the top, bottom, or both. The *d*'s, which are considered relevant stimuli, must be crossed out when they have 2 dashes in any position. The following scores can be obtained: total effectiveness in the test/selective attention index (TOT) and concentration index (CON).

(b) Wechsler Intelligence Scale Coding and Symbol Search tests for children (WISC-IV; Wechsler, 2005). These tests basically assess cognitive processing speed, but also attention, or cognitive flexibility. The Coding test consists of copying a set of symbols, associated with a number, in a certain order. The Symbol Search test involves observing two groups of symbols and indicating whether any of them coincide. The tests have a completion time of 120 s. A Processing Speed Index is obtained from the results.

(c) General Self-Efficacy Scale (Schwarzer and Jerusalem, 1995; Baessler and Schwarzer, 1996; Sanjuán et al., 2000). This consists of 10 items and analyzes the perception of one's competence to handle a wide range of situations. It is evaluated with scores between 1 (*strongly disagree*) and 10 (*strongly agree*). The internal consistency (Cronbach's Alpha) value for this study was 0.84.

(d) General Health Questionnaire in its 28-item version (GHQ-28; Goldberg, 1978; Lobo et al., 1986). This was initially designed to assess psychiatric disorders in a community setting and in non-psychiatric clinical settings, although it has subsequently been used for other populations. It is composed of 28 items and explores the following 4 dimensions: somatic symptoms, anxiety and insomnia, social dysfunction, and severe depression. It is answered with scores from 0 (*absence of health problems*) to 3 (*presence of health problems*). The internal consistency (Cronbach's Alpha) values for this study were somatic symptoms =0.83, anxiety and insomnia = 0.74, social dysfunction = 0.78, and severe depression = 0.81.

(e) Satisfaction with Life Scale (SWLS; Diener et al., 1985; Atienza et al., 2000). This analyzes life satisfaction and is made up of 5 items. It is answered with scores between 1 (*strongly disagree*) and 7 (*strongly agree*). The internal consistency (Cronbach's Alpha) value for this study was 0.81.

(f) Anthropometric and physical fitness measurements. To describe the sample, height and weight were analyzed using a conventional measuring rod and scale, respectively. The fat mass percentage was measured with a bioimpedance meter (Tanita® BC-601 Body Composition Monitor). Explosive power in the lower body was evaluated with the horizontal jump test (Eurofit, 1993). Speed was asssessed using the 5 $\times$ 10 meter test (Eurofit, 1993). Maximum oxygen consumption was obtained indirectly with the *Course Navette* test (Léger et al., 1988; Eurofit, 1993), an incremental round trip test over 20 meters, increasing the speed by 0.5 km/h every minute from 8.5 km/h. Oxygen consumption was calculated using the formula $VO_2max = 31.025 + 3.238S–3.248A + 0.1536SA$, where S is the speed reached in the last completed stage and A is the age of the participant.

Procedure

The sample was obtained in schools fron the city of Malaga (Spain) by contacting each school and requesting permission for adolescents to participate. In addition, informed consent was obtained from the parents or legal guardians of the participants. Throughout the process, the ethical principles set forth in the Declaration of Helsinki (World Medical Association, 2013) were respected. In addition, this study is part of a line of research that has been positively evaluated by the Ethics Committee of the University of Malaga (No. 243, CEUMA Registry No.: 18-2015-H).

Anthropometric and physical condition evaluations were carried out in Physical Education classes. Cognitive assessment was conducted in a noise-free classroom and in groups. The questionnaires were self-administered and completed in a group, in a normal classroom. In addition, written data were obtained on the number of hours spent each day in physical exercise, using a simple form. Specifically, information was collected on structured physical activity, but not that which was not (e.g., walking to school, shopping, climbing the stairs, etc.). That is, whether it was federated or not, only the information related to the training of a sport or that activity that was carried out with a specific purpose was collected (e.g., running, playing basketball with friends, etc.). On the basis of this information, the sample was divided into three groups: Group 1, low level of physical exercise (less than 2 h per week); Group 2, moderate level of physical exercise (2 to 4 h per week); and Group 3, high level of physical exercise (more than 4 h per week).

