DE-ESCALATING THREAT: THE PSYCHOPHYSIOLOGY OF POLICE DECISION MAKING

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DE-ESCALATING THREAT: THE PSYCHOPHYSIOLOGY OF POLICE DECISION MAKING

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EDITORIAL
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Editorial: De-escalating Threat: The Psychophysiology of Police Decision Making

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Editorial on the Research Topic

De-escalating Threat: The Psychophysiology of Police Decision Making

Police officers are required to make rapid, high-stakes decisions on a routine basis. Scientific research on making decisions during situations that are perceived as threatening is situated in the context of neurological and physiological processing (LeDoux and Pine, 2016). However, despite advances in the empirical understanding of decision making during high-stakes events, popular ("layperson") discussion surrounding police decision making has not been readily informed by contemporary research on neurological processing of threat or psychophysiological reactivity to stress. Rather, social debate tends to focus on psychosocial issues, including the narrative that police attitudes and beliefs are the central factors directing police behavior (e.g., Phillips and Sobol, 2012).

The goal of this Frontiers Research Topic: "*De-escalating Threat: The Psychophysiology of Police Decision Making,*" is to bring awareness to the emerging theoretical and empirical examination of police decision making, including neuroscience and psychophysiological perspectives. Theoretical models and recent research indicate that performance during cognitively demanding tasks is related to a psychophysiological feedback network comprised of bidirectional signals between the following:

A). Higher order cognitive and emotional processing regions of the brain (e.g., prefrontal cortex (PFC) and limbic system),
B). Subcortical regions of the central autonomic network (e.g., brainstem),
C). The peripheral autonomic nervous system (ANS) (e.g., parasympathetic and sympathetic), including the heart and lungs (Thayer et al., 2009; LeDoux and Pine, 2016; Smith et al., 2017; Arpaia and Andersen, 2019).

Thus, from theoretical and empirical perspectives, the research within this special edition will consider how the functioning of the bidirectional signals between the brain and the central and peripheral nervous systems relate to police decision making in order to inform police training, policy, and legal judgements regarding police behavior.

All of the articles in this special section can be placed into one of three groupings. In the first set of articles, the authors demonstrate that psychophysiological stress can be measured in field settings and that these biometric indices are associated with important indicators of skill performance, situational factors, and individual characteristics that interact to influence police

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decision making. Two critical findings emerge from this research. First, the variables identified in these investigations appear malleable by a number of factors, most importantly, training history and psychophysiological readiness to perform occupational tasks (Arble et al.). Second, traditionally it was thought that higher arousal always equated with poorer performance due to the potential for cognitive, perceptual, and sensory distortions observed among humans under extreme threat. For example see Giessing et al. in which the authors examine the level of impairment in shooting skills associated with high stress, anxiety-producing scenarios. However, other articles in this issue identify evidence that physiological arousal during threat may impact police skills differentially. Specifically, Arble et al. examined police simulations of life-threatening events and found that physiological arousal was associated with detriments in verbal communication but not tactical or non-verbal "automatic" skills. Baldwin et al. found arousal was influenced differentially by call type (e.g., priority, weapon present) and stage (e.g., briefing, *en route*) among active duty officers on real calls. Furthermore, Anderson et al. and Bertilsson et al., highlight that stress related biochemicals and ANS arousal impacts police differentially, sometimes to the officers' benefit and others to the detriment of skills. In light of these findings, implications for police training and evaluation are explored.

In a second set of articles, authors apply theory drawn from studying civilian behavior to that of police decision making. The biopsychosocial model (BPS) is used to develop an understanding of how police officer evaluations of occupational challenges, and their ability to overcome them, impact their performance (Kelley et al.). Similarly, the Theory of Constructed Emotion (TCE) (Barrett, 2016) is used as a platform to characterize the neurobiological mechanisms underlying adaptive police decision-making (Fridman et al.). Specifically, Fridman et al., articulate a critical role played by the ANS in regulating the short-term energy expenditures that are crucial to performance success in the high-pressure context police officers are expected to operate within. Across these articles, theoretical application is accompanied by the understanding that any actual police encounter has a wide range of variables that influence the outcome of the event (e.g., whether a shooting happens or not) and that these variables are very different in the real world as compared to laboratory settings. Thus, the authors propose important areas for future investigation to demonstrate the viability of these theories within the context of police field work.

In a third set of articles, authors review findings from experimental studies to better understand the effect of complex motor learning and psychophysiology on risk assessment and decision making. Harman et al. apply basic findings from experimental studies in judgment and decision making to posit that reactions to risk and threat are strongly influenced by previous decisions made in similar contexts (e.g., police experience on the road, in training, or even through media exposure). Di Nota and Huhta provide a synthesis of evidence from fields including cognitive psychology, adult education, clinical neuroscience, and applied psychophysiological research as it pertains to police training. The review concludes with concrete recommendations to promote evidence-based practices for training skills essential to modern policing, including physical use of force tactics, verbal communication, situational awareness, and high-stakes decision making. The insights across these articles provide a direct translation of current scientific knowledge into actionable recommendations for existing training policies and procedures that serve to protect the safety of both police and the general public.

The articles in this special section utilize evidence-based approaches to probe empirical and theoretical questions related to de-escalating high-stakes situations, and informed decision making regarding the use of force, skills training and motor learning. The articles in the section highlight the need to empirically test theoretical models under ecologically valid conditions (Andersen et al., 2018).

AUTHOR CONTRIBUTIONS

JA and EA drafted the manuscript. PC provided conceptual and editorial contributions. All authors contributed to manuscript revision, read, and approved the submitted version.

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ORIGINAL RESEARCH
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Differential Effects of Physiological Arousal Following Acute Stress on Police Officer Performance in a Simulated Critical Incident

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Background: Police officer response in a critical incident is often a life-or-death scenario for the officer, the suspect, and the public. Efficient and accurate decisions are necessary to ensure the safety of all involved. Under these conditions, it is important to understand the effects of physiological arousal in response to acute stress on police officer performance in critical and dangerous incidents. Prior research suggests that physiological arousal following a stressor differentially affects police performance – communication may be impaired, whereas well-rehearsed, tactical behaviors may be resilient.

Objectives: In this study, we examine the differential effects of physiological arousal across three police skill domains: verbal communication, nonverbal communication, and tactical skill.

Methods: A sample of Swedish police cadets ($N = 17$) participated in a critical incident simulation, which was a reenactment of a real-life incident that had resulted in a police officer death; the simulation included multiple calls, dynamic environments, and surprise threats. An expert rater evaluated the cadets across multiple domains of skill, and physiological arousal was monitored by continuous heart rate monitoring and measures of circulating cortisol and antithrombin taken before and after the incident simulation.

Results: The simulation increased police officer arousal, as reflected in elevated heart rate, but this alone did not predict differences in performance. Greater increase in antithrombin was associated with better general performance, but a specific deficit in verbal communication as compared to tactical performance and nonverbal communication. Change in cortisol was unrelated to the skill assessments.

Conclusions: Police officer performance during a critical incident simulation is affected by physiological arousal. The findings are discussed with implications for police officer decision-making and real-world performance.

Keywords: decision-making, verbal communication, antithrombin, cortisol, stress, police

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INTRODUCTION

The work of police officers is challenging and dangerous. Police officers are required to operate effectively in the face of physical danger, taxing hours, and institutional burdens. There is a wealth of literature to suggest that the pressures of police work are severe and multifaceted, leading to physical, emotional, and social consequences (Anshel, 2000; Marmar et al., 2006; Reynolds and Wagner, 2007; Arble and Arnetz, 2017). Unfortunately, these negative effects may contribute to the worsening of police officer mental and physical health by disrupting performance during critical incidents (Nieuwenhuys and Oudejans, 2011; Arble et al., 2018). In a critical incident, police officers are sometimes asked to make life and death decisions based upon their assessment of a given situation and the people within them. Mistakes made in these moments bear great consequences for all involved, and the pursuant emotional strain increases the risk of the police officer making mistakes in the future (Klinger, 2006; Leino et al., 2011). The professional necessity of competent law enforcement performance during highly charged situations thus requires a better understanding of the factors responsible for performance within stressful encounters.

"Stress" refers to behavioral and physiological responses that are arousing and aversive, but importantly, whose effects are mediated by cognitive and dispositional factors within the individual (Kim and Diamond, 2002). Following a stressor, there is a complex neurohormonal response that will fluctuate based upon the intensity, nature, and duration of the stressor, as well as several internal factors of the individual experiencing it (Joëls and Baram, 2009). Empirical research distinguishes between acute stress – an ephemeral psychological or physiological response immediately following a stressor – and chronic, or persistent, stress. Although these are convenient theoretical distinctions, their application to understanding the effects of stress on police officer performance is muddled by the nature of police work that presents acute stressors frequently (i.e., multiple incidents a day), as well as sources of chronic stress, such as in anticipation of an incident, shift work, psychological trauma, or negative media coverage (Anderson et al., 2002; Novak et al., 2016). A general theoretical model articulates the effects of stress on skill acquisition and performance follows a nonlinear function: moderate stress and arousal are often adaptive and can bolster performance, whereas high levels of stress and chronic exposure to stress sometimes impair cognitive function and behavioral performance (Yerkes and Dodson, 1908; Sandi, 2013). However, several factors moderate this relationship, including task complexity, and tasks that have multiple or high cognitive demands show a negative relationship with even moderate levels of acute stress (Meunier et al., 2013; Sandi, 2013). Negative effects of acute stress on individual performance of complex tasks are well documented (LeBlanc et al., 2005; LeBlanc, 2009), specifically those assessing memory (de Quervain et al., 2000; Kim and Diamond, 2002), working memory and attentional control (Lupien et al., 1999; Plessow et al., 2012; Schwabe and Wolf, 2012), and decision-making (Cumming and Harris, 2001; Wetzel et al., 2006). Police officer actions during a critical incident stem from these cognitive processes, and therefore, it is useful to consider this theoretical framework when evaluating possible consequences of acute stress on police officer performance.

Several investigations have examined the effects of stress on job performance and decision-making of police officers (Correll et al., 2007; Arnetz et al., 2009; Wright, 2010). Police officers are a useful population for this area of study, because they are often required to make immediate decisions of great consequence across a variety of unpredictable situations. For example, an officer approaching a reportedly armed suspect must attempt to communicate with the suspect while simultaneously visually scanning for the presence of weapons, considering other threats within the environment (e.g., other potential suspects, nearby civilians who could be in danger), evaluating the suspect's potential escape routes, potentially coordinating movements with a partner, maintaining radio communication, and considering the nature of the suspect in question (e.g., the suspect's mental state, or if the individual is in fact the actual suspect). These extreme cognitive demands must also be done while the officer is likely to be highly emotionally aroused. In this context of demanding cognitive engagement and emotional arousal, the police officer will be required to make a split-second decision not only to potentially discharge their firearm but also to do so accurately. To add further complication to the matter, many critical incidents arise spontaneously during routine response calls, denying the officers the opportunity to plan or mentally rehearse (Burrows, 2007).

Investigations into the matter have identified numerous factors that contribute to police officer performance during stress. These factors include decision-making styles (Brown and Daus, 2015), dispositional factors (Daus and Brown, 2012), organizational training and culture (e.g., the perception of support from the department; Loyens and Maesschalck, 2010), and situational characteristics (Westmarland, 2005).

Perhaps most critically, acute physiological arousal of police officers has been highlighted as a significant contributor to performance under stress. Acute arousal provides a surge of awareness and energy, increased vigilance to threat, increased responsiveness, and may contribute to successful recovery post-incident (McEwen, 1998, 2006; Munck, 2000; Vonk, 2008; Verhage et al., 2018). In contrast, other functions are found to be impaired during acute arousal, including disrupted visual processing of peripheral information (colloquially referred to as "tunnel vision"; AlSaqr and Dickinson, 2017), declines in executive functioning (McCormick et al., 2007), and difficulty in utilizing environmental feedback (Akinola and Mendes, 2012). Taken together, the cognitive processes and behavioral performance that are required in police work appear to be differentially affected by acute stress, and those functions that characteristically have higher cognitive demands appear to be vulnerable to disruption. One common example of this is the tactical decision to discharge a weapon, and officers under high acute stress conditions or reporting high trait anxiety are more likely to discharge their weapon and have poor shot accuracy (Nieuwenhuys and Oudejans, 2010; Nieuwenhuys et al., 2012). Fatigue, either due to acute or chronic stressors, further alters behavioral choices, including tactical decisions to shoot or pursue a suspect (Hope, 2016). Whereas acute stress or anxiety may impair complex and intentional behaviors, defensive behaviors (Renden et al., 2014) and tactical actions that have been practiced to achieve automaticity (Renden et al., 2017b) appear to be less impaired. Accordingly, intervention studies among police officers have attempted to harness the benefits of physiological arousal, while minimizing its potentially deleterious effects. This intervention research suggests that with extensive practice and repetition, police officers can call upon well-rehearsed tactical procedures under duress, thereby translating physiological arousal into decisive and effective tactical responding (Shipley and Baranski, 2002; Renden et al., 2015, 2017b; Andersen and Gustafsberg, 2016).

Equally important as tactical decisions, an officer ability to effectively communicate is essential to resolving a critical incident safely. Verbal and nonverbal communication are other examples of behaviors that stem from complex and demanding cognitive processing, for which there is evidence of semantic and declarative memory functions to be impaired by acute stress at both very high and very low levels (Sandi and Pinelo-Nava, 2007). Acute physiological arousal (as measured by indices such as cortisol) is predictive of impaired communication skills (Schlotz et al., 2006) with some research suggesting that nonverbal communication (e.g., eye contact) can be predicted by physiological stress levels even prior to the encounter (van Dulmen et al., 2007). In police officers, high acute stress and high trait anxiety predict poor verbal communication during an arrest (Renden et al., 2017a).

Based upon the reviewed evidence, there is seemingly a paradox of police officer performance under stress – aspects of awareness and vigilance are bolstered, whereas behaviors that rely on complex cognitive processes, including communication, are disrupted and well-rehearsed, proceduralized skills are seemingly spared. All of these functions are relevant to police officer performance and decision-making ability during critical incidents directly have consequences to officer and public safety. Therefore, it is imperative to understand the effects of police officer physiological arousal (i.e., acute stress response) on tactical and communication skills during a critical incident. In the extant literature, few studies have considered these specific domains of police performance in the field, which hampers translation of the research to effective training interventions. A study that continually monitored police officer heart rates while on duty concluded that arousal was highest just prior to and during a critical incident, and officers did not fully recover before ending their shift (Anderson et al., 2002), which underscores the need for research simulations that enjoy high ecological validity. We aim to address this limitation in the current study by examining the relationship between acute physiological arousal and police officer tactical and communication skills during a simulated critical incident that was modeled after a real-life occurrence.

We evaluated police officer physiological arousal with complementary indicators taken from the cascade of biological responses following threat and stress. Cortisol is secreted from the pituitary-adrenocortical axis, and because it is one of the most critical hormones to increase short-term resilience to stress, it is a common target for field assessment of stress response (McEwen, 1998, 2006). Cortisol gradually increases following a stressor, reaching peak levels within 20–30 min and remains elevated for approximately an hour post-stress (Kirschbaum et al., 1993; Engert et al., 2011). Stress activates the sympathetic nervous system as evident by elevated heart rate (McEwen, 1998, 2006). Increased heart rate indicates greater arousal, and moderate rather than extreme increase and rapid recovery to baseline rate indicate an adaptive response (Schuler and O'Brien, 1997; McEwen, 1998, 2006). In addition, there are secondary effects of stress. For example, stress increases blood viscosity as an adaptive response to reduce the risk of fatal hemorrhage following a fight (von Känel et al., 2001). As a natural countermeasure, the anticoagulant, antithrombin, is released throughout the body's vasculature, especially where large blood vessels bifurcate or blood flow is turbulent and there is increased risk of clotting (Arnetz and Ekman, 2006). Thus, increased antithrombin is an ideal response during a stressful encounter to minimize the risk of stress-induced blood clotting (von Känel et al., 2001; Arnetz and Ekman, 2006). A 5–10% elevation in antithrombin has been observed following stressful psychological tasks in a laboratory, with return to basal levels within 45 min post-stress (Austin et al., 2013). In the present study, we use change in cortisol and antithrombin from pre- to post-incident and maximum heart rate during the incident as indicators of individual physiological arousal.

With the use of these indicators of physiological arousal, we tested the hypothesis that greater stress response differentially affects police skills that rely on complex cognitive functions. Specifically, we hypothesize that greater increase in antithrombin and cortisol, as well as higher maximum heart rate, will predict lower scores on verbal and nonverbal communication with the suspect, which are conceived to have high cognitive demands. In contrast, elevation in physiological arousal indicators will predict better tactical skill, which is considered to rely predominantly on procedural memory.

MATERIALS AND METHODS

Participants

Participants were 18 healthy, male police officers with 1 year of experience on the Swedish police force. Ages were not reported. All officers were fluent in Swedish and English. This sample has been described before in a previous report (Arnetz et al., 2009), and here, we report a novel investigation of the effect of physiological arousal on performance of specific skills (verbal and nonverbal communication and tactical skill). The sample reported here was selected randomly from a parent study of 75 police cadets who had participated in a behavioral intervention of imagery and skills training 1 year prior.

A random sub-sample of cadets from the two conditions of the parent intervention study was invited to participate in the critical incident simulation. A total of 25 participants were invited to participate, based upon availability, facility in both English and Swedish language, and continued employment as police officers. Of the 25 invited, 18 cadets agreed to participate. At study completion, one individual had incomplete skill ratings and was removed from analysis; all analyses reported here include *N* = 17. The study was approved by the Karolinska Institute Ethics Committee, and all participating officers provided written informed consent.

Critical Incident Simulation

The critical incident simulation was modeled after a real-life scenario that had resulted in the death of a police officer. The real-life incident was analyzed in detail, and the critical incident simulation was designed in consultation with police officers who were experts in police training. The critical incident simulation included multiple calls and potentially hostile encounters in order to elicit physiological arousal that is common to police officers.