Data Analysis

Descriptive and inferential analyses were performed. The Kolmogorov–Smirnov test was used to analyze the normality of the data. Analysis of variance (ANOVA) were used to assess differences between the groups. Bonferroni statistic would be used to analyze multiple *post hoc* comparisons if there were significant differences between groups. Cohen's *d* was used to estimate the size of the effect between groups. Correlations were assessed with the Pearson and Spearman coefficients. In order to ascertain the predictive capacity of physical condition for the other variables, linear regression analyses (successive steps) were used (Ruiz-Barquín, 2008). The SPSS computer program, version 20.0, was used for statistical processing.

RESULTS

Descriptive Analysis and Normality of Data

Tables 1, **2** show the descriptive statistics and the Kolmogorov–Smirnov test for the total sample and each group, divided by hours of activity per week. The results indicated normality problems in some variables (bold text, **Table 2**). The ln(x), x2, and 1/x algorithms were used to correct this. All variables were adjusted.

Inter-Group Mean Differences

The ANOVAs performed indicated that there were differences between the groups in the variables fat mass percentage, horizontal jump test, VO_2max, 5 × 10 speed test, D2-TOT, D2-CON, Symbol Search, Coding, Processing Speed, general self-efficacy, somatic symptoms, anxiety and insomnia, and life satisfaction. There were no differences between groups in social dysfunction, and severe depression (GHQ). **Table 3** shows the comparisons between groups (with Bonferroni correction) for each variable. Furthermore, Levene's test indicated that there was homegeneity between group variances in each case ($p < 0.05$).

TABLE 1 | Mean and standard deviation of physical fitness assessment tests and cognitive and well-being indicators.

	Total (*n* = 208)		Group 1 (*n* = 76)		Group 2 (*n* = 68)		Group 3 (*n* = 64)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
FM%	21.57	9.54	27.67	9.14	21.09	7.38	15.04	7.21
HJT	164.86	39.92	144.61	34.35	162.64	35.26	190.41	36.38
VO_2max	42.93	8.19	37.87	7.01	43.54	6.75	48.15	7.28
5 × 10	18.85	2.24	19.90	2.19	18.84	2.13	17.65	1.80
D2-TOT	59.79	18.73	54.28	17.90	60.27	17.89	65.65	18.89
D2-CON	58.57	20.59	53.00	19.33	59.38	19.68	64.17	21.51
SYM	11.38	2.46	10.78	2.73	11.29	2.15	12.15	2.23
COD	10.09	3.08	9.33	2.99	10.24	2.76	10.80	3.33
PS	105.20	12.21	101.54	13.37	105.53	9.77	109.09	11.91
GSE	6.88	1.97	6.14	2.20	6.88	1.40	7.71	1.87
GHQ-SS	0.74	0.44	0.81	0.49	0.84	0.40	0.57	0.36
GHQ-AI	0.92	0.73	1.04	0.74	1.06	0.71	0.63	0.64
GHQ-SDy	0.93	0.46	0.97	0.53	0.97	0.45	0.83	0.37
GHQ-SDe	0.43	0.53	0.46	0.56	0.51	0.55	0.31	0.47
LS	4.88	1.26	4.51	1.27	4.77	1.09	5.43	1.25

Abbreviations: M, Mean; SD, Standard deviation; FM%, Body fat mass percentage; HJT, Horizontal jump test (cm); VO_2max, Maximum rate of oxygen consumption (mL/kg/min); 5 × 10, Speed test (s); D2, D2 test; TOT, Total effectiveness in the test/Selective attention index; CON, Concentration index; SYM, Symbol Search; COD, Coding test; PS, Processing speed; GSE, General self-efficacy; GHQ, Health perception questionnaire; SS, Somatic symptoms; AI, Anxiety and insomnia; SDy, Social dysfunction; SDe, Severe depression; and LS, Life satisfaction.

Correlation and Linear Regression Analysis

Tables 4, **5** shows the correlations between measures of physical fitness and cognitive functioning. There were significant relationships among them. Maximum oxygen consumption was the measure of physical fitness that best correlated with the measures of cognitive functioning.

Table 6 shows the linear regression analyses (successive steps) with which we attempted to identify the physical fitness variables that predict the values of the psychological measures analyzed. The models meet the assumptions of linearity in the relationship between predictor variables and criteria, homoscedasticity, and normal distribution of residuals whose mean value is 0 with a standard deviation of almost 1 (0.99). The Durbin–Watson value was between 1.60 and 2.05, which is appropriate according to Pardo and Ruiz (2005), indicating that it can be assumed that the residuals are independent and the assumption of independence of the independent variables with respect to the dependent variable is met. The models obtained included a single variable, in most cases maximum oxygen consumption (**Table 6**).

DISCUSSION

The purpose of this study was to analyze how physical exercise and physical fitness are related to certain cognitive and psychosocial functioning variables. The results obtained show relationships between the measures studied and therefore

TABLE 2 | Skewness, kurtosis, and Kolmogorov–Smirnov statistic of physical fitness, cognitive, and psychological assessment tests.

	Total (*n* = 208)			Group 1 (*n* = 76)			Group 2 (*n* = 68)			Group 3 (*n* = 64)		
	S	*K*	*K–S*	*S*	*K*	*K–S*	*S*	*K*	*K–S*	*S*	*K*	*K–S*
FM%	0.15	−1.19	1.28	−0.69	−0.39	1.16	−0.01	−1.02	0.96	1.01	−0.32	1.06
HJT	0.25	−0.93	**1.57***	1.07	0.72	0.97	0.09	−0.78	0.76	−0.41	−0.46	0.80
VO_2max	0.14	−1.21	**1.54***	1.22	0.06	1.29	0.19	−1.57	1.01	−0.94	−0.36	1.34
5 × 10	0.43	−0.84	1.35	−0.18	−0.57	0.54	0.39	−0.85	0.94	1.54	2.16	1.32
D2-TOT	−0.13	−1.15	**1.51***	0.51	−0.92	**1.59***	−0.14	−0.94	1.04	−0.90	−0.19	0.98
D2-CON	−0.10	−1.15	1.27	0.38	−0.93	1.29	−0.01	−0.88	1.17	−0.75	−0.70	1.28
SYM	0.29	0.38	**1.66****	0.18	−0.44	0.98	0.45	−0.03	0.97	0.92	1.71	**1.75****
COD	0.43	0.35	**1.48***	0.11	0.00	1.22	0.43	0.92	**1.52***	0.67	−0.20	1.19
PS	0.18	0.17	**1.51***	0.19	−0.12	0.72	0.19	0.64	0.87	0.52	−0.37	1.18
GSE	−0.33	−0.27	1.16	−0.27	−0.94	**1.42***	0.15	−0.12	1.01	−0.29	−0.63	1.13
GHQ-SS	0.43	0.01	1.28	0.38	0.09	0.84	0.26	−0.35	1.04	0.40	−0.74	1.19
GHQ-AI	0.65	−0.26	**1.62***	0.38	−0.53	0.83	0.62	0.16	0.71	1.19	0.61	**1.53***
GHQ-SDy	0.88	1.61	1.28	1.04	0.84	**1.51***	0.81	2.59	0.98	0.00	−0.31	1.03
GHQ-SDe	1.56	2.30	**1.82****	1.52	2.35	**1.76****	1.52	2.31	**1.91****	1.76	2.43	**1.49***
LS	−0.14	−1.13	**1.59***	0.04	−1.45	1.32	−0.10	−1.07	**1.46***	−0.55	−0.63	1.26

*Abbreviations: S, Skewness; K, Kurtosis; K–S, Kolmogorov–Smirnov statistic; FM%, Body fat mass percentage; HJT, Horizontal jump test; VO_2max, Maximum oxygen consumption; 5 × 10, Speed test; D2, D2 Test; TOT, Total effectiveness in the test/Selective attention index; CON, Concentration index; SYM, Symbol Search; COD, Coding test; PS, Processing speed; GSE, General self-efficacy; GHQ, Health perception questionnaire; SS, Somatic symptoms; AI, Anxiety and insomnia; SDy, Social dysfunction; SDe, Severe depression; and LS, Life satisfaction. *p < 0.05 and **p < 0.01.*

TABLE 3 | Inter-group (*post-hoc*) comparisons for each variable with significant differences.