The protocol for the incident was standardized across participants, and the critical incident and all associated physiological data collection were completed 8–10 am during the police training academy session. Each officer was equipped with a set of handcuffs, a loaded paintball gun, an extra round of ammunition, a closed radio system, and an unmarked police car. Officers were instructed to perform usual patrol work and were dispatched in pairs, consistent with typical protocol. Following deployment, the officers received three dispatch calls prior to the critical incident scenario. The first call requested assistance with an individual suspected of selling illicit drugs at the police academy building. Before arriving at the scene, the officer received a second call indicating that the suspect had moved to the shooting range where he was demonstrating aggressive and hostile behavior toward the public. Officers pursued the suspect to the shooting range, and before arriving, they received a third call that redirected the officer to investigate a suspicious vehicle at a restricted military airfield. Before completing the call, the officer was called off again and redirected to investigate the critical incident – the scene of a post office robbery. Police officers were directed to the critical incident approximately 90 min after deployment.

Dispatch informed the officer that a post office had been robbed, the suspect had fled the scene, and the identity of the informant who had reported the incident was unknown. The officer was instructed to meet the building maintenance manager inside an exterior door, which had been damaged during the robbery. These instructions were designed to lower the police officer expectations of the degree of danger in the call, creating a surprising hostile encounter.

Upon arrival at the scene, the police officer observed the informant (an actor) standing 60 yards away from the building in an open field, and the informant was pointing at the damaged exterior door. The officer then walked 15–20 yards to approach the door. Without warning, two masked and heavily armed suspects (actors) exited the building. The suspects took aim at the police officers, and the first suspect immediately fired a shot from his paintball weapon. The second suspect turned right and stopped. The second suspect only spoke English, and although participating officers were fluent in English, they were not instructed of this requirement prior to the incident. The actors portraying the suspects were instructed to follow the police officers' clear, unambiguous orders when they reasonably comprehended the meaning (i.e., in a language they understood or communicated *via* body language and hand signals). The simulation ended when the police officer handcuffed the suspects. The critical incident was completed within approximately 30 min (within 2 h of deployment in total).

Police Skill Assessment

Police officers performed the critical incident simulation in pairs, but performance was rated individually. An independent police officer, who was an expert in the subject matter, observed the critical incident simulation from a rooftop vantage point. Each police officer was rated in eight domains: tactics, verbal communication, nonverbal communication, material management/dexterity, self-control, control of the suspect, control of the public, and confidence in incident management safety. Each domain was rated on a scale ranging from "poor" (0) to "excellent" (100). Scores across the domains were summed to calculate Total Performance Rating, which ranged from 0 to 800, and higher scores indicated better overall performance (Arnetz et al., 2009). Total Performance Rating is a summary measure that is comparable to a job performance rating a police officer may receive in the academy or on duty. Here, the measure was used to assess effects on general performance in a preliminary analysis. The hypothesized differential effects of physiological arousal were tested with specific scale ratings for verbal and nonverbal communication and tactical skill.

Physiological Arousal Indicators

On the day of the critical incident simulation, the police officers fasted in the morning. Blood samples were collected prior to the critical incident simulation, following which the officers ate a standard breakfast meal before deployment to the simulation scenario. A second blood sample was collected immediately following simulation completion, with no more than a 15-min delay. Circulating antithrombin and cortisol in blood serum were measured using standard laboratory tests. Increase in each of these biomarkers is consistent with a healthy, adaptive response to stressful situations (McEwen, 1998, 2006; von Känel et al., 2001). To measure change in circulating antithrombin and cortisol, the difference of post-incident measure from pre-incident measure was calculated, and positive change scores indicated an increase. Heart rate was used as an indicator of psychophysiological arousal. Officers wore a portable monitor to measure heart rate before and after the simulation, as well as continuously throughout the incident. The baseline heart rate measure was collected during the simulation before the dispatch call for the critical incident, and final heart rate measurements were taken within 10 min of simulation's conclusion. Because heart rate was expected to recover quickly in this sample of healthy cadets, maximum heart rate during the incident was used as a proxy indicator of maximum arousal during the critical incident. In secondary analyses, change in heart rate from pre- to post-incident was also tested as a predictor of skill rating.

Statistical Analysis

All statistical analysis was completed in SPSS (v.23) software. Prior to hypothesis testing, change scores for cortisol and antithrombin were calculated, and all data were screened for normality and univariate outliers. Preliminary analysis included paired t-tests of change in heart rate, antithrombin and cortisol from pre- to post-incident, and a linear regression to assess a possible general effect of these physiological arousal indicators on Total Performance Rating. Following this preliminary analysis that provides important contextual information, the hypothesis was tested in a repeated measures general linear model (GLM) that included a three-level skill factor (tactical skill, verbal communication, and nonverbal communication) as a dependent variable predicted by the physiological indicators. The three physiological arousal indicators – maximum heart rate during the critical incident, change in cortisol, and change in antithrombin – were weakly correlated ($r = -0.27$ to 0.04, all $p \geq 0.29$), and therefore, all indicators were entered simultaneously to predict differences in skill rating. Significant omnibus *F*-tests of the interaction term skill × physiological indicator were decomposed by Pearson bivariate correlations. Significance testing was set as $p < 0.05$ for all tests. In secondary analysis with the same repeated measures GLM structure, we assessed change in heart rate as an alternate to maximum heart rate predicting skill rating. Effect size estimates are reported for each test coefficient: within-subjects Cohen's d for estimates from paired t-tests and partial eta squared (η_p^2) for GLM linear regression coefficients. The current sample provided sufficient sensitivity to find at least a moderate effect size of change in arousal indicators ($d = 0.63$), a moderate-large size arousal indicators predicting performance skill ($f^2 = 0.87$), and difference between skills ($f = 0.40$) to significance (all estimates assuming power = 0.80, $\alpha = 0.05$; Faul et al., 2009). Based upon the available sample size and informed by the literature, we have conservatively selected hypothesis tests that would be sufficiently powered.

RESULTS

Physiological Arousal Indicators

Prior to hypothesis testing, we examined the distributions in physiological indicators of stress and possible mean changes in these measures between pre- and post-critical incident simulations. Heart rate (beats/min) significantly increased from pre- ($M = 67.94$, $SD = 8.74$) to post-encounter [$M = 83.47$, $SD = 11.06$; $t(16) = -4.77$, $p < 0.001$, $d = 1.16$], and during the encounter, maximum heart rate was substantially elevated [$M = 157.82$, $SD = 15.59$; $t(16) = -18.54$, $p < 0.0001$, $d = 4.50$]. As compared to before the encounter, antithrombin (AT kIE/L) demonstrated a nonsignificant trend for increase [$t(16) = -2.12$, $p = 0.05$, $d = 0.51$] and cortisol (nmol/L) demonstrated a nonsignificant trend for decrease [$t(16) = 2.05$, $p = 0.06$, $d = 0.50$]. Although tests of mean change in circulating markers failed to reach statistical significance, individuals varied in the magnitude of change in antithrombin ($M = 0.06$, $SD = 0.12$) and cortisol ($M = -81.29$, $SD = 163.62$), as well as change in heart rate ($M = 15.53$, $SD = 13.43$), and we hypothesized that individual differences in these physiological markers will predict differences in performance. Because heart rate was expected to recover quickly, maximum heart rate during the encounter was used as a proxy for maximum stress response in the moment and change in antithrombin and change in cortisol as additional markers of the cumulative physiological response. Secondary analyses further tested change in heart rate as a predictor of skill rating.

Mixed Effects of Physiological Arousal on Police Skills

During the simulated encounter, an expert officer rated the performance of each participating police officer across multiple domains, and Total Performance Rating was used as an index

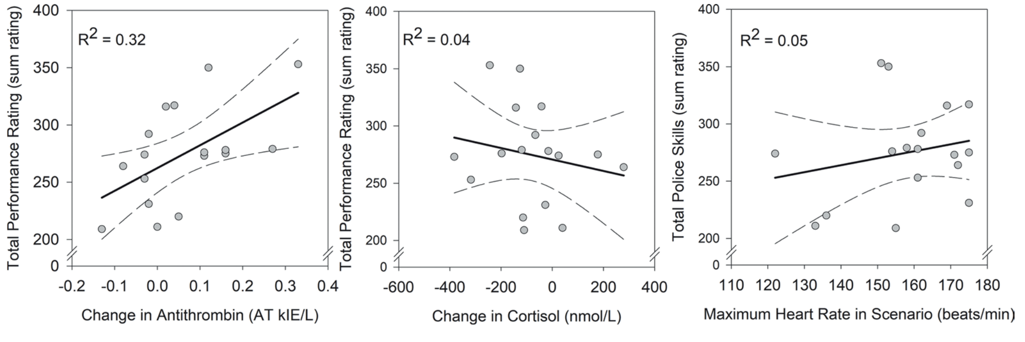

FIGURE 1 | Correlations between indicators of physiological arousal and Total Performance Rating. The regression model that included all three indicators of physiological arousal identified change in antithrombin as a significant predictor [$F(1, 13) = 5.46$, $p = 0.036$, $\eta_p^2 = 0.30$], whereas change in cortisol [$F(1, 13) = 0.05$, $p = 0.83$, $\eta_p^2 = 0.004$] and maximum heart rate during the encounter [$F(1, 13) = 0.84$, $p = 0.38$, $\eta_p^2 = 0.06$] were unrelated to overall performance. The correlations are depicted with bolded, solid lines and 95% confidence intervals are displayed with broken lines; bivariate coefficients are reported for each.

of overall performance in preliminary analysis. Total Performance Rating scores ranged from 209 to 353. Greater increase in antithrombin over the course of the simulated encounter was associated with greater overall performance: $F(1, 13) = 5.46$, $p = 0.036$, $\eta_p^2 = 0.30$ (**Figure 1**). Change in cortisol [$F(1, 13) = 0.05$, $p = 0.83$, $\eta_p^2 = 0.004$] and maximum heart rate during the encounter [$F(1, 13) = 0.84$, $p = 0.38$, $\eta_p^2 = 0.06$] were unrelated to overall performance (**Figure 1**). The model including the three physiological indicators of stress explained approximately 36% of variance in performance ($R^2 = 0.359$). This analysis provides important contextual information to interpret the hypothesis test.

The hypothesis that the effects of physiological arousal may differentially affect specific skills was tested in a repeated measures GLM. The range of scores for tactical skill (range = 20–49; $M = 34.88$), verbal communication (range = 15–60; $M = 36.41$), and nonverbal communication (range = 7–49; $M = 29.12$) were comparable, and mean ratings did not significantly differ between skills [$F(2, 12) = 1.91$, $p = 0.19$, $\eta_p^2 = 0.24$]. The effects of greater increase in antithrombin were differential across police skills [Skill × Change in Antithrombin, $F(2, 12) = 4.08$, $p = 0.04$, $\eta_p^2 = 0.41$]. Greater increase in antithrombin was associated with worse verbal communication ($r = -0.56$, $p = 0.02$), explaining approximately 32% of variability in performance (**Figure 2**). Although not significant, increase in antithrombin was associated with better tactical performance ($r = 0.12$, $p = 0.66$) and nonverbal communication ($r = 0.23$, $p = 0.37$). Change in cortisol [$F(2, 12) = 0.38$, $p = 0.69$, $\eta_p^2 = 0.06$] and maximum heart rate [$F(2, 12) = 1.26$, $p = 0.32$, $\eta_p^2 = 0.17$] did not differentially predict skill ratings. Taken together, greater increase in antithrombin was associated with overall better police performance during a critical incident, but a specific deficit in verbal communication.

In a secondary analysis, change in heart rate was considered as an alternate to maximum heart rate to predict individual differences in performance. Change in heart rate did not predict differences in Total Performance Rating [$F(1,13) = 0.01$, $p = 0.91$, $\eta_p^2 = 0.001$]. Greater increase in heart rate differentially effected skill ratings [Skill × Change in Heart Rate, $F(2, 12) = 4.08$, $p = 0.04$, $\eta_p^2 = 0.41$]. Examining Pearson correlations, no single correlation was statistically significant but the direction of effects differed: greater increase in heart rate was negatively correlated with verbal communication ($r = -0.35$, $p = 0.17$) and positively correlated with tactical skill ($r = 0.11$, $p = 0.69$) and nonverbal communication ($r = 0.26$, $p = 0.32$). Accounting for the effects of change in heart rate, change in antithrombin remained a significant predictor in the model [$F(1, 12) = 5.28$, $p = 0.02$, $\eta_p^2 = 0.47$]. In summary, greater increase in antithrombin and greater increase in heart rate – indicators of greater physiological arousal – were associated with lower verbal communication skill, whereas effects on nonverbal communication and tactical skills were not significant and trended in the positive direction.

DISCUSSION

The present study provides a unique view of the physiological predictors of police officer performance during stressful encounters. The realistic critical incident simulation provided a strong analogue to real-world performance. The officers were forced to respond to a rapidly changing environment, shifting objectives, and uncertainty regarding potential threats. The simulated critical incident appears to have induced stress similar to a real-life experience. As evidence of the simulation's efficacy, police officers demonstrated increased heart rate during the scenario and trends for elevated antithrombin. The result was an ecologically valid and rich assessment of police officer performance across multiple domains: tactics, verbal communication, and nonverbal communication, for which skill ratings were differentially predicted by physiological arousal.

In the present sample, elevated antithrombin emerged as a significant predictor of police officer performance. Antithrombin plays a central role in countering the body's chemical cascade mechanisms that are involved in creating

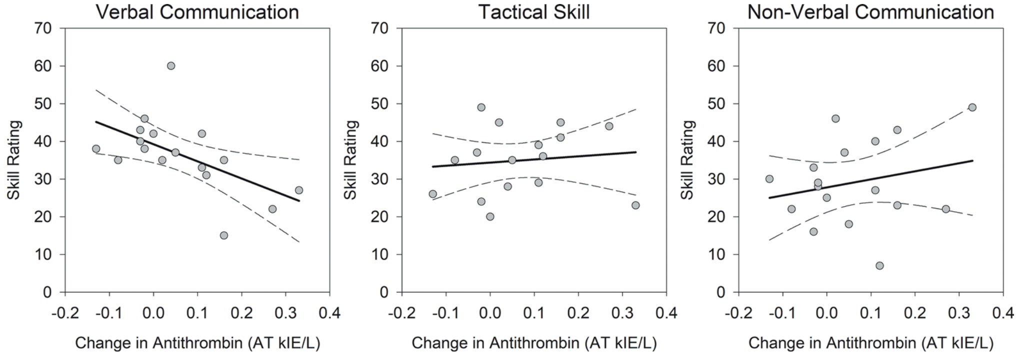

FIGURE 2 | Differences in police officer skill performance predicted by change in antithrombin. Change in antithrombin differentially affected the examined police skills: $F(2, 12) = 4.08$, $p = 0.04$, $\eta_p^2 = 0.41$. Greater increase in antithrombin during the simulated critical incident was associated with worse verbal communication ($r = -0.56$, $p = 0.02$). The correlations with tactical skill ($r = 0.12$, $p = 0.66$) and nonverbal communication ($r = 0.23$, $p = 0.37$) were not significant, but positive. The correlations are depicted with bolded, solid lines and 95% confidence intervals are displayed with broken lines.

blood clots during trauma; thus, increased antithrombin has been considered an adaptive anticoagulant response that is desirable during stress (Yanada et al., 2002). Observed elevation in antithrombin and other anticoagulants persists for an extended time after the stressor has been removed, presumably for its benefits to reduce the risk of blood clot from trauma that may be favored in evolution (Austin et al., 2013). As an index of physiological arousal, greater increase in antithrombin predicted higher Total Performance Rating. Total Performance Rating (the sum across multiple skill ratings) is comparable to the assessments police officers would receive in training and when on duty and represents a summary of job performance across multiple skill domains. The result is consistent with the expectation of healthier physiological responses predicting better performance in the field. Several laboratory studies have demonstrated that moderate levels of physiological arousal are adaptive and positively correlate with skill acquisition, accuracy, and long-term retention (Yerkes and Dodson, 1908; Sandi, 2013). The Total Performance Rating reported here includes multiple types of skills, some that are complex and explicit (i.e., verbal communication), some that are conceptually related to proceduralized or implicit skill (i.e., tactical skill), as well as less complex skills (i.e., materials management) and self-referential ability (i.e., self-control, confidence). In this manner, the Total Performance Rating provides a nonspecific summary of job performance, and it is in this measure that we identified a positive correlation between physiological arousal and performance.

Yet, when specific police skills were considered distinctly – verbal and nonverbal communication that are complex skills and tactical skill that included well-rehearsed behaviors – increased antithrombin was not universally positive. Specifically, greater increase in antithrombin was negatively associated with verbal communication, and a nonsignificant, but positive, association with tactical skill and nonverbal communication. Our hypothesis was partially supported, finding evidence of deficits in verbal communication, although the effects on nonverbal communication and tactical skill were not statistically significant.

Considering elevated antithrombin as an indicator of the police officer stress response, it is plausible that skills that were more effortful were differentially affected. This is consistent with another study that reported high acute stress and high trait anxiety negatively correlated with verbal communication by police officers during an arrest (Renden et al., 2017a). Verbal communication is cognitively demanding, requiring attentional and processing resources that, during a critical incident, would be also in use by visual scanning and working memory as the officer assessed the scene. When under psychological and emotional stress, effortful and explicit cognitive functions, like those required for verbal communication, tend to falter (Lupien et al., 1999; Newcomer et al., 1999; Oei et al., 2006; Sandi, 2013). Stress-related impairments to declarative memory (Morgan et al., 2004; Taverniers et al., 2013), which we speculate may have contributed to poor verbal communication in this study, is consistent with the evidence of inaccurate officer reporting in post-incident reports and debriefing that is associated with stress response and fatigue (see Hope, 2016 for a review). In this study, the cognitive demands for verbal communication were likely heightened because the Swedish officers were required to speak to the suspects in a language they were fluent in, but not native to. To our knowledge, the effects of acute or chronic stress on verbal communication in police officers during a critical incident have not been well studied. As communication is a critical strategy in resolving an incident without lethal force, further research in this area may identify targets for training intervention.

In contrast to the negative effect on verbal communication, nonverbal communication and tactical response were weakly, but positively, correlated with increased antithrombin. It is possible that both skills relied more upon procedural knowledge and thereby were more resilient to physiological arousal in the stressful encounter (Kirschbaum et al., 1996; Lupien et al., 1997; Sandi, 2013). Officers can train for a variety of scenarios, emphasizing the use of core tactics that will be employed in a multitude of situations (e.g., how to hold a firearm, the techniques for subduing a subject to apply handcuffs). These specific techniques can be drilled and repeated to the point of automaticity, thereby reinforcing procedural memory. Similarly, common nonverbal cues can be rehearsed and become like habits. Bearing this interpretation, prior intervention studies that have used repeated rehearsal have found that behavioral skills, such as tactical self-defense, are resilient to the effects of acute stress (Shipley and Baranski, 2002; Renden et al., 2015, 2017b; Andersen and Gustafsberg, 2016). However, other observational studies report a negative effect of acute stress on tactical behaviors, such as handcuffing and arrest procedures (Renden et al., 2014) and the use of force while controlling a suspect (Hope, 2016). Considering the available evidence, it is plausible that with intentional training, rehearsed tactical skills and nonverbal communication may be resilient to acute stress during a critical incident. Although the details of a situation will change, these well-rehearsed techniques can be relied upon during a stressful event, unlike verbal communication that cannot be easily stereotyped.

Effective communication during a police encounter will necessarily depend upon the utterances of the individuals involved. Determining basic verbal commands that can be rehearsed to aid automaticity, even during stressful encounters, may be a useful target for future cadet training programs. However, proceduralized skills by nature are inflexible and there may be a risk of an officer relying too much on such skills when under duress. Much as tunnel vision may unduly restrict situational awareness, an over-reliance on proceduralized communication skills may interfere with the breadth of verbal engagement that is sometimes required in a critical incident. As an alternative, police officers could instead rehearse techniques to increase flexibility and awareness during stressful situations, thereby allowing for the cognitive freedom to engage in improved verbal performance (Arble et al., 2017).

If we extend this evidence to police officer decision-making and performance in the real world, there are two important implications. First, successful decision-making among police officers relies upon several distinct skill domains, across which the officer may be differentially successful. Returning to the previous example of approaching a potentially armed suspect, an officer may be quite successful in positioning himself/herself as to avoid attack and may also be successful in identifying the presence of a weapon. However, failure to verbally engage with the suspect and deescalate the situation could undo the successes achieved in the other domains. Second, articulating an ideal physiological response for police officers is quite complex. The police officer health, personal history, and baseline anxiety may modify their ideal physiological responsiveness (Otte et al., 2005; Daus and Brown, 2012). Furthermore, the psychophysiological needs for quick reaction times and visual scanning may not be entirely congruent with the needs required to address an individual in a calm, authoritative manner. Experiments and interventions focusing on one performance domain (e.g., decisions to shoot) as a measure of decision-making may wish to consider the addition of alternative performance domains to address this complexity.

The present results identify the importance of physiological responsiveness as a predictor of police officer performance in response to critical incidents. However, not all physiological indicators of stress were associated with performance – we did not find evidence of maximum heart rate during the scenario or change in cortisol correlating with performance. A constrained elevation in heart rate is ideal for performance (McEwen, 2002) and is of particular importance during critical decision-making moments within an encounter (Arnetz et al., 2009). In this sample, heart rate was elevated to indicate arousal in the scenario but did not predict individual differences in police skills. Similarly, the release of cortisol is theorized to be beneficial during dangerous situations, providing an increase in vigilance and arousal (Otte et al., 2005; McEwen, 2006). It is further believed that an elevation in cortisol levels during stressful experiences will subsequently assist in returning the body to a state of homeostasis, thereby facilitating successful recovery (McEwen, 1998, 2006).

Following this evidence, we expected a moderate increase in cortisol during the training scenario to predict better performance, but here we found a nonsignificant trend for decrease in this sample. The statistical trend indicating decrease in cortisol may be an artifact of measures that were taken in the morning (8–10 am), as cortisol is naturally high in the early circadian rhythm and decreases with waking time (Hellhammer et al., 2009). The failure of cortisol to emerge as a significant predictor of performance may also reflect the complex nature of the hormone and its effects. Excessive cortisol activation has been associated with negative outcomes, both physical (Whitworth et al., 2005) and emotional (Carroll et al., 2007). Furthermore, there is evidence to suggest that the relationship between cortisol and cognitive function may be moderated by several variables, including previous trauma (Yehuda, 2002). In the present context, the role of anticipatory anxiety may be particularly important. When inducing cortisol *via* anticipatory stress, studies suggest that individuals become riskier in their decision-making and less accurate overall (Starcke et al., 2008). Thus, although cortisol activation may prove adaptive for some, for others (particularly those with high anticipatory anxiety), the hormone may prove a hindrance. The current study design precludes tests of possible moderators of the effects of cortisol or heart rate, and therefore, we cannot presently test this hypothesis. Future studies of larger samples that include detailed personal and health histories would be positioned to evaluate the importance of individual factors in police officer decision-making under stress.

The reported evidence should be interpreted with consideration of its limitations. First, the analyses are reported from a small sample of cadets, which was sufficient to detect some hypothesized effects to significance, but tests of cortisol and heart rate may be underpowered. Further, we were unable to effectively test possible nonlinear relationships between physiological markers and performance ratings in a sample of this size nor was the sample sufficient to power a larger model testing differential effects across all of the performance domains that were rated during the simulation. This warrants a larger follow-up study to address these important research questions. Second, the sample was selected to include male cadets and does not represent the diversity of the international community of police officers. Nonetheless, we report on physiological markers of stress that are well validated and typical police skill domains, and therefore, the results here can be applied to understanding the effects of physiological arousal and stress on police performance across communities. Physiological response to acute stress (Novais et al., 2016) and associated behavioral consequences (Allwood and Salo, 2012; Arble et al., 2018) varies as a function of age and sex, which we cannot consider here due to the selection of only male cadets and age was not reported in the study. Third, the analyses are correlational and based upon observational data and therefore cannot comment on causality. The physiological response to psychological and emotional stress is well established, and we take advantage of this knowledge in this study design, but we do not directly manipulate circulating biomarkers. Fourth, the sample was drawn from a parent study that included a behavioral intervention of imagery and skills training 1 year prior. The sample in the present report represents both the control (50%) and intervention conditions (50%), selected at random. We do not test possible intervention-related differences in the present analysis, which were not hypothesized, and the small sample size is expected to be insufficient for such a test. The degree to which intervention may modify the differential effects of stress on communication is left to future studies to address. Finally, the simulation was designed as an analogue to an actual event and was developed to be conducted within a police academy training setting. This setting, though adding some ecological validity, provided logistical constraints. For example, all testing was done in the morning hours and possible time-of-day effects that are relevant for circulating cortisol could not be examined. Further, under different simulation parameters, with a team of multiple raters with complementary areas of expertise (e.g., an expert in police tactics in addition to an expert in communication) could have provided a more nuanced evaluation of police officer performance.

CONCLUSION

The present study demonstrates that physiological arousal during a critical incident differentially affects police officer verbal communication, nonverbal communication, and tactical skills. These differential effects speak to the complex nature of effective police work, the difficulties in assessing and defining ideal police performance, and further suggest that police training must address the array of intrapersonal and situational demands facing officers in the field. Future studies may consider adaptive training interventions that leverage nonverbal communication and tactical skills that appear to be robust to the effects of physiological arousal during a critical incident.

ETHICS STATEMENT

The study was approved by the Karolinska Institute's Ethics Committee and all participating officers provided written informed consent.

AUTHOR CONTRIBUTIONS

EA and AD conducted data analysis, data interpretation, and prepared the manuscript. BA conceived the study, conducted the study, was awarded funding for the study, and prepared the manuscript.

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Effects of Coping-Related Traits and Psychophysiological Stress Responses on Police Recruits' Shooting Behavior in Reality-Based Scenarios

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Police officers are often required to perform under high-stress circumstances, in which optimal task performance is crucial for their and the bystanders' physical integrity. However, stress responses, particularly anxiety and increased cortisol levels, shift attention from goal-directed to stimulus-driven control, leaving police officers with poor shooting performance under stress. Cardiac vagal activity and coping-related traits (i.e., self-control, sensation seeking) might help individuals to maintain performance under stress. So far, only few studies have integrated coping-related traits, psychophysiological stress markers and occupationally meaningful measures of behavior to investigate police officers' work performance under stress. Therefore, the present study investigated 19 police recruits (M_{age} = 22.84, SD = 3.30) undergoing a reality-based shooting scenario in two experimental conditions in a within-design: low stress (LS) against a non-threatening mannequin, and high stress (HS), involving physical threat by an opponent. Psychological (i.e., anxiety, mental effort) and physiological stress responses (i.e., salivary cortisol, alpha-amylase, cardiac vagal activity) as well as shooting accuracy were repeatedly assessed. It was hypothesized that under stress, police recruits would demonstrate elevated psychophysiological stress responses and impaired shooting performance. Elevated psychophysiological stress responses would negatively influence shooting performance, whereas self-control, sensation seeking and cardiac vagal activity would positively influence shooting performance. While recruits reported significantly higher anxiety and mental effort in the HS scenario, both scenarios elicited comparable physiological responses. Overall, shooting accuracy was low and did not significantly decrease in the HS scenario. Shooting performance was predicted by self-control in the LS scenario and by post-task cardiac vagal activity in the HS scenario. While increased anxiety hints at a successful stress manipulation, physiological responses suggest similar stress levels for both scenarios, diminishing potential behavioral differences between the scenarios. Performance efficiency decreased under stress, as indicated by increasing mental effort. Findings on self-control suggest that suppressing negative stress responses might lead to impaired goal-directed attention, resulting in performance decrements. For police research and training, high-realism scenarios afford an opportunity to investigate and experience psychophysiological stress responses.

Keywords: performance under stress, police officers, anxiety, cortisol, alpha-amylase, cardiac vagal activity

INTRODUCTION

On duty, police officers often encounter threatening situations which are accompanied by high levels of acute stress (Anderson et al., 2002). Activities like arresting suspects, responding to general and domestic disturbances or – in more severe cases – using fire weapons impose high stress on the officers and can sometimes be life-threatening. In case of performance failures, police shootings can have tremendous consequences for the officers themselves, colleagues, suspects or innocent bystanders. However, good shooting techniques alone do not appear sufficient for performing well under stressful circumstances: In training situations, hit rates reach 90%, whereas in real-life shootings they do not exceed 50% (Morrison and Vila, 1998; Timmer and Pronk, 2011). Therefore, it is essential to understand how stress and its psychophysiology impacts performance.

Stress results from the individual's perception of a discrepancy between the demands being placed by the environment and coping resources present in a particular situation (Lazarus and Folkman, 1984). Police officers are often required to respond to situations which threaten their physical integrity or psychological well-being, e.g., spotting a stolen vehicle, a high speed chase or conflict with a suspect (Anderson et al., 2002). These critical incidents are sudden, powerful events that are likely to overwhelm the police officers' coping resources and to be perceived as outside of their immediate control. When an individual perceives the environmental demands as succeeding its coping resources, a negative, unpleasant psychological state of stress ensues, commonly accompanied by anxiety (Lazarus and Folkman, 1984). Critical incidents in police work hold high levels of novelty, uncontrollability and personal as well as others' threat of injury or death. Given these characteristics, the body responds to these external demands by an activation of the fast reacting sympathetic adrenomedullary system (SAM; Nater and Rohleder, 2009) and the slower hypothalamo-pituitary-adrenal (HPA) axis (McEwen, 1998; Dickerson and Kemeny, 2004). Although the short-term activation of the systems might be adaptive to maintain bodily homeostasis (the so-called allostasis; Sterling and Eyer, 1988), chronically increased or dysregulated allostasis (referred to as allostatic overload) can lead to disease (McEwen, 1998). Given the regular encounter with critical incidents and the high level of organizational stress, police officers might be at risk for allostatic overload (Anderson et al., 2002, 2016a). Indeed, several studies have shown that critical incidents place high physiological demands on police officers, as measured by salivary cortisol (sCorti) and salivary alpha-amylase (sAA) as surrogate markers of the activation of the HPA and SAM system (Nater and Rohleder, 2009). Although physiological response patterns were inconsistent across studies, it was found that police officers showed increases in subjective stress, heart rate, sCorti and sAA in response to various simulated police scenarios (Regehr et al., 2008; Taverniers and De Boeck, 2014; Strahler and Ziegert, 2015). Groer et al. (2010) compared physiological responses during two virtual reality scenarios of different intensity: the lengthy chase of an armed suspect produced the largest responses in sCorti and sAA, while sAA, but not sCorti was increased during the short chase of a motorcyclist (Groer et al., 2010).

Besides the activation of the HPA and SAM system, heart rate variability (HRV) provides further insight into how people react to stress and perform under stress (Mosley et al., 2018). HRV, defined as the time interval between successive heart beats, represents the cardiac vagal activity, that is the contribution of the parasympathetic nervous system to cardiac function (Laborde et al., 2017). The neurovisceral integration model (Thayer et al., 2009) assumes that cardiac vagal activity indexes an individual's ability to self-regulate through the organization of physiological resources within central-peripheral neural feedback mechanisms. Higher cardiac vagal activity allows higher adaptability and greater behavioral flexibility in demanding environments (Thayer et al., 2009). Indeed, police officers showed increases in cardiac vagal activity (indicated by high-frequency HRV) in simulated high stress scenarios when facing physical threats compared to medium stress scenarios (Brisinda et al., 2015). Linking cardiac vagal activity to performance under stress, Thompson et al. (2015) found that a smaller reduction in cardiac vagal reactivity (from baseline to task) was associated with better performance in a shooting task.

Stress responses, particularly anxiety and elevated cortisol levels, have been associated with impairments in goal-directed behavior (Eysenck et al., 2007; Schwabe and Wolf, 2011). According to the attentional control theory (Eysenck et al., 2007), anxiety impairs attentional control by increasing the influence of the stimulus-driven system. This impairment leads to an attentional bias to external and internal goal-irrelevant, threat-related information and reduces the level of attention devoted to the current task goals (Eysenck et al., 2007). Initially developed to explain the effect of anxiety on cognitive tasks, the attentional control theory also applies to perceptual motor tasks (Nieuwenhuys and Oudejans, 2012, 2017). Besides anxiety, increased cortisol levels were also shown to influence cognitive functions through a shift from goal-directed control to stimulus-driven behavior under acute stress (Hermans et al., 2014), resulting in performance decrements in perceptual motor tasks (Doan et al., 2007; Cook and Crewther, 2012; Lautenbach et al., 2014). In contrast, Regehr et al. (2008) found that greater cortisol release in response to a reality-based police scenario was associated with higher levels of performance in police recruits. Importantly, stress responses might only impair the efficiency, not necessarily the effectiveness of performance. The attentional control theory postulates that performance decrements might potentially be overcome by the execution of additional mental effort (Eysenck et al., 2007; Nieuwenhuys and Oudejans, 2017).

Based on real-life data demonstrating performance decrements in shooting accuracy under stress (Morrison and Vila, 1998; Timmer and Pronk, 2011), research has evolved to investigate the mechanisms underlying these decrements. Officers reported to be more anxious under stressful circumstances and performed worse in a handgun shooting task, although they reported to invest extra mental effort (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010, 2011). In line with the ACT, gaze behavior of these officers in high stress circumstances revealed that they focused more on threat-related, task-irrelevant stimuli (e.g., opponent's gun or face) than they did in the low stress condition (Nieuwenhuys and Oudejans, 2010, 2011). Similarly, Vickers and Lewinski (2012) showed that elite police officers had more fixations on task-relevant locations (e.g., locations where a gun could be hidden) and prepared earlier for shooting than novices, resulting in better shooting performance. In contrast, novices even shifted their gaze away from the opponent to their own gun during shooting (Vickers and Lewinski, 2012). Given the importance of continuous visual information input during aiming and shooting, this finding indicates that efficiency of attentional control decreased and thereby, impaired perceptual-motor performance (Nieuwenhuys and Oudejans, 2010).

Although it seems well documented that stress generally impairs performance, people may be distinguished based on their ability to maintain or even increase performance under stress (Geukes et al., 2012). Possibly, variation in performance under stress can be explained by individual differences in task-relevant personality traits that become activated depending on the presence of trait-relevant situational cues (Tett and Gutermann, 2000). In case of extreme stress situations, literature has shown that self-control (Englert and Bertrams, 2015; Landman et al., 2016) and sensation seeking (Zuckerman, 1994; Frenkel et al., 2018; Frenkel et al., unpublished) affect psychophysiological stress responses and performance.

Considering the high risk to the physical integrity in police work, sensation seeking, defined as "seeking of varied, novel, complex, and intense sensations and experiences, and the willingness to take physical, social, legal and financial risks for the sake of such experience" (Zuckerman, 1994, p. 27) might be a relevant personality trait for police performance under stress. According to the psychobiological model (Zuckerman, 1994, 1996), individuals differ in their reaction to novel and intense stimulation: Low sensation seekers (LSS) are overwhelmed by intense stimulations, resulting in attenuated responses and the experience of aversive reactions, such as anxiety (Frenkel et al., 2018). In contrast, high sensation seekers (HSS) experience intense stimulations as pleasant and rewarding, which increases central nervous activity, allowing them to cope efficiently. HSS used more stress-reducing coping strategies (Tschiesner, 2012) and showed attenuated cortisol responses to stress (Couture et al., 2008; Frenkel et al., 2018).