	ANOVA				Group 1 vs Group 2 *Sig.*	Group 2 vs Group 3 *Sig.*	Group 1 vs Group 3 *Sig.*
	$F_{[2,205]}$	*Sig.*	η2	1–β			
FM%	43.94	<0.001	0.30	0.99	<0.001[1]	<0.001[1]	<0.001[3]
HJT	29.94	<0.001	0.23	0.99	<0.01[1]	<0.001[1]	<0.001[2]
VO_2max	38.26	<0.001	0.27	0.99	<0.001[1]	<0.001[1]	<0.001[2]
5 × 10	21.24	<0.001	0.17	0.99	<0.01[1]	<0.001[1]	<0.001[2]
D2-TOT	6.92	<0.01	0.06	0.92	–	–	<0.001[1]
D2-CON	5.49	<0.01	0.05	0.85	–	–	<0.01[1]
SYM	5.86	<0.01	0.05	0.87	–	–	<0.01[1]
COD	4.29	<0.05	0.04	0.74	–	–	<0.05[1]
PS	7.20	<0.01	0.07	0.93	–	–	<0.001[1]
GSE	11.49	<0.001	0.10	0.99	–	<0.05[1]	<0.001[1]
GHQ-SS	8.06	<0.001	0.07	0.96	–	<0.01[1]	<0.01[1]
GHQ-AI	8.18	<0.001	0.07	0.96	–	<0.01[1]	<0.01[1]
LS	10.67	<0.001	0.09	0.99	–	<0.01[1]	<0.001[1]

Abbreviations. FM%, Body fat mass percentage; HJT, Horizontal jump test; VO_2max, Maximum oxygen consumption; 5 × 10, Speed test; D2, D2 Test; TOT, Total effectiveness in the test/Selective attention index; CON, Concentration index; SYM, Symbol Search; COD, Coding test; PS, Processing speed; GSE, General self-efficacy; GHQ, Health perception questionnaire; SS, Somatic symptoms; AI, Anxiety and insomnia; and LS, Life satisfaction. Cohen's d: [1]d > 0.20; [2]d > 0.40; and [3]d > 0.60.

meet the objective of the research. Specifically, the data reveal differences in the measures evaluated in favor of adolescents who performed more hours of physical exercise per week, as well as significant associations of physical fitness with cognitive functioning and the various psychosocial indicators.

Firstly, we observed that adolescents who were physically active for a larger number of hours achieved higher scores in measures of cognitive functioning, specifically selective attention, concentration, and speed of processing. This is in line with previous studies that identify a relationship between physical exercise and these measures in the adolescent population (Hillman et al., 2005; Pontifex et al., 2011; Guiney and Machado, 2013; Tine, 2014; Reloba-Martínez et al., 2017). In addition, it is noteworthy that there were no differences between adolescents with low and moderate levels of physical exercise (Groups 1 and 2). That is, only those who engaged in a high number of hours of activity per week (Group 3) showed significant differences from those with lower levels. This coincides with previous research that draws attention to the need for physical exercise to attain a certain degree of intensity and frequency in

TABLE 4 | Correlation between measures of physical fitness and cognitive functioning.

	D2		WISC-IV		
	TOT	CON	SYM	COD	PS
FM%	−0.20**	−0.19**	−0.32**	−0.21**	−0.31**
HJT	0.23**	0.22**	0.31**	0.19**	0.29**
VO_2max	0.36**	0.32**	0.38**	0.21**	0.35**
5 × 10	−0.17*	−0.16*	−0.26**	−0.16*	−0.24**

*Abbreviations. FM%, Body fat mass percentage; HJT, Horizontal jump test; VO_2max, Maximum oxygen consumption; 5 × 10, Speed test; D2, D2 test; TOT, Total effectiveness in the test/Selective attention index; CON, Concentration index; SYM, Symbol Search; COD, Coding test; and PS, Processing speed. *p < 0.05 and **p < 0.01.*

TABLE 5 | Correlation between measures of physical fitness and psychosocial variables.