Another trait associated with performance under stress is self-control, generally defined as the ability to willingly exert control over the self by the self (Muraven and Baumeister, 2000). Self-control has been shown to have facilitative effects on perceptual-motor performance under stress as it can help to buffer the negative effects of anxiety. Incorporating the ideas of the ACT (Eysenck et al., 2007), Englert and Bertrams (2015) concluded that self-control enables individuals to counteract the attention disruption under stress in order to obtain performance (Englert et al., 2015a,b). Supporting these theoretical considerations, police officers with high self-control did experience anxiety and increased HR in stressful circumstances, but were able to maintain shooting accuracy (Landman et al., 2016). Instead of utilizing extra effort to suppress or down-regulate their emotional responses, officers with high self-control appear to invest extra mental effort to maintain a goal-directed focus.

Since it is virtually impossible to predict and unethical to manipulate stressful encounters with hand guns in real life, knowledge on police officers' psychophysiological stress responses and shooting performance in critical incidents is limited (Regehr et al., 2008; Taverniers and De Boeck, 2014; Strahler and Ziegert, 2015). One approach toward the study of psychophysiological stress responses in such situations is to examine police officers' shooting performance during simulated high-realism shooting scenarios. Following Baumeister et al. (2007) call for more research involving directly observable behaviors in real-world psychological research, the present study applied a reality-based shooting scenario in two conditions: low stress (LS) against a non-threatening mannequin, and high stress (HS), involving physical threat by an opponent who occasionally shot back using colored soap cartridges. Police recruits reported their perceived anxiety as well as the mental effort after each scenario. sCorti and sAA were examined as physiological markers of HPA axis and SAM reactivity, respectively. HRV as index of cardiac vagal activity was continuously monitored throughout the study. Recruits' behavioral responses were assessed by shooting accuracy. To the best of our knowledge, so far, no empirical study has integrated measures of intra-individual changes in emotional and cognitive stress responses, various biopsychological stress markers and shooting performance. Therefore, the study had two aims: (1) to examine the psychological, physiological, and behavioral stress responses of police recruits in reality-based scenarios and (2) to examine the effects of psychophysiological stress responses and coping-related personality traits on shooting performance. It was hypothesized that:

> *Hypothesis 1*: Police recruits would experience elevated stress responses in the HS scenario as compared to the LS

scenario (i.e., increases in anxiety, mental effort, sCorti as well as sAA and reduced cardiac vagal reactivity).

Hypothesis 2: Shooting accuracy would decrease in the HS scenario as compared to the LS scenario.

Hypothesis 3: Resting cardiac vagal activity and smaller reduction of cardiac vagal activity from baseline to task would be positively associated with shooting accuracy.

Hypothesis 4: Higher levels of sensation seeking would be associated with reduced stress responses and higher shooting accuracy.

Hypothesis 5: Higher levels of dispositional self-control would be associated with reduced stress responses and higher shooting accuracy.

MATERIALS AND METHODS

The study design was approved by the ethics committee of the Faculty of Behavioural and Cultural Studies, Heidelberg University, Germany. Written informed consent was obtained from the participating police recruits after receiving detailed information about the design of the study, including the potential risks and benefits. Participants received no financial compensation. Given the involvement of firearms, the present study was executed under the responsibility of certified police firearms instructors, following their standard safety protocol.

Participants

Data reported here stems from a sample of third-semester police recruits. Overall, 19 German students (3 women, 16 men) participated during two training sessions. Participants were between 19 and 33 years old ($M_{age} = 22.84$, $SD = 3.30$). All recruits have already been on duty for 2 months in the riot police and were licensed to carry their handgun on duty. None of them has fired at a suspect or has been shot at.

Participants' BMI ranged from 21.22 to 28.40 kg/m^2 ($M = 24.63$, $SD = 2.02$). Eight participants reported to be smokers, but did not differ in physiological measures (i.e., sCorti and sAA). Participants did not report any current or chronic medical or psychiatric diseases. However, one participant was on medication containing cortisone and was therefore excluded from sCorti analyses. One woman took hormonal contraceptives, but her sCorti levels were normal and therefore included in the analyses. The women not taking contraceptives ($n = 2$) were tested during the luteal phase, as indicated by self-report.

Tasks

Each police officer participated in a 1-h session that involved undergoing the LS scenario first and then the HS scenario.

The set-up of the scenarios is depicted in **Figure 1**. In both scenarios, participants were required to walk up a 20 m long hallway taking self-protection measures, until they reached the door of the last room on the right-hand side. All other rooms were marked and were not relevant in the scenario. As soon as participants had reached the last door, they had to open this door and search the room for the target person. Subsequently, participants had to fire six consecutive shots on the target person. In agreement with real-life situations and police guidelines, participants retreated behind the door and shot around the corner, resulting in a shooting distance of approximately 5 m. Recruits used a handgun that was identical to their duty weapon (Heckler & Koch, P30) but adjusted to shoot with colored soap cartridges (Simunition®, FX Marking Ammunition).

In the LS scenario, participants received precise instructions from the experimenter, eliminating ambiguity and uncertainty of the situation. Participants were instructed that they would encounter the target person in the last room and as soon as the target person would appear in their field of vision, they had to fire six consecutive shots. In the LS scenario, the target person was a life-sized mannequin that stood straight up, facing the participant and holding its arms as if pointing a gun toward the participant. The mannequin was supposed to eliminate the threat of physical harm. The mannequin was fitted with target areas indicating the score of a hit in this area. Participants were aware that shooting accuracy would be assessed but received no further explanations about the scoring grid.

In the HS scenario, participants received limited instructions from the experimenter increasing feelings of ambiguity, uncertainty and uncontrollability. They were told to act in accordance with the police guidelines in the following scenario and that they had to use their gun to solve the situation. Then, participants were sent toward the hallway – "the operation site" (see **Figure 1**) – where they encountered the civilian who called the police. This person was played by a male, Caucasian experimenter (32 years old). He suddenly came around the corner and approached the participant franticly: "Come quickly! There is a shooting! I heard shots in the last room! You need to go there!". The involvement of the civilian is assumed to further increase psycho-social stress. In the HS scenario, the target person was an experienced police operation instructor who wore protective gear and a handgun loaded with colored soap cartridges. While the participants walked up the hallway, the instructor fired two or three shots, so that participants heard the shooting, which intended to induce physical threat. As soon as the participants opened the door, the instructor stood still in the same stance as the mannequin, pointing the gun at the participant. After the participants had fired six shots, the instructor played as being hurt and went down to the ground.

Both scenarios were timed using a digital stopwatch (CASIO, HS-3V-1RET). The scenarios started as soon as the police recruits entered the hallway leading up to the target room. After firing the last shot, the scenarios ended. On average, the LS scenario lasted 41 s ($SD = 14$) and the HS scenario 46 s ($SD = 26$). Additionally, both scenarios were videotaped with two cameras (GoPro HERO 4 Silver). One camera recorded the interaction of the participants with the experimenter/role player in the hallway, and the second camera recorded the shooting in the target room (see **Figure 1**). Videotapes were used for further analyses of shooting accuracy.

Measures

Psychological Measures

Recruits' state anxiety in response to the stress manipulation was measured during baseline measurements and directly after

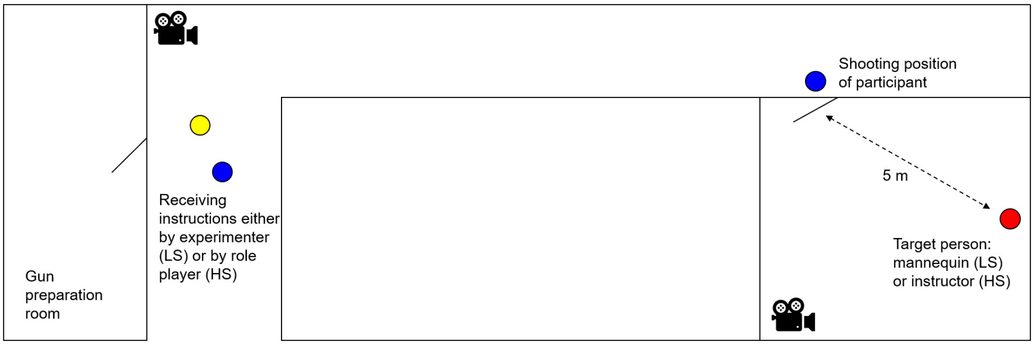

FIGURE 1 | Experimental set-up of the scenarios. Participants prepared their gun in the gun preparation room and then received instructions either by the experimenter in the low stress (LS) scenario or by the role player in the high stress (HS) scenario. Participants were required to walk up the hallway taking self-protection measures. When they have reached the last door on the right side, they were required to open this door and search the room for the target person. As soon as the target person appeared in their visual field, they were required to fire six consecutive shots on the target person. Shooting distance was approximately 5 m. Target person was either represented by a mannequin in the LS scenario or a police instructor in the HS scenario. Scenarios were videotaped by two cameras.

the scenarios using the Anxiety Thermometer (Houtman and Bakker, 1989). The Anxiety Thermometer is a 10-cm continuous scale on which participants rated their state anxiety they had experienced during the scenarios, ranging from *not anxious at all* to *extremely anxious*. Validity and test-retest reliability correlations coefficients range between 0.60 and 0.78 (Houtman and Bakker, 1989). For analyses, the entries were transformed into values ranging from 0 to 10.

Perceived mental effort was assessed during baseline measurements and directly after each scenario using the German version of the rating scale mental effort (RSME; Zijlstra, 1993; German version: Skala subjektiv erlebter Anstrengung, SEA; Eilers et al., 1986). The SEA is a continuous 110-mm scale, on which each 10 mm interval and verbal anchors are marked. Participants rated their perceived mental effort during the scenarios by marking the specific value on the scale. For analyses, entries were transformed into values ranging from 0 to 11.

Sensation seeking was measured using the German version of the Sensation Seeking Scale – Form V (SSS-V; Zuckerman, 1994; German version: Beauducel et al., 2003). Participants were required to answer either A or B for each of the 40 items. Answers A and B designate behaviors that are either characteristic of sensation seekers (“I would like to learn to fly an airplane”) or non-sensation seekers (“I would not like to learn to fly an airplane”). Total scores range between 0 and 40. The SSS-V has been used in over 600 studies and was found to have sufficient psychometric properties in many languages. Cronbach’s α in the norm sample was 0.82 (Beauducel et al., 2003) and in the present study 0.63. Recruits’ sensation seeking scores (M = 23.00, SD = 4.63, range = 15–31) were similar to the scores obtained by the norm sample (M = 22.70, SD = 5.70; Beauducel et al., 2003).

Dispositional self-control was assessed using the German version of the Self-Control Scale (SCS; Tangney et al., 2004; German version, SCS-K-D: Bertrams and Dickhäuser, 2009). It consists of 13 items which are answered on a 5-point Likert scale ranging from 1 = *not at all like me* to 5 = *very much like me*. Consequently, total scores range from 13 to 65. An example item is as follows: “People would say that I have iron self-discipline.” In the present study, the internal consistency of the SCS-K-D was satisfactory (α = 0.83) and similar to the one in the norm sample (α = 0.79). Overall, police recruits (M = 44.42, SD = 7.41) scored significantly above the norm sample, i.e., 39.85, $t(18) = 2.69$, $p = 0.015$, indicating that the recruits had considerably higher self-control than undergraduate psychology students tested by Tangney and Colleagues (2004).

Physiological Measures

Salivary samples were collected using salivette sampling devices (Sarstedt AG & Co., Nümbrecht, Germany) at six points during the experiment (see **Figure 2**). Sampling time was exactly 1 min during which participants had to chew the cotton swabs as regularly as possible. Saliva samples were immediately stored in a coolbag with cooling elements. At the end of the testing day, they were stored at −20°C until further analyses. Biochemical analyses were conducted by the Steroid Laboratory of the Institute of Pharmacology, Heidelberg University, Germany. After thawing, saliva samples were centrifuged at 30000 rpm for 5 min, which resulted in a clear supernatant of low viscosity. Fifty microliters of saliva were used for duplicate analyses.

Free cortisol levels were measured using a commercially available immunoassay (IBL International, Hamburg, Germany). Intra- and interassay coefficients of variation were below 8% (Schultheiss and Stanton, 2009).

Salivary alpha-amylase levels were measured using the analyzer ADVIA Chemistry XPT (Siemens, München, Germany) and the reagents #03031177 (Siemens, München, Germany). Saliva was diluted 1:200 using 0.9% saline solution.

HRV as an index of cardiac vagal activity was measured using a wearable, portable, externally applied ECG recorder and wireless transmitter for ECG measurement (eMotion Faros 180°). Two disposable ECG pre-gelled electrodes (Ambu L-00-S/25, Ambu GmbH, Bad Nauheim, Germany) were placed below the right clavicle and on the left side of the chest below the 12th rib, respectively. Inter-beat intervals were continuously recorded with a sampling rate of 1000 Hz until 30 min after the start of the HS scenario. After sitting quietly for a few minutes, a baseline

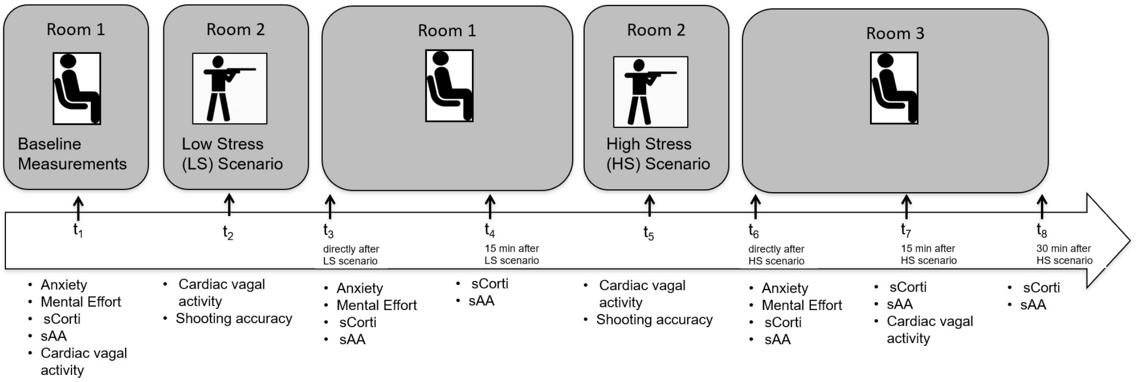

FIGURE 2 | Overview of the study timeline. Participants were required to undergo two shooting scenarios in a low stress (LS) and high stress (HS) condition. Their psychological, physiological and behavioral responses were assessed at t_1–t_8. Anxiety and mental effort were assessed through questionnaires at three points. Salivary cortisol (sCorti) and salivary alpha-amylase (sAA) were assessed at six points. Cardiac vagal activity was recorded continuously, but four intervals were chosen for analyses. Dispositional self-control and sensation seeking were assessed through questionnaires at t_7.

reading of cardiac vagal activity was recorded for 2 min. Since physical activity heavily influences HRV parameters, making the interpretation unambiguous, task cardiac vagal activity was assessed directly before the scenarios for 1 min following the recommendations (Esco and Flatt, 2014; Laborde et al., 2017). Post-task cardiac vagal activity was assessed 18 min after the start of the scenario for 2 min in a sitting position. HRV was analyzed using Kubios HRV (Biosignal Analysis and Medical Imaging Group, University of Eastern Finland, Finland). The full ECG recordings were inspected visually and artifacts were corrected manually (Laborde et al., 2017). Root Mean Square of Successive Differences (RMSSD) from time domain analyses was calculated for quantification of short-time HRV, as it is deemed a reliable measure of cardiac vagal activity under ambulatory trails since it is relatively free of respiratory influences as compared to high frequency parameters (Laborde et al., 2017). Cardiac vagal reactivity was calculated by subtracting baseline cardiac vagal activity from task cardiac vagal activity. Cardiac vagal recovery was calculated by subtracting task cardiac vagal activity from post-task cardiac vagal activity.

Behavioral Measure

Police recruits' performance was assessed through shooting accuracy. Scores were assigned to hits on different body parts of the opponent (hips: 50, chest: 20, head: 20, legs: 10, arms: 5), representing the effectiveness of a hit in this area (as rated by an experienced police instructor). In line with the current police guidelines, hits in the hips were awarded with the greatest scores. Hits in the respective areas were identified by the police instructor and a research assistant with the help of the video material. Shooting accuracy was then calculated by sum of the scores divided by maximum score (maximum score = number of shots * 50).

Procedure

All testing sessions were conducted during regular training sessions between 02.00 p.m. and 08.00 p.m., when cortisol levels are most stable (Kudielka et al., 2004). The sessions took place in a vacant office building that serves as a police training location. Participants were instructed to refrain from smoking, eating, or drinking any beverages except water at least 1 h prior to the study and during the study protocol. An overview of the study timeline is displayed in **Figure 2**. After participation, participants were fully debriefed about the aims of the study and were instructed not to talk to each other about the content of the study.

Statistical Analyses

All dependent variables were checked for outliers (three interquartile ranges above 3rd/under 1st quartile; Tukey, 1977) and normal distribution was tested using the Kolmogorov–Smirnov test. According to the recommendations of Kirschbaum (1991), sCorti values and the variable of cardiac vagal activity were naturally log-transformed.

To investigate the effect of the stress manipulation on anxiety, mental effort, HRV, sCorti, sAA and shooting accuracy in the HS and LS scenarios were compared using repeated measures ANOVAs and contrasts (difference). For psychological variables a 1 × 3 ANOVA (time: t_1, t_3, t_6) was conducted, for sCorti and sAA a 1 × 6 ANOVA (time: t_1, t_3, t_4, t_6, t_7, t_8), for cardiac vagal activity a 1 × 4 ANOVA (time: t_1, t_2, t_5, t_7) and for the behavioral variable a 1 × 2 ANOVA (LS vs. HS scenario). Greenhouse–Geisser corrected *p*-values were reported when the assumption of sphericity was violated as indicated by the Mauchly test. Significant main effects were further analyzed with Bonferroni corrected *post hoc* tests. To explore the contribution of coping-related variables to the stress responses and shooting accuracy, bivariate correlations were run, followed by hierarchical stepwise linear regression analyses. Using hierarchical regression, anxiety, mental effort, sCorti, sAA, cardiac vagal activity, cardiac vagal reactivity, cardiac vagal recovery and shooting accuracy, respectively in the LS and HS scenario, were entered as dependent variables. The first block included dispositional self-control, sensation seeking, and baseline cardiac vagal activity. The second block was used to explore the contribution of the situational stress responses. For cardiac vagal reactivity and recovery, task and post-task cardiac vagal activity were excluded at this stage, as reactivity and recovery are derived from these tonic variables.

All statistical analyses were performed using IBM SPSS 21 (Chicago, IL, United States). p-values < 0.05 are considered significant and for ANOVAs, η_p^2 was presented as a measure of effect size. In this regard, values $\approx$0.02 represent a small effects, values $\approx$0.15 represent medium-size effects and values $\approx$0.35 represent large effects (Cohen, 1992).

RESULTS

Outlier analysis revealed two outliers in anxiety at t_1 and three outliers in cardiac vagal activity (at t_1, t_4, and t_7). Normal distribution was violated in three variables. As ANOVAs are robust against this violation, variables were not transformed (Schmider et al., 2010).

Differences Between Low and High Stress Scenarios

Descriptive data of anxiety, mental effort, cardiac vagal activity, sCorti, sAA, and shooting accuracy are presented in **Table 1**.

TABLE 1 | Descriptive statistics of anxiety, mental effort, sCorti, sAA, cardiac vagal activity, and shooting accuracy at each measurement point.

		M	*SD*
Anxiety (*N* = 19)	t_1	1.92	1.55
	t_3	4.63	2.25
	t_6	6.46	1.71
Mental effort (*n* = 17)	t_1	1.76	1.72
	t_3	3.71	2.38
	t_6	6.12	2.35
sCorti in nmol/l (*n* = 17)	t_1	4.59	2.84
	t_3	5.00	2.66
	t_4	6.53	4.13
	t_6	5.94	3.21
	t_7	5.61	3.94
	t_8	4.56	2.91
sAA in U/ml (*N* = 19)	t_1	154.57	88.49
	t_3	168.73	98.48
	t_4	121.57	68.14
	t_6	156.51	82.38
	t_7	124.52	77.02
	t_8	100.87	55.33
Cardiac vagal activity in ms (*n* = 14)	t_1	57.41	41.98
	t_2	34.15	39.16
	t_5	28.18	24.82
	t_7	57.04	63.48
Shooting accuracy (*n* = 16)	LS scenario	22.66	9.52
	HS scenario	24.39	12.43

HR, heart rate; sCorti, salivary cortisol; sAA, salivary alpha-amylase; LS, low stress; HS, high stress.

Psychological Stress Responses

Anxiety and mental effort during the experiment are depicted in **Figure 3**.

Anxiety changed significantly over time, $F(2,36) = 39.90$, $p < 0.001$, $\eta_p^2 = 0.69$. Contrasts show that anxiety significantly increased from baseline in the LS scenario [$F(1,18) = 24.04$, $p < 0.001$, $\eta_p^2 = 0.57$] and further increased in the HS scenario, $F(1,18) = 61.95$, $p < 0.001$, $\eta_p^2 = 0.76$. All pairwise comparisons yielded significant results (all $p < 0.006$).

Similarly, the stress manipulation affected the reported mental effort, $F(2,32) = 31.88$, $p < 0.001$, $\eta_p^2 = 0.67$. Participants invested more mental effort in the LS scenario than during baseline [$F(1,16) = 10.92$, $p = 0.004$, $\eta_p^2 = 0.41$] and more mental effort in the HS than in the LS scenario, $F(1,16) = 60.66$, $p < 0.001$, $\eta_p^2 = 0.79$. Again, all *post hoc* pairwise comparisons yielded significant results (all $p < 0.013$).

Physiological Stress Responses

Changes in sCorti, sAA and HRV in the course of the experiment are depicted in **Figures 4**, **5**.

sCorti levels significantly varied in the course of the experiment, $F(2.02,32.34) = 4.36$, $p = 0.021$, $\eta_p^2 = 0.21$. Results of the contrast analysis showed that sCorti levels significantly raised after the LS scenario, $F(1,16) = 7.01$, $p = 0.018$, $\eta_p^2 = 0.31$. However, they did not further increase after the HS scenario, $F(1,16) = 0.02$, $p = 0.891$, $\eta_p^2 < 0.01$. In contrast, Bonferroni corrected *post hoc* tests demonstrated that sCorti levels significantly decreased after the LS scenario (from t_4, t_6 and t_7 to t_8, all $p < 0.021$), but baseline sCorti levels at t_1 and t_3 did not significantly differ from sCorti levels at any other measurement point (all $p > 0.237$).

Stress manipulation had a significant impact on sAA levels, $F(2.90,52.13) = 16.47$, $p < 0.001$, $\eta_p^2 = 0.48$. Contrast analysis showed that sAA did not significantly increase from baseline in the LS scenario [$F(1,18) = 2.45$, $p = 0.135$, $\eta_p^2 = 0.12$] and from t_4 in the HS scenario, $F(1,18) = 3.09$, $p = 0.096$, $\eta_p^2 = 0.15$. Bonferroni corrected post-hoc tests revealed that baseline sAA values were relatively high, as they differed significantly from the values in other resting conditions (i.e., t_4, t_7, and t_8; all $p < 0.026$). sAA values after the LS and HS scenario were significantly higher than values in the resting conditions other than baseline (all $p < 0.031$), which did not significantly differ from each other (all $p > 0.119$).

Cardiac vagal activity significantly varied in the course of the experiment, $F(3,39) = 9.79$, $p < 0.001$, $\eta_p^2 = 0.43$. Results of the contrast analysis showed that cardiac vagal activity significantly decreased from baseline to the LS scenario [$F(1,13) = 12.72$, $p = 0.003$, $\eta_p^2 = 0.50$] and further decreased to the HS scenario, $F(1,13) = 13.48$, $p = 0.003$, $\eta_p^2 = 0.51$. After the HS scenario, cardiac vagal activity increased significantly, $F(1,13) = 4.77$, $p = 0.048$, $\eta_p^2 = 0.27$. Bonferroni-corrected *post hoc* tests supported that cardiac vagal activity significantly decreased from baseline to the LS scenario ($p = 0.021$) and to the HS scenario ($p = 0.006$). However, cardiac vagal activity in the LS and HS scenario as well as during baseline and post-task did not significantly differ from each other (all $p = 1$).

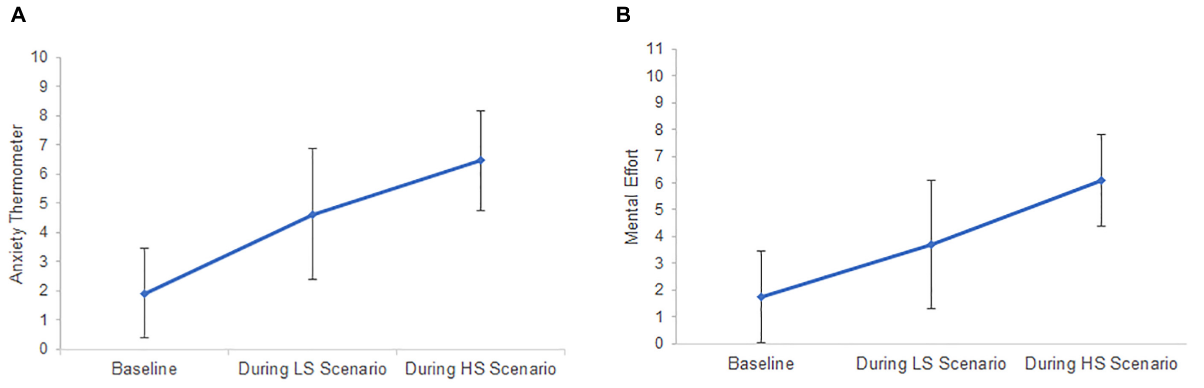

FIGURE 3 | Psychological response profiles to the low stress (LS) and high stress (HS) scenario regarding mean anxiety **(A)** and mean mental effort **(B)**. Error bars represent standard deviation.

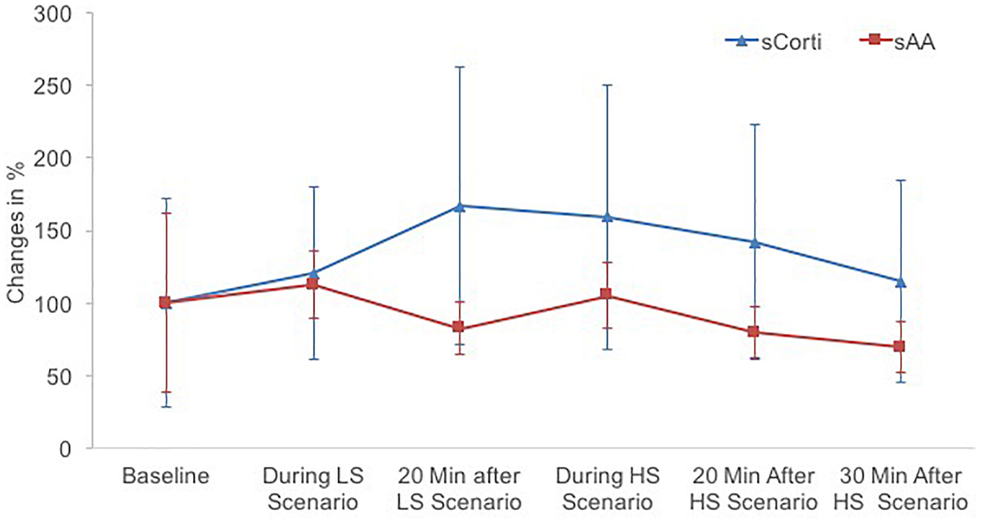

FIGURE 4 | Physiological response profiles to the low stress (LS) and high stress (HS) scenario regarding mean salivary cortisol (sCorti) and mean salivary alpha-amylase (sAA). Error bars represent standard deviation.

Behavioral Stress Response

Shooting accuracy in the LS vs. HS scenario is depicted in **Figure 6**. Shooting accuracy did not differ between the LS and HS scenario, $F(1,15) = 0.14$, $p = 0.718$, $\eta_p^2 = 0.01$.

Correlations

Tables 2, **3** show an overview of Pearson's correlation coefficients of all study variables in the LS and HS scenario, respectively.

Dispositional self-control correlated significantly with anxiety in the LS and HS scenario (negatively) and with cardiac vagal reactivity in the HS scenario (negatively). Cardiac vagal activity at baseline correlated significantly with anxiety in the LS scenario (negatively). Post-task cardiac vagal activity correlated significantly with mental effort in the LS scenario (negatively). Similarly, cardiac vagal recovery correlated significantly with mental effort in the HS scenario (negatively).

Regression Analyses

Hierarchical stepwise regressions were performed to predict psychophysiological stress responses (i.e., anxiety, mental effort, sCorti, sAA, cardiac vagal activity, cardiac vagal reactivity, cardiac vagal recovery) and performance (i.e., shooting accuracy) in the LS and HS scenario, respectively. The first block was used to identify salient dispositional predictors (sensation seeking, self-control, and baseline cardiac vagal activity) and the second block included the remaining stress responses (i.e., anxiety, mental effort, sCorti 20 min after the scenario, sAA directly after the scenario, task cardiac vagal activity, post-task cardiac vagal activity, cardiac vagal reactivity, and cardiac vagal recovery). Regressions can be found in **Tables 4**, **5**.

Regression Analyses in the LS Scenario

For shooting accuracy, the regression analysis identified self-control as a significant predictor, R^2 change = 0.48, $p = 0.019$.

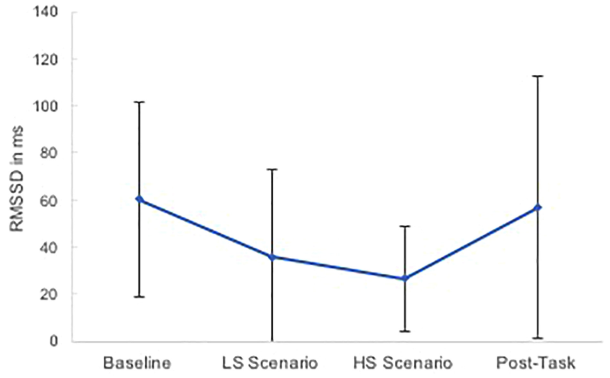

FIGURE 5 | Cardiac vagal response profiles to the low stress (LS) and high stress (HS) scenario. Error bars represent standard deviation.

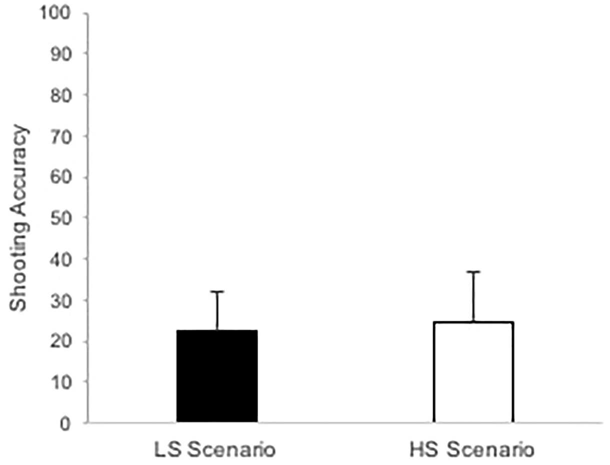

FIGURE 6 | Mean percentage of shooting accuracy in the low stress (LS) and high stress (HS) scenario. Error bars represent standard deviation.

It accounted for 48% (adjusted R^2 = 0.42) of the variance in shooting accuracy in the LS scenario. For anxiety, regression analyses identified two significant predictors. Self-control was extracted as the first factor, R^2 change = 0.57, p = 0.003. The second factor was mental effort, R^2 change = 0.21, p = 0.011. Both predictors accounted for 78% (adjusted R^2 = 0.74) of the variance in anxiety in the LS scenario. For mental effort, anxiety was identified as significant predictor (R^2 change = 0.64, p = 0.001), accounting for 64% (adjusted R^2 = 0.60) of the variance. In the LS scenario, sAA was significantly predicted by cardiac vagal recovery (R^2 change = 0.32, p = 0.046) explaining 32% (adjusted R^2 = 0.25) of the variance in the LS scenario. Cardiac vagal activity in the LS scenario was significantly predicted by cardiac vagal activity at rest, R^2 change = 0.31, p = 0.048 accounting for 31% (adjusted R^2 = 0.25) of variance. For cardiac vagal recovery, sAA was extracted as a significant factor, R^2 change = 0.32, p = 0.046. It accounted for 32% (adjusted R^2 = 0.25) of variance.

For sCorti and cardiac vagal reactivity in the LS scenario, no significant predictors were extracted.

Regression Analyses in the HS Scenario

For shooting accuracy, post-task cardiac vagal activity was identified as a significant predictor, R^2 change = 0.39, p = 0.040, explaining 39% (adjusted R^2 = 0.32) of the variance in the HS scenario. Anxiety in the HS scenario was significantly predicted by mental effort, R^2 change = 0.38, p = 0.032, accounting for 38% (adjusted R^2 = 0.32) of the variance. For mental effort in the HS scenario, four factors were extracted. The first factor identified was anxiety (R^2 change = 0.38, p = 0.032), the second factor was cardiac vagal recovery (R^2 change = 0.29, p = 0.019), the third factor was sAA (R^2 change = 0.16, p = 0.025) and the fourth was cardiac vagal activity (R^2 change = 0.09, p = 0.028). All predictors together explained 92% (adjusted R^2 = 0.88) of the variance of mental effort in the HS scenario. Cardiac vagal reactivity in the HS scenario was significantly predicted by three factors. The first predictor identified was baseline cardiac vagal activity (R^2 change = 0.78, $p < 0.001$), the second predictor was self-control (R^2 change = 0.10, $p < 0.018$) and the third predictor was sCorti 20 min after the scenario (R^2 change = 0.05, p = 0.036). Together, they accounted for 94% (adjusted R^2 = 0.91) of the variance.

For sCorti, sAA and cardiac vagal activity in the HS scenario, no significant predictors were extracted.

DISCUSSION

The present study investigated the psychological (i.e., anxiety, mental effort), physiological (i.e., sCorti, sAA, cardiac vagal activity) and behavioral responses (i.e., shooting accuracy) of police recruits during a simulated shooting scenario under a HS and a LS condition. The aim of the study was twofold: (1) to examine the stress responses of police recruits in reality-based scenarios and (2) to examine the effects of stress responses and coping-related personality traits (i.e., sensation seeking and self-control) on shooting performance.

Hypothesis 1 predicted elevated psychophysiological stress responses in the HS scenario as compared to the LS scenario. It was supported by the psychological, but not by the physiological stress responses. Police recruits reported significantly higher levels of anxiety and mental effort in the HS scenario as compared to the LS scenario. This finding is in line with other studies that incorporated LS vs. HS conditions for police officers during handgun shooting or similar situations (Nieuwenhuys and Oudejans, 2010, 2011; Taverniers and De Boeck, 2014). In contrast, recruits showed similar physiological stress reactions to the LS and HS scenario. That is, sAA significantly increased and cardiac vagal activity significantly decreased during both scenarios compared to baseline conditions. While the increases in sAA and decreases in cardiac vagal activity during reality-based scenarios complement a great body of research showing strong physiological stress responses to reality-based scenarios (Groer et al., 2010; Taverniers and De Boeck, 2014; Brisinda et al., 2015; Strahler and Ziegert, 2015), the missing differentiation between the LS and HS scenario might be explained through

TABLE 2 | Correlation matrix for low stress (LS) scenario.