	GSE	GHQ				LS
		SS	AI	SDy	SDe	
FM%	−0.34**	0.32**	0.29**	0.17*	0.11	−0.32**
HJ	0.33**	−0.37**	−0.35**	−0.17*	−0.12	0.30**
VO_2max	0.41**	−0.46**	−0.34**	−0.14*	−0.19*	0.31**
5 × 10	−0.23**	0.32**	0.32**	0.15*	0.08	−0.24**

*Abbreviations. FM%, Body fat mass percentage; HJT, Horizontal jump test; VO_2max, Maximum oxygen consumption; 5 × 10, Speed test; GSE, General self-efficacy; GHQ, Health perception questionnaire; SS, Somatic symptoms; AI, Anxiety and insomnia; SDy, Social dysfunction; SDe, Severe depression; and LS, Life satisfaction. *p < 0.05 and **p < 0.01.*

TABLE 6 | Linear regression analysis (successive steps).

R	R^2 corrected	D-W	Criterion variable	Predictor variable	Standardized beta	T	VIF
0.34	0.11	1.62	D2-TOT	VO_2max	0.34	1.00	1.00
0.30	0.09	1.60	D2-CON	VO_2max	0.30	1.00	1.00
0.39	0.15	1.89	SYM	VO_2max	0.39	1.00	1.00
0.21	0.04	1.96	COD	VO_2max	0.21	1.00	1.00
0.35	12	1.95	PS	VO_2max	0.35	1.00	1.00
0.37	0.14	1.72	GSE	VO_2max	0.37	1.00	1.00
0.50	0.24	1.96	GHQ-SS	VO_2max	−0.50	1.00	1.00
0.35	0.12	2.05	GHQ-AI	HJT	−0.35	1.00	1.00
0.19	0.03	1.72	GHQ-SDy	VO_2max	−0.19	1.00	1.00
0.18	0.03	1.86	GHQ-SDe	VO_2max	−0.18	1.00	1.00
0.32	0.10	1.62	LS	FM%	−0.32	1.00	1.00

Abbreviations. D2, D2 test; TOT, Total effectiveness in the test/Selective attention index; CON, Concentration index; SYM, Symbol Search; COD, Coding test; PS, Processing speed; GSE, General self-efficacy; GHQ, Health perception questionnaire; SS, Somatic symptoms; AI, Anxiety and insomnia; SDy, Social dysfunction; SDe, Severe depression; LS, Life satisfaction; VO_2max, Maximum oxygen consumption (mL/kg/min); HJT, Horizontal jump test (cm); FM%, Body fat mass percentage; T, Tolerance; and VIF, Variance Inflation Factor.

order to produce functional brain changes (Herting et al., 2014; Reloba-Martínez et al., 2017).

There is therefore no guarantee that doing a certain number of hours of physical exercise per week or at a certain intensity will explain this phenomenon, so to understand it better we need to monitor the level of physical fitness achieved. In this study, the groups into which the sample was divided had different levels of physical fitness, and the group that engaged in the most hours of physical exercise per week achieved the best results. This is consistent with the arguments of authors such as Chaddock et al. (2018) or Esteban-Cornejo et al. (2017), who consider that improvement in physical fitness is an suitable indicator to explain cognitive changes. It is also in line with other data obtained, which show that measures of physical fitness are significantly correlated with attention, concentration, and processing speed. Specifically, cardiorespiratory fitness, assessed by indirect calculation of maximum oxygen consumption, was a particularly significant value; indeed, it was the main predictor in the linear regression models. This connects with other studies which identity this variable as the one that best explains cognitive functioning (Chaddock et al., 2014; Herting et al., 2014; Reloba-Martínez et al., 2017).

As described in previous research, physical exercise contributes to brain plasticity. In other words, it helps the brain to be more prepared to change its functioning. Possibly only exercise does not produce the change, but it does produce greater sensitivity for it to occur. And for this, a series of physiological phenomena occur so that the brain is more willing to be modified. However, for this to occur a high impact on the body must be produced, which would be reflected in the level of fitness reached by the person (Chaddock et al., 2010, 2018; Esteban-Cornejo et al., 2017). That is why, in recent years, the data supports that physical exercise of moderate and high intensity and frequency would better explain the changes produced in the functioning of the brain. In addition, these studies show that exercises that increase cardiorespiratory fitness, cause greater synthesis of biomolecules such as BDNF or IGF-1, and facilitate volume increase in cortical and subcortical gray matter (Esteban-Cornejo et al., 2017; Tari et al., 2019).