	1	2	3	4	5	6	7	8	9	10	11	12
(1) Self-control	—	−0.26	−0.62**	−0.54*	0.30	0.06	0.23	0.17	−0.03	−0.52	−0.11	−0.32
(2) Sensation Seeking		—	0.30	0.17	0.35	−0.38	−0.18	0.13	−0.04	0.09	0.10	0.12
(3) Anxiety			—	0.79***	−0.18	0.29	−0.50*	−0.31	−0.45	0.39	−0.17	0.05
(4) Mental Effort				—	−0.18	0.37	−0.33	−0.19	−0.51*	0.22	−0.39	−0.36
(5) sCorti (20 min after LS scenario)					—	−0.03	−0.31	−0.31	−0.26	−0.11	0.04	0.02
(6) sAA						—	−0.01	−0.04	−0.15	0.31	−0.29	−0.15
(7) Baseline CVA							—	0.55*	0.56*	−0.48	−0.03	−0.21
(8) Task CVA								—	0.57*	0.30	−0.14	−0.01
(9) Post-task CVA									—	0.14	0.67**	0.21
(10) Reactivity CVA										—	−0.06	0.33
(11) Recovery CVA											—	0.17
(12) Shooting accuracy												—

*sCorti, salivary cortisol; sAA, salivary alpha-amylase; CVA, cardiac vagal activity; *p < 0.05, **p < 0.01, ***p < 0.001.*

TABLE 3 | Correlation matrix for high stress (HS) scenario.

	1	2	3	4	5	6	7	8	9	10	11	12
(1) Self-control	—	−0.26	−0.51*	−0.25	0.14	−0.01	0.23	0.18	−0.02	−0.55*	−0.03	−0.00
(2) Sensation Seeking		—	−0.10	−0.29	0.29	−0.27	−0.18	−0.10	−0.04	0.18	0.08	−0.30
(3) Anxiety			—	0.64**	−0.12	0.19	−0.07	0.02	0.09	0.40	−0.05	0.10
(4) Mental Effort				—	−0.16	0.59**	0.01	0.35	−0.25	0.29	−0.54*	0.08
(5) sCorti (20 min after HS scenario)					—	−0.03	−0.47	−0.33	−0.41	0.26	−0.12	−0.03
(6) sAA						—	0.01	0.12	−0.17	0.04	−0.20	−0.10
(7) Baseline CVA							—	0.50	0.56*	−0.88***	0.16	0.02
(8) Task CVA								—	0.53*	−0.14	0.07	−0.32
(9) Post-task CVA									—	−0.28	0.84***	−0.34
(10) Reactivity CVA										—	−0.13	−0.13
(11) Recovery CVA											—	−0.31
(12) Shooting accuracy												—

*sCorti, salivary cortisol; sAA, salivary alpha-amylase; CVA, cardiac vagal activity; *p < 0.05, **p < 0.01, ***p < 0.001.*

the nature of the scenarios. Brisinda et al. (2015) were able to distinguish medium- und high-risk scenarios based on cardiac vagal activity patterns. However, in their study, only high-risk scenarios, but not medium-risk scenarios involved shooting tasks, whereas in the current study, even the LS scenario required shooting. sCorti followed an unexpected pattern with the highest levels 20 min after the LS scenario and thereafter, steadily decreasing, which is comparable to findings of decreasing cortisol after simulated police incidents (Strahler and Ziegert, 2015; Arble et al., 2019). Strahler and Ziegert (2015) suggested blunted cortisol responses due to long-term chronic stress as well as adaption to endocrine stress responses following frequent encounters of acute stress as possible explanations for this finding. In contrast, the missing profound sCorti response after the HS scenario contradicts the findings of increased sCorti levels after reality-based scenarios in police officers (Regehr et al., 2008; Groer et al., 2010). Possibly, police recruits' sCorti levels did not further increase after the HS scenario because they were still in the midst of dealing with the first acute stress response to the LS scenario.

Subsequent to the inconsistent pattern of psychological and physiological stress responses, hypothesis 2, predicting decreases in shooting accuracy in the HS scenario, was not supported. Shooting accuracy in the LS and HS scenario was extremely low and did not differ significantly from each other. Nonetheless, in line with the attentional control theory (Eysenck et al., 2007), efficiency decreased in the HS scenario, since police recruits reported to invest more mental effort in the HS scenario. Others found decreased shooting performance under HS compared to LS conditions (Nieuwenhuys and Oudejans, 2010, 2011; Taverniers and De Boeck, 2014) but the divergent pattern in our study might be due to near floor performance under LS and/or the elevated physiological stress responses in the LS scenario.

Contradicting hypothesis 3, neither baseline cardiac vagal activity nor cardiac vagal reactivity predicted shooting performance in the LS and HS scenario. However, shooting performance was significantly predicted by post-task cardiac vagal activity in the HS scenario. Surprisingly, higher levels of post-task cardiac vagal activity were associated with worse shooting performance. Given the correlation between post-task and task cardiac vagal activity (see **Table 3**), police recruits with high levels of cardiac vagal activity in recovery might also have high levels of cardiac vagal activity during the task. In a previous study on shooting performance under stress, a

TABLE 4 | Multiple (stepwise) regressions for stress responses in the low stress (LS) scenario.

Model	Unstandardized coefficients *B*	*SE*	Standardized coefficients β	*T*
Shooting accuracy				
(1) Self-control	−1.69	0.59	−0.69	−2.85*
Anxiety				
(1) Self-control	−0.26	0.07	−0.76	−3.83*
(2) Self-control	−0.16	0.06	−0.46	−2.58*
Mental Effort	0.49	0.16	−0.55	3.11*
Mental Effort				
(1) Anxiety	0.90	0.20	0.80	4.39**
sAA				
(1) CVA recovery	−42.92	19.07	−0.56	−2.25*
Cardiac vagal activity				
(1) CVA baseline	0.99	0.45	0.56	2,22*
Cardiac vagal recovery				
(1) sAA	−0.01	0.00	−0.56	−2.25*

*sCorti, salivary cortisol; sAA, salivary alpha-amylase; CVA, cardiac vagal activity; *p < 0.05, **p < 0.01.*

TABLE 5 | Multiple (stepwise) regressions for stress responses in the high stress (HS) scenario.

Model	Unstandardized coefficients *B*	*SE*	Standardized coefficients β	*T*
Shooting accuracy				
(1) Post-task CVA	−9.98	4.17	−0.62	−2.40*
Anxiety				
(1) Mental effort	0.37	0.15	0.62	2.49*
Mental effort				
(1) Anxiety	1.02	0.41	0.62	2.49*
(2) Anxiety	1.07	0.31	0.65	3.41**
CVA recovery	−1.93	0.67	−0.54	−2.86*
(3) Anxiety	0.90	0.25	0.55	3.67**
CVA recovery	−1.84	0.51	−0.52	−3.58**
sAA	0.01	0.01	0.41	2.75*
(4) Anxiety	0.86	0.18	0.52	4.70**
CVA recovery	−1.89	0.38	−0.53	−4.98**
sAA	0.01	0.00	0.36	3.21*
Task CVA	0.85	0.31	0.31	2.77*
Cardiac vagal reactivity				
(1) Baseline CVA	−1.19	0.20	−0.88	−5.99***
(2) Baseline CVA	−0.80	0.20	−0.59	−3.93**
Self-control	−0.06	0.02	−0.43	−2.87*
(3) Baseline CVA	−0.97	0.18	−0.73	−5.56**
Self-control	−0.06	0.02	−0.40	−3.33**
sCorti	−0.27	0.11	−0.25	−2.52*

*sCorti, salivary cortisol; sAA, salivary alpha-amylase; CVA, cardiac vagal activity; *p < 0.05, **p < 0.01, ***p < 0.001.*

larger vagal withdrawal in the HS, but not in the LS condition, was found to be adaptive (Mosley et al., 2017). Similarly, the high levels of post-task cardiac vagal activity in the current study might reflect a smaller cardiac vagal withdrawal during the task, resulting in worse shooting performance, as police recruits might have not met the high situational demands of the HS scenario (Mosley et al., 2017). As findings on the link between cardiac vagal reactivity and performance under stress are diverse, further research is needed to clarify the role of cardiac vagal activity as an indicator of self-regulation under differing situational demands.

As a coping-related personality trait, sensation seeking did not predict shooting performance nor stress responses in the LS and HS scenario. This finding does not support hypothesis 4 and contradicts a body of research suggesting stress-buffering effects of sensation seeking (Couture et al., 2008; Tschiesner, 2012; Frenkel et al., 2018; Frenkel et al., unpublished). Therefore, further investigations into the role of sensation seeking are necessary to allow deeper conclusions. Previous studies with significant findings on sensation seeking made use of dichotomization into extreme groups of low and high sensation seekers (Shabani et al., 2011; Frenkel et al., 2018). In future studies with police officers, the comparison of low and high sensation seekers might increase effect sizes and reveal the hypothesized differences in stress responses. Furthermore, it might be especially interesting to investigate samples of experienced police officers or special forces, in which a self-selection based on relevant personality traits might have occurred. The current sample consisted of relatively unexperienced police recruits. Work experience has been identified as a predictor for less anxiety and better performance under stressful circumstances (Vickers and Lewinski, 2012; Landman et al., 2016). Therefore, more experienced police officers and special forces might yield different results.

Hypothesis 5, predicting that self-control positively influences shooting performance, was not supported. In the LS scenario, self-control significantly predicted anxiety and shooting performance: While higher self-control was associated with less anxiety, higher self-control also worsened shooting performance. In contrast, high levels of self-control were associated with less cardiac vagal reactivity in the HS scenario, which was assumed to be beneficial for shooting performance. Landman et al. (2016) found that self-control reduced the impact of stress on shooting accuracy, but not on anxiety and HR. This finding suggests that self-control helps police officers to prevent psychophysiological stress responses from influencing their attention and behavior, without reducing the emotional response itself. In line with mindfulness- and acceptance-based theory (Gardner and Moore, 2004), they argued that attempting to suppress or change the unwanted thoughts and emotions might even be counter-productive as it might decrease goal-directed attention. This explanation is supported by the negative association of trait emotionality and shooting performance of rifle shooters (Mosley et al., 2018): the ability to ignore the emotional state during shooting in HS circumstances improved shooting performance. Possibly, in the current study, police recruits with high levels of self-control tried to regulate their anxiety in the LS scenario, which decreased their goal-direct attention resulting in inaccurate shooting performance. These findings across several studies further strengthen the need for future research that integrates several coping-related variables in order to gain a more holistic view of performance under differing situational demands.

To date, there are only few studies that integrate coping-related variables, endocrine, autonomic and emotional stress responses as well as occupationally meaningful behavior to investigate performance under stress (Baumeister et al., 2007; Driskell et al., 2008). Applying a reality-based environmental stressor of high external validity is a feasible way to mimic stressful real-life settings. So far, previous studies comparing LS vs. HS conditions usually used artificial, static shooting tasks in the LS condition and only implemented complex scenarios in the HS condition (Taverniers and De Boeck, 2014). Therefore, the present study was the first attempt to create two comparable naturalistic shooting scenarios of varying stress intensities. Various stressors that had been identified to be relevant for police work (i.e., uncertainty, physical threat and social evaluation) have been integrated in the HS scenario used in the present study. However, it is striking that even in the LS scenario, which lacked these stressors, physiological stress responses were high while shooting accuracy was low. This finding is in line with the claim that police training does not appear to sufficiently prepare police officers for the demands on duty (Morrison and Vila, 1998) and that the officers themselves demand more realistic training conditions (Renden et al., 2015). Currently, training of police officers primarily focuses on equipping them with technical, physical and tactical skills, while emotional and psychological components of performance are neglected. As a result, many training practices do not adequately simulate the conditions likely to be experienced by officers in real-world encounters (Morrison and Vila, 1998; Andersen et al., 2016b). The results of the present study highlight that police training should consist of high-realism scenarios that provide police officers with the opportunity to experience how psychological and physiological arousal impacts their behavior under stress and afford an opportunity to improve performance under extreme stress. Integrating psychological skills training into standard training curricula might increase positive outcomes in both acute stress situations and in health-related, long-term consequences (Papazoglou and Andersen, 2014). Research on police training has shown that training with threat-induced anxiety (e.g., through opponents shooting back) improves perceptual motor performance under stress (Oudejans, 2008; Nieuwenhuys and Oudejans, 2011; but see Nieuwenhuys et al., 2015). However, these training interventions have not specifically addressed dealing with unwanted thoughts and emotions. Therefore, psychoeducation during training should emphasize the adaptive function of psychophysiological stress responses enhancing job performance in acute stress situations and also explain the negative long-term effects of chronic stress responses on physical and mental health (Papazoglou and Andersen, 2014). Given the results on self-control, for future effective police training, it might be interesting to combine training under stress with techniques aiming at accepting psychophysiological arousal and maintaining a goal-directed focus (Christopher et al., 2018). Confronting officers with their own psychophysiological stress responses (e.g., using inexpensive heart rate monitors) during realistic scenario training might make them aware of the importance of managing stress responses as a benefit to their health (Papazoglou and Andersen, 2014).

There are also some limitations that need to be considered in light of the current study. Notably, generalizability is limited due to the small sample of police recruits which was sufficient to detect some hypothesized effects, but regression analyses might have been underpowered. Although police recruits were licensed to carry a gun and had delivered police services on duty already, they might have yielded different results than sworn police officers. Professional experience has been identified as a moderator of psychophysiological stress responses (McEwen, 2008; Landman et al., 2016; but see Strahler and Ziegert, 2015) and shooting performance under stress (Vickers and Lewinski, 2012). However, overall, sworn police officers show similar patterns of elevated psychophysiological stress responses and impaired performance in critical incidents (Nieuwenhuys and Oudejans, 2010, 2011; Taverniers and De Boeck, 2014). Clearly, the difference between novice and expert police officers warrants a larger follow-up study to clarify the role of work experience in stress responses and performance under stress.

Overall sCorti and sAA levels in the present study are relatively low (for comparison see Taverniers and De Boeck, 2014; Strahler and Ziegert, 2015). Although the mean increase of 1.94 nmol/l from baseline to 20 min after the LS scenario equals the increase after a reality-based scenario observed by Groer et al. (2010; $M = 1.93$), the missing profound sCorti reaction may be explained by the short duration of the scenarios. Groer et al. (2010) found markedly increased sAA and sCorti levels after a lengthy scenario of 6 min duration, while sCorti was not increased after a shorter scenario of 2 min duration. Similarly, our results also suggest that sAA is a more sensitive biomarker of acute stress events of short duration than sCorti.

We consider the reality-like environment in the present scenarios a strength, but it has the potential drawback that experimental control was limited. While increased anxiety in the HS scenario hints at higher perceived stress levels in the HS scenario, the physiological stress responses suggest similar stress responses for both scenarios, diminishing potential behavioral differences between the LS and HS scenario. This discrepancy between psychological and physiological aspects of the stress response is an often-reported phenomenon, whereby the underlying mechanisms are still not completely understood (e.g., Campbell and Ehlert, 2012). Based on previous literature on the nature of stressors, the manipulation of stress intensity should have worked fine, but the fixed order of conditions might have caused physiological stress levels in the LS scenario to be elevated and stress levels in the HS scenario to be lowered, respectively. Learning experiences in the LS scenario might have improved performance in the HS scenario: First, experiences in the LS scenario might have directly improved behavior because of knowledge or skill acquisition during the LS scenario. Second, positive experiences in the LS scenario might have changed cognitive appraisal processes concerning the upcoming HS scenario (Lazarus and Folkman, 1984). High sAA baseline levels hint at anticipatory stress before the LS scenario. Given that the scenarios might have been too short to activate the HPA axis, the high sCorti levels 20 min after the LS scenario could be interpreted as an additional indicator of anticipatory stress. The police recruits, who were relatively unexperienced in shooting scenarios, might have expected extremely stressful scenarios that succeed their coping resources, resulting in elevated stress levels (Lazarus and Folkman, 1984). Engaging in trained routines and mastering the LS scenario, police recruits might have experienced that their coping resources are sufficient to meet the demands of the scenario, which might have in turn reduced their stress response (Lazarus and Folkman, 1984). This interpretation is in line with several findings of physiological indicators of police officers' anticipatory stress at the start of each shift (Anderson et al., 2002; Zefferino et al., 2006) and before amok training (Strahler and Ziegert, 2015). Further research is necessary to determine which aspects of reality-based scenarios exactly cause increased anxiety and physiological stress responses. Certainly, novelty, unpredictability and threat to physical integrity applied in this study are valid options to test in future research. For these studies, it might be beneficial to use virtual reality, as it can be designed and manipulated to experience many different conditions (Düking et al., 2018). Combined with real-time assessment of physiological parameters (e.g., HRV, see Brisinda et al., 2015), it allows to directly link a stress response to a presented stress cue.

Furthermore, the operationalization of shooting accuracy must be critically discussed. Integrating a score that reflects the effectiveness of a hit in a specific part of the body makes the measure of shooting accuracy more sensitive to changes in shooting accuracy. In line with current police guidelines of shooting behavior, the highest score (score = 50) was attached to the hip, as police officers are required to aim for the hip. However, no explicit instructions about the scores attached to each target area were provided in the present study. Most of the police recruits appeared to aim for the chest (score = 20), as a hit in this area is highly effective and offers a larger target area than the hip. In this sense, aiming for the chest might be highly adaptive, but was not rewarded in the present study. However, *post hoc* analyses with a simplified scoring grid (considering all hits on either hip, chest or head as an hit) also demonstrated no significant difference between the LS and HS scenario.

Additionally, previous studies suggest that psychophysiological stress responses might have differential effects on police work performance (Renden et al., 2014, 2017; Arble et al., 2019). While observational studies report a negative effect of stress on tactical behaviors such as handcuffing or arrest procedures (Renden et al., 2014), increases in physiological stress responses did not impair general police work performance, but specifically impaired verbal communication as compared to tactical performance and non-verbal communication (Arble et al., 2019). These differential effects demonstrate the complex nature of effective police work and the difficulties to define and asses ideal police performance. Future studies should apply reality-based scenarios that allow performance measurements of all relevant police skill domains to gain a holistic view of police work performance under stress.

The present study raises several issues that require future research. It seems well-documented that police officers experience severe psychophysiological stress responses (Groer et al., 2010; Taverniers and De Boeck, 2014; Strahler and Ziegert, 2015; Arble et al., 2019) and show impaired perceptual-motor performance under stress (Nieuwenhuys and Oudejans, 2010, 2011, 2017; Renden et al., 2014, 2017; Arble et al., 2019). However, it remains unclear through which mechanisms performance can be maintained. In the attentional control theory, individuals are assumed to spend extra mental effort in an attempt to lower anxiety, inhibit stimulus-driven impulses and/or enforce goal-directed control (Nieuwenhuys and Oudejans, 2017). So far, no study has directly tested how mental effort needs to be utilized to effectively maintain performance. Findings of the current study as well as of Landman et al. (2016) point in the direction that mental effort should not be spent on down-regulating anxiety. In contrast, a collection of experiments suggests a crucial role of inhibitory functions for performance under stress (Ducrocq et al., 2016). When elucidating the underlying mechanisms of mental effort, the role of psychophysiological stress responses should be considered: Do psychophysiological stress responses need to be decreased *per se* to maintain performance? Or do self-regulatory processes prevent stress responses from negatively influencing attention and performance? Understanding the mechanisms of how performance can be maintained under stress will allow the conceptualization of effective police training interventions.

Considering the health-related consequences of constant stress experiences, more research is needed to investigate how chronic stressors (e.g., shift work, work overload, fear of danger; Anderson et al., 2002) and/or frequent exposure to critical incidents adds up to allostatic load or overload in police officers and how this affects work performance under acute stress (McEwen, 1998). Therefore, future studies should expose police officers to multiple stressors limiting the availability of energetic resources (e.g., due to preceding physical exhaustion, sleep deprivation or limited recovery). In light of the unexpected sCorti patterns (also see Strahler and Ziegert, 2015), future studies should incorporate cross-sectional comparisons between police recruits, experienced officers and/or special forces and longitudinal designs to investigate the long-term effects of regular stress exposure in police officers: Do officers adaptively habituate to these critical incidents protecting performance delivery? Or do they show maladaptive, inadequate stress responses (e.g., hypocortisolism) resulting in performance decrements?

CONCLUSION

In conclusion, police recruits exposed to reality-based shooting scenarios demonstrated greater increases in anxiety and mental effort in response to the HS scenario than the LS scenario. However, both scenarios elicited similar physiological responses (i.e., sAA secretion and decreases in cardiac vagal activity). Accordingly, shooting accuracy in both scenarios was relatively low and did not differ between the LS and HS scenario. Post-task cardiac vagal activity was directly linked to shooting performance. Specifically, lower post-task cardiac vagal activity was associated with better shooting performance. This strengthens the need to assess rest, reactivity, and recovery (the three Rs) of cardiac vagal activity (Laborde et al., 2017). In addition, high dispositional self-control was related to lower levels of anxiety, but impaired shooting performance in the LS scenario. Possibly, the attempt to control unwanted emotions and thoughts impairs the goal-directed focus on the task, resulting in performance decrements. Therefore, it is vitally important that police officers get to know and learn to accept psychological and physiological stress responses during reality-based training to ensure optimal task performance in HS situations. Using reality-based scenarios that are reflective of challenges individuals need to face in real life provides a comprehensive picture of psychological, physiological, and behavioral stress responses in critical incidents. This knowledge allows to refine effective police training programs, which in turn increases the security of police officers, suspects and civilians.

DATA AVAILABILITY

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

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Declaration of Helsinki and under the supervision of experienced police instructors 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 Faculty of Behavioral and Cultural Studies, Heidelberg University, Germany.

AUTHOR CONTRIBUTIONS

In this interdisciplinary project, each author contributed to the study planning, data analysis, and interpretation with an additional focus on their respective area of competence. CK and MB were responsible for the biochemical analyses of the saliva samples. MF, CZ, AN, FE, and HP contributed crucially in drafting the aim of the study, concretizing the design, and finishing the manuscript. JR supervised the statistical analyses and the final draft of the manuscript. LG wrote the first draft of the manuscript and was essentially responsible for the statistical analyses and interpretation of the data, as well as for the communication between all authors during the development of the article.

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Stress Levels Escalate When Repeatedly Performing Tasks Involving Threats

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Police work may include performing repeated tasks under the influence of psychological stress, which can affect perceptual, cognitive and motor performance. However, it is largely unknown how repeatedly performing stressful tasks physically affect police officers in terms of heart rate and pupil diameter properties. Psychological stress is commonly assessed by monitoring the changes in these biomarkers. Heart rate and pupil diameter was measured in 12 male police officers when performing a sequence of four stressful tasks, each lasting between 20 and 130 s. The participants were first placed in a dimly illuminated anteroom before allowed to enter a brightly lit room where a scenario was played out. After each task was performed, the participants returned to the anteroom for about 30 s before performing the next sequential task. Performing a repeated sequence of stressful tasks caused a significant increase in heart rate ($p = 0.005$). The heart rate started to increase already before entering the scenario room and was significantly larger just after starting the task than just before starting the task ($p < 0.001$). This pattern was more marked during the first tasks ($p < 0.001$). Issuance of a verbal "abort" command which terminated the tasks led to a significant increase of heart rate ($p = 0.002$), especially when performing the first tasks ($p = 0.002$). The pupil diameter changed significantly during the repeated tasks during all phases but in a complex pattern where the pupil diameter reached a minimum during task 2 followed by an increase during tasks 3 and 4 ($p \leq 0.020$). During the initial tasks, the pupil size ($p = 0.014$) increased significantly. The results suggest that being repeatedly exposed to stressful tasks can produce in itself an escalation of psychological stress, this even prior to being exposed to the task. However, the characteristics of both the heart rate and pupil diameter were complex, thus, the findings highlight the importance of studying the effects and dynamics of different stress-generating factors. Monitoring heart rate was found useful to screen for stress responses, and thus, to be a vehicle for indication if and when rotation of deployed personnel is necessary to avoid sustained high stress exposures.

Keywords: stress escalation, heart rate, pupil dilation, repetition, operative police tactics

INTRODUCTION

The term "stress" can be used to describe the effects of many different strains on our physiology, e.g., stress due to illnesses, temperature and dehydration (Ulrich-Lai and Herman, 2009). In this article, we will focus on two specific types of stress. The first category is physical stress, which is induced by physical activity. Physical stress affects many of our neurobiological functions, causing e.g., increased heart rate, breathing rate, vasodilation (widening of blood vessels) and increased body temperature (Burton et al., 2004). The second stress category is commonly termed "psychological stress" or as "the stress response" (Bracha, 2004; Qin et al., 2009; LeDoux and Pine, 2016). The stress response is produced by reflexive neural (autonomic sympathetic) and neuroendocrine (hypothalamic-pituitary-adrenal) processes, and is activated by external (e.g., a barking dog) or internal cognitive information (e.g., memories or nightmares), that are subconsciously or consciously perceived as a threat (Ulrich-Lai and Herman, 2009). Hence, a stress response might be activated subconsciously, and thus, the physical and neurological processes activated by stress might be initiated before a human in his/her conscious mind have identified a threat motivating feeling fear or anxiety (LeDoux, 2000; Pariyadath and Eagleman, 2007; LeDoux and Pine, 2016).

A stress response can be activated regardless of current physical activity and affect simultaneously several human functions. Both physical and psychological stress (the stress response) increase heart rate, blood pressure and breathing (Freyschuss et al., 1988; Ulrich-Lai and Herman, 2009). However, the psychological stress response may also cause several physical changes with sometimes opposite effects than those caused by physical stress, e.g., a narrowing of peripheral blood vessels (vasoconstriction) instead of a widening (Ulrich-Lai and Herman, 2009). Psychological stress and the stress response can in different contexts either improve or impair the perceptive, cognitive and motor performance depending on factors like the properties of the perceived threat and the strength of the stress response (Siddle, 1995; Stefanucci et al., 2008; Qin et al., 2009; Bertilsson et al., 2013; Petersson et al., 2017). The performance typically follows an inverted U-function with increasing stress levels, i.e., the performance increases when the stress levels increase from low to moderate and thereafter decreases if the stress levels increase from moderate to high levels (Yerkes and Dodson, 1908; Siddle, 1995; Grossman and Christensen, 2004). Even a subconsciously activated reflexive stress response will also be different in strength depending on the fast subconscious threat level assessment (LeDoux, 2000; LeDoux and Pine, 2016).

An issue that to date has received little attention is that police officers often are exposed to repeated stressful events over shorter (minutes) and longer (hours) periods (Gyamfi, 2012). Police officers often have to solve stressful situations demanding situational awareness, decision-making skills and motor skills (Gächter et al., 2011). Repeated stress exposures has been shown to causes cognitive impairment in rats (Yuen et al., 2012), and similar effects has been detected in humans (Phelps and LeDoux, 2005). Moreover, high levels of stress may cause perceptual and memory distortions (Artwohl, 2002; Qin et al., 2009; Dahl et al., 2018). The long term effects of continuous psychological stress or not reaching homeostasis for longer periods can be dire, with occupational stress burnout (Gächter et al., 2011), e.g., thinning of brain prefrontal and temporal cortical regions and increased amygdala volume (Savic, 2015). Exposures to traumatic events may also increases the susceptibility for posttraumatic stress syndrome (Bomyea et al., 2012). Whether accumulative effects of repeated stressful exposures can be detected using biomarkers heart rate and pupil diameter monitoring is unknown.

To enable police officers to train performing demanding skills when under stress, realistic scenario training might be an important vehicle to inoculate police officers to the often debilitating effects of strong stress responses (Saunders et al., 1996; Bertilsson et al., 2017; Petersson et al., 2017). However, if the training scenarios are too difficult and cause strong feelings of failure or pain, the scenario training may instead produce fear conditioning (Atkins and Norris, 2004), and thus, a worse performance in stressful situations. On the other hand, if the scenarios are too easy and evoke no stress, the participants may not gain the wanted stress inoculation that produces improved performance in stressful situations (Oudejans, 2008). Hence, it is important that training designers and instructors can continuously monitor the stress response of participants performing a scenario using reliable measures to ensure that the training evokes levels of stress that are optimal for stress inoculation.

One frequently used approach to monitoring stress levels is by using biomarkers, such as heart rate (Freyschuss et al., 1988; Carroll et al., 2000; Sawai et al., 2007). However, one drawback with monitoring heart rate is that both physical and psychological stress may cause increased heart rates. Thus, if the training scenario includes performing various kinds of physical activity, the heart rate might be an ambiguous source of information for describing levels of stress. A workaround might be that the participants perform the physical activity alone without active stressors at a separate occasion, thereby allowing a baseline heart rate level caused by performing the physical tasks to be determined (Bertilsson et al., 2013). However, it is doubtful that a good baseline can be established using this method because also without active stressors in a scenario, subjects might feel psychological stress, e.g., from performing tasks in front of experts and colleagues. Another method to assess stress levels is to record the amount of cortisol (Kirschbaum et al., 1995), a stress hormone released through the neuroendocrine (hypothalamic-pituitary-adrenal) system as a part of the psychological stress response (Ulrich-Lai and Herman, 2009). However, monitoring cortisol levels requires access to a laboratory facility. Moreover, it may take more than 20 min until a stress response produce detectable increased levels of cortisol and the response amplitude may differ markedly between subjects and tests performed (Kirschbaum et al., 1995; Bozovic et al., 2013). Hence, cortisol can be used to determine that a stress response has occurred, but provide a poorer measure of when it occurred and what caused the stress response to occur.

Pupil diameter is another commonly used biomarker (Beatty, 1982; Pedrotti et al., 2014) that reflects stress through a sympathetic nerve response that dilates the pupil (Hall and Chilcott, 2018; Wang et al., 2018). A problem with using pupil size as an index of the stress response is that ambient light levels also have a strong effect on pupil diameter through the parasympathetic pupillary light reflex (Bressloff, 1996; Pong and Fuchs, 2000; Hall and Chilcott, 2018). Hence, a short glance toward a lamp, for instance, will induce a large change in the size of the pupil.

The study objective was to determine whether repeatedly performing moderately stressful tasks, executed in a rapid sequence with only a brief rest between tasks, caused an altered stress response as assessed by the biomarkers heart rate and pupil diameter. Another objective was to determine if both biomarkers described the stress response process similarly or reflected different characteristics, i.e., suggesting an individual practical usefulness. Our hypothesis is that both heart rate and pupil diameter will increase when repeatedly performing moderately stressful tasks, but not necessarily in an identical way.

MATERIALS AND METHODS

Experiments were performed in accordance with the Helsinki declaration and the recorded data was handled according to the protocol approved by the Ethics Review Board at the Lund University, Sweden (Dnr 2014-36). All participants provided written informed consent.

Subjects

Twelve healthy male subjects [age *M* = 30.7 (SD 3.2) years] participated in the study, but heart rate recordings from one subject and pupil diameter recordings from another subject had to be excluded due to recording malfunctions. All participants were experienced police officers with at least 5 years prior experience of field duty work. Only fully healthy subjects were allowed to take part in the test scenarios. All subjects had normal visual acuity.

Equipment

Heart rate, breathing rate and body posture were recorded with a Zephyr Bioharness® 2.0 (Zephyr technology corporation, Annapolis, MD, United States), and pupil diameter was recorded with eye tracking glasses from SensoMotoric Instruments (SMI), Berlin, Germany. Additionally, the subjects' performance in the scenario room was monitored by three Go-Pro 3.0 cameras that which also recorded sound. The Go-Pro cameras were placed in different positions so that the actions of all actors in the scenario was always recorded by at least one Go-Pro camera, see **Figure 1**. Before the task sequence started, a three-point calibration of the SMI glasses was performed followed by manual inspection of the calibration accuracy by asking the participant to fixate another set of points on a wall. Additionally, a specific movement task was performed to enable time-synchronization of the heart- and breathing rate recordings made with the bioharness and the pupil diameter recordings provided by the eye-tracking glasses. The bioharness system sampled the ECG activity at 250 Hz and the SMI glasses recorded the pupil diameter at 30 Hz.

Procedure

Four different tasks were performed by the participants in a fixed sequence (see **Table 1**). Before starting the first task scenario, the participants were sitting down resting for at least 10 min listening to music. The first scenario started shortly after the participants were outfitted with the recording equipment (see "Equipment" below), and the equipment had been calibrated and synchronized together. The participants were also equipped with a SigSauer® pistol adapted for Simunition® cartridges and a pepper spray canister that for training purposes contained water without Oleoresin Capsicum (OC). Each task was preceded by the participant standing for about 30 s in a dimly lit (4.6 Lux) anteroom. All tasks started when participants opened a door and quickly entered the scenario room, where a specific scenario started to play out immediately including 2 or 3 human figurants. When the door to the brighter lit scenario room was opened, the illumination the participant was exposed to first increased to 191 Lux. After completely having entered into the scenario room, in which the scenario played out, the participant was exposed to about 385 Lux illumination. When a scenario instructor judged the policing task to be completed, he terminated the task with a verbal "abort" command, and the participant returned to the anteroom for a brief rest lasting about 33 s (*M* = 33.2, SD = 9.4 s) before the next task commenced. The subject received no detailed instructions about the scenario to address, and was merely asked to deal with the situation.

The physical activity during and between tasks was monitored by recording the number of steps made during each time window analyzed. The steps made was determined from inspecting the recordings from the four cameras used in the test setup. The policing actions performed by the participant during all scenarios involved at most medium walking cadence (i.e., $\leq$1.3 steps/s) (see **Table 2**). The participants continued to carry the bioharness equipment, monitoring the heart rate, for about 5 h after the four scenario tasks were completed. The lowest heart rate recorded during this 5-h period was denoted the heart rate at rest (see **Table 3**).

Analysis

The heart rate and pupil diameter were analyzed offline by a custom-made program. The Onset time of each task was defined as when the door between the anteroom and scenario room was opened, and thus, when the scenario was revealed to the participant. The Offset time of the task was defined as the moment when the scenario instructor terminated the task with a verbal "abort" command. For both heart rate and pupil diameter, analyses windows were defined as a 5-s period before the task onset (denoted Pre Onset) and as a 5-s period after the task onset (Post Onset). Additionally, analyses windows were defined as a 5-s period before the task offset (denoted Pre Offset) and as a 5-s period after the task offset (Post Offset). These analysis windows are illustrated in **Figure 2**.