Secondly, differences between the groups in our study according to the amount of physical exercise undertaken indicate that the most active and fittest group achieved the best scores for psychosocial indicators. These results support previous findings that highlight this phenomenon in populations of similar ages (Eime et al., 2013; Lubans et al., 2016), and specifically they are consistent with other work that assesses general self-efficacy, perception of health, and satisfaction with life (Zullig and White, 2011; Bombak, 2013; Ho et al., 2015; Kantomaa et al., 2015; Fraguela-Vale et al., 2016).

Furthermore, this previous research indicates that physical fitness was a determining factor in assessing the effects of physical exercise on these psychological variables. It is pertinent to point out that in our study some dimensions of the GHQ, such as social dysfunction or serious depression, showed no differences between the groups divided according to hours of physical exercise per week. However, when correlation and linear regression analyses were performed, physical fitness was shown to be significantly related to these factors. This coincides with the arguments put forward in other studies, which consider it necessary to assess physical fitness to better understand how physical exercise relates to these types of variables (Reigal et al., 2014). In addition, cardiorespiratory fitness also emerges, in most cases, as the physical fitness factor most closely related to the other variables, which is in line with what has been described in other studies (Becerra-Fernández et al., 2013).

Probably, the relationship between physical exercise, fitness and psychosocial functioning is justified for multiple reasons. Among them, when physical exercise is performed, personal skills are increased. Not only the physical ones, which is obvious, but also those derived from the social context in which it develops. Thus, when doing physical exercise, you have to interact with other people and you have to learn to improve social skills. Therefore, learning would be generated that would affect the perception of personal competence. In addition, there is an improvement in physical health, but also a greater subjective feeling of well-being caused by enjoyment with the activity that is performed.

This work has some limitations. First, the sample was made up of both boys and girls, but the analyses have not been differentiated by gender for each group. Future research should seek to verify whether the results are similar for each gender. Second, the design employed does not allow for the establishment of causal relationships. Thus, quasi-experimental or longitudinal designs could provide valuable information about changes in the variables studied due to the practice of physical exercise. Finally, it would be interesting in subsequent research to assess the relationships between measures of cognitive and psychosocial functioning, given that more complete profiles could be established on how these variables are associated with each other. In any case, the results of this study provide valuable information on the relationships between physical exercise, physical fitness, and cognitive and psychosocial functioning in adolescents, which suggests the need to continue promoting the practice of physical exercise among the young population.

CONCLUSION

The study findings indicate that adolescents who practiced more weekly physical exercise and had a higher level of physical fitness scored better on the cognitive functioning and psychosocial tests evaluated. Besides, cardiorespiratory fitness was predictor of all the variables analyzed, except the factor anxiety and insomnia (self-rated health), and life satisfaction that were predicted by horizontal jump measurements and fat mass, respectively. Among others, if increasing the level of physical exercise and fitness can affect their cognitive and psychosocial functioning, it would be contributing to having a healthier life and increasing their ability to adapt to the daily demands of life. Thus, adolescents must face multiple situations, such as academic ones, social interactions, etc., that could be favored by the continued practice of physical exercise. For all this, and referring to the evidence collected on this subject, it is necessary to indicate that despite the large amount of leisure time activities availables to adolescents today, active lifestyle habits are likely to be among those that bring the most direct and indirect benefits to their health and well-being. Therefore, any effort to develop this type of behavior will have been worthwhile.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by University of Malaga. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AH-M, VM-S, RJ-R, and RR participated in the study design and data collection, performed the statistical analyses, contributed to the interpretation of the results, wrote the manuscript, approved the final manuscript as presented, reviewed and provided feedback to the manuscript, and made substantial contributions to the final manuscript. All authors contributed to the article and approved the submitted version.

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