Statistical Analysis

The heart rate and pupil diameter during the four repeated tasks were analyzed using repeated measures GLM ANOVA. The

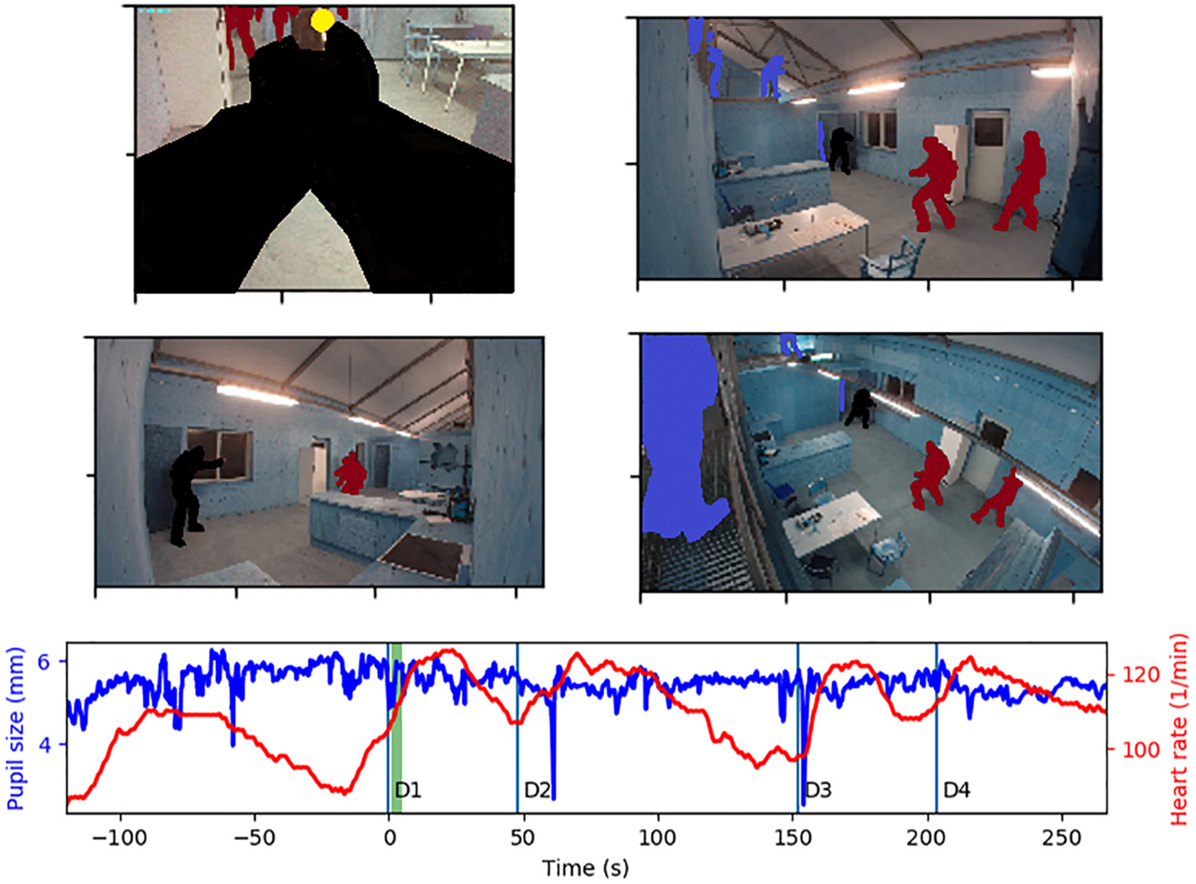

FIGURE 1 | The participant's performance of the tasks was monitored by a forward-facing camera mounted on the SMI glasses, and three go-pro cameras mounted in the room. The study participant is marked in black, his gaze location is a yellow dot (top-left figure), the scenario figurants are marked in dark-red and the scenario instructors are marked in blue. The participant's pupil diameter was monitored by the SMI glasses and a Bioharness equipment recorded heart rate. The period marked in green in the diagram shows from what period the images displayed originate. The onsets of task 1–4 are denoted as D1–D4 in the diagram.

TABLE 1 | Scenario description, duration, and rest in between performing the tasks.

Task	Scenario description	Duration [Mean (SD)] (seconds)	Time interval to next scenario [Mean (SD)] (seconds)
1.	**Immediate** threat encounter scenario; Hostage situation where a person holds a knife against another person's throat from behind. When the police officer enters the room, the person with the knife let go of the hostage and walks toward the police officer.	26 (8)	32 (11)
2.	**Delayed** threat encounter scenario; A person is sitting at a table and acts calmly when the police officer enters the room. Suddenly an angry non-compliant person appears from behind a fridge with a knife and moves slowly toward the police officer.	34 (22)	34 (12)
3.	**Immediate** threat encounter scenario; Hostage situation with a gun threat. A person is sitting in a chair and another person holds him from behind and points a gun point blank at his head and then turns the gun against the police officer.	25 (6)	33 (4)
4.	**Delayed** threat encounter scenario; Compliant persons in a room with two dangerous objects hidden in plain sight. When the police officer opens the door, one person is standing to his right and suddenly another curious person appears from behind the opened door.	136 (48)	

TABLE 2 | Physical activity.

Walking cadence [a,b]		Pre Onset	Post Onset	Scenario activity[c]	Pre Offset	Post Offset	Between scenario[d]
Task 1	Steps/s[e]	0.0 (0.0)	0.7 (0.1)	0.4 (0.1)	0.3 (0.1)	1.0 (0.1)	0.0 (0.0)
	Duration	5.0 (0.0)	5.0 (0.0)	15.3 (2.2)	5.0 (0.0)	5.0 (0.0)	32.1 (3.1)
Task 2	Steps/s[e]	0.0 (0.0)	0.9 (0.1)	0.4 (0.1)	0.7 (0.1)	1.2 (0.1)	0.0 (0.0)
	Duration	5.0 (0.0)	5.0 (0.0)	22.9 (6.0)	5.0 (0.0)	5.0 (0.0)	34.8 (3.2)
Task 3	Steps/s[e]	0.0 (0.0)	0.6 (0.1)	0.6 (0.1)	0.7 (0.1)	1.1 (0.1)	0.1 (0.0)
	Duration	5.0 (0.0)	5.0 (0.0)	15.2 (1.6)	5.0 (0.0)	5.0 (0.0)	31.9 (1.3)
Task 4	Steps/s[e]	0.0 (0.0)	0.4 (0.1)	0.4 (0.1)	0.7 (0.1)	1.3 (0.1)	–
	Duration	5.0 (0.0)	5.0 (0.0)	118.8 (15.0)	5.0 (0.0)	5.0 (0.0)	–

[a] *Physical activity described as walking cadence steps/second, mean (SEM).* [b] *Duration of each analyzed time windows, mean (SEM).* [c] *Scenario activity = Activity between Post Onset and Pre Offset.* [d] *Between scenario = Activity between Post Offset and the next task Pre Onset.* [e] *For comparison, the medium walking cadence for a healthy person is about 1.3–1.6 steps/s Tudor-Locke et al. (2018).*

TABLE 3 | Physical characteristics.

Physical characteristics [a,b]	Age	HR Rest	HR Pre Onset Task 1	HR Task 1[c]	HR Task 2[c]	HR Task 3[c]	HR Task 4[c]
	30.7 (1.1)	71.3 (4.4)	105.9 (3.8)	119.2 (5.3)	119.6 (4.3)	122.1 (4.1)	117.5 (3.7)

[a] *Physical characteristics are described as mean (SEM).* [b] *The duration of the Pre Onset window is 5 s.* [c] *The duration of tasks 1–4 is the active scenario time from Onset to Offset, see* ***Table 2*** *for details.*

FIGURE 2 | Example of a participant's heart rate (blue) and pupil diameter (red) when performing a task. The 5-s analyses windows submitted to detailed analyses are marked by the horizontal bars denoted Pre onset, Post onset, Pre offset, and Post offset.

main factors and factor interactions analyzed were: "Repetition" (Task 1–4; d.f. 3); and "Window" which was evaluated for three different pairs of analysis windows [door opening (Pre Onset vs. Post Onset), task execution (Post Onset vs. Pre Offset) and abort command (Pre Offset vs. Post Offset); d.f. 1]. The repeated measures GLM ANOVA analysis method was used after ensuring that all dataset combinations analyzed in the study with this statistical method produced model residuals that had normal or close to normal distribution (Altman, 1991).

Wilcoxon matched-pairs signed-rank tests (Exact sig. 2-tailed) were used for within-group *post hoc* comparisons, i.e., analyzing the accumulated changes from task 1 to task 4. Moreover, as part of the *post hoc* evaluation, the best fitting dynamic patterns and time constants describing the changes in heart rate and pupil diameter during the four time windows (Pre Onset, Post Onset, Pre Offset, and Post Offset) during each task were determined by using regression models after evaluating different regression models for best fit (linear, exponential etc.). A linear regression model was found to describe best the changes in heart rate whereas an exponential regression model was found to describe best the changes in pupil diameter over time.

Spearman's two-tailed correlation analyses were used for determining relationships between the subject's age and heart rate at rest and heart rate across performing the repeated tasks. Moreover, correlations analysis was also used to determine relationships between the heart rate recorded across performing the repeated tasks.

In all analyses, p-values <0.05 or $p < 0.01$ were considered significant after Bonferroni correction, depending on the number of within-subject tests performed. The Shapiro-Wilk test revealed that some datasets were not normally distributed and that normal distribution could not be obtained by log-transformation. Thus, non-parametric statistical methods able to appropriately handle non-normal distributions were used in all *post hoc* evaluations (Altman, 1991).

A sample size analyses, using the statistical package G-power^{TM}, were performed on the heart rate recorded during rest and average heart rate while performing each of the four tasks. The analysis revealed an effect size for each of the tasks of 2.6 (task 1); 2.9 (task 2); 3.3 (task 3), and 2.9 (task 4) which shows that with the p-value set to 0.05 (2-tailed), our study would require $n = 4$ subjects to reach a power value of 0.8 for this parameter.

The statistical analyses were performed with SPSS version 24 and the power analysis was performed with GPower version 3.1.9.4.

RESULTS

Test Condition Evaluation

The resting time between performing any of the four stressful tasks was not significantly different ($p \geq 0.400$), see **Table 1**. Moreover, the duration of the three first tasks was not significantly different ($p \geq 0.158$). However, the duration of the fourth and last task was significantly longer than that of all the three initial tasks ($p < 0.001$).

Physical Activity During Each of the Time Windows Investigated

The test subjects were always standing still during the 5 s Pre Onset window 0.0 (0.0) steps/s, see **Table 2**. The physical activity across all scenarios and scenario windows Post Onset, Scenario activity and Pre Offset, were on average not exceeding 0.9 (0.1) steps/s. The Post Onset physical activity was significantly larger during task 2 compared with task 4 ($p = 0.005$). The Post Offset activity consisted mostly of returning back to the anteroom, which at most reach an activity of 1.3 (0.1) steps/s. During the between scenario times, the test subjects were typically standing still 0.1 (0.0) steps/s. For comparison, the medium walking cadence for a healthy person is about 1.3–1.6 steps/s (Tudor-Locke et al., 2018).

The heart rate recorded during rest was significantly lower than during Pre Onset of task 1 ($p < 0.001$) and significantly lower than during any of the tasks 1–4 ($p < 0.001$), see **Table 3**. Moreover, the heart rate recorded during Pre Onset of task 1 ($p < 0.001$) was significantly lower than during any of the tasks 1–4 ($p < 0.010$). The average heart rate recorded during tasks 1–4 were not significantly different between each other.

Correlation analyses between the subject's age and heart rate during each of the windows analyzed revealed no significant relationship. However, the heart rate at rest was significantly correlated to the heart rate at Pre Onset of task 1 ($p = 0.014$, $R = 0.711$). Moreover, the heart rate at Pre Onset of task 1 were significantly correlated to the average heart rates during tasks 1–3 ($p \leq 0.013$, $R \geq 0.718$). Finally, the average heart rates recorded during tasks 1–4 were significantly correlated to each other ($p \leq 0.011$, $R \geq 0.727$).

Effects of Repetition and Window on Heart Rate When Repeatedly Performing Tasks

Repeatedly performing stressful tasks significantly increased the heart rate during door opening across the four tasks ($p = 0.005$) (**Figure 3** and **Table 4**). Moreover, the heart rate was significantly larger post onset than pre onset for all tasks ($p < 0.001$). The interaction between main factors Repetition x Window revealed that the heart rate pre onset was lower than post onset at the initial tasks but the differences decreased during the last tasks ($p < 0.001$).

The heart rate values recorded at scenario pre offsets were significantly lower than the heart rate recorded after receiving the command "abort" ($p = 0.002$). However, the interaction between main factors Repetition x Window revealed that this difference decreased significantly over repeated tasks ($p = 0.002$).

Post hoc analyses were performed to determine the total accumulated effects of performing repeated tasks (**Figure 3**). The heart rate at pre onset was significantly lower at task 1 compared

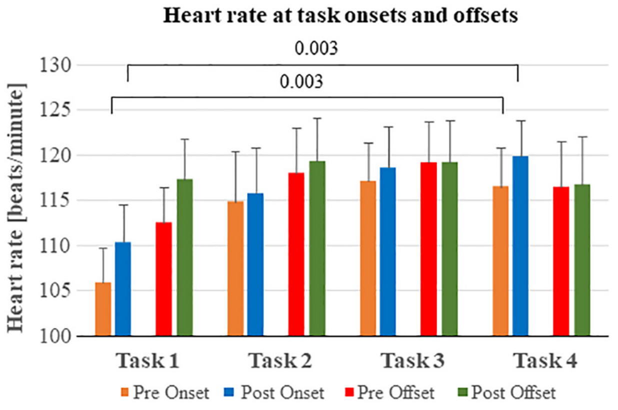

FIGURE 3 | Heart rate before and after task onsets and offsets. The heart rate became increasingly larger at task onset by each test performed. The heart rate continued to increase until just before task offset, but primarily while performing the first tasks in the series.

TABLE 4 | Effects on the heart rate of performing repeated tasks.

Task phase	Repetition[a]	Window[a]	Repetition × Window[a]
Door opening (pre onset vs. post onset)	**0.005 [12.7]**	**<0.001 [21.1]**	**<0.001 [22.3]**
Task execution (post onset vs. pre offset)	0.068 [4.2]	0.766 [0.1]	0.345 [1.0]
Abort command (pre offset vs. post offset)	0.085 [3.7]	**0.002 [18.0]**	**0.002 [17.0]**

[a] *p-values and (F-values). The notation "<0.001" means that the p-value is smaller than 0.001. Bold values indicate significance.*

with task 4 ($p = 0.003$). Moreover, the heart rate at post onset was significantly lower at task 1 compared with task 4 ($p = 0.003$).

Post hoc regression analysis of the heart-rate time series during the 5-s windows revealed for task 1 significant heart rate increases during the pre onset (rate of change 43.6 beats per minute (bpm), $p < 0.001$) and the post onset windows (64.0 bpm, $p < 0.001$) (**Table 5**). A similar significant heart rate increase was found during task 4 pre onset (33.1 bpm, $p = 0.017$) and post onset (41.8 bpm, $p = 0.001$) windows. Moreover, a significant heart rate increase during pre offset (52.3 bpm, $p < 0.001$) and post offset (54.2 bpm, $p < 0.001$) windows was found during task 1.

Effects of Repetition and Window on Pupil Diameter When Repeatedly Performing Tasks

Repeatedly performing tasks significantly changed the pupil diameter at the door opening (pre onset and post onset) in a complex pattern, i.e., the pupil diameter reached a minimum during task 2 and increased diameter again during task 3 and 4 ($p = 0.008$) (**Figure 4** and **Table 6**).

During task execution (post onset and pre offset), the pupil diameter changed in the same complex pattern of reaching the smallest pupil diameter while performing task 2 followed by an increase during tasks 3 and 4 ($p = 0.020$). However, the interaction between main factors Repetition × Window suggests that the pupil diameter at post onset was smaller than pre offset during the first tasks but changed during the last task 4 ($p = 0.014$).

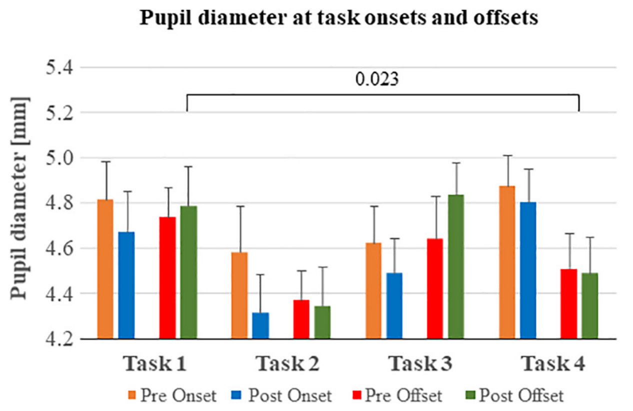

FIGURE 4 | Pupil diameter before and after task onsets and offsets. The pupil diameter reached a minimum in all analysis windows (Pre onset, Post onset etc.) during task 2. In tasks 1 and 3, the participant encountered an immediate threat, in most cases within the first 5 s of scenario. During tasks 2 and 4 the threat appeared delayed more than 5 s into the scenario.

TABLE 5 | Linear regression analysis of temporal trends in heart rate for each task phase.

	Window	*p*-value[a]	Constant[b]	Time constant[c]
Task 1	Pre Onset	**<0.001 [12.6]**	**104.1**	**43.6**
	Post Onset	**<0.001 [22.1]**	**107.7**	**64.0**
	Pre Offset	**<0.001 [16.5]**	**110.4**	**52.3**
	Post Offset	**<0.001 [13.6]**	**115.1**	**54.2**
Task 2	Pre Onset	0.521 [0.4]	114.4	11.3
	Post Onset	0.257 [1.3]	115.0	18.4
	Pre Offset	0.250 [1.3]	117.3	18.5
	Post Offset	0.607 [0.3]	118.9	8.1
Task 3	Pre Onset	0.402 [0.7]	116.6	11.7
	Post Onset	0.087 [2.9]	117.6	25.4
	Pre Offset	0.585 [0.3]	118.8	8.0
	Post Offset	0.134 [2.3]	119.6	23.3
Task 4	Pre Onset	**0.017 [5.7]**	**115.1**	**33.1**
	Post Onset	**0.001 [10.6]**	**118.1**	**41.8**
	Pre Offset	0.678 [0.2]	116.2	6.7
	Post Offset	0.889 [0.0]	116.9	–2.4

[a] *p-values and (F-values). The notation "<0.001" means that the p-value is smaller than 0.001.* [b] *Heart rate starting value for window.* [c] *Linear change in heart rate (beats per minute). Bold values indicate significance.*

TABLE 6 | Effects on the pupil diameter of performing repeated tasks.

Task phase	Repetition[a]	Window[a]	Repetition × Window[a]
Door opening (pre onset vs. post onset)	**0.008 [15.1]**	0.160 [2.6]	0.653 [0.2]
Task execution (post onset vs. pre offset)	**0.020 [8.4]**	0.583 [0.3]	**0.014 [9.7]**
Abort command (pre offset vs. post offset)	**<0.001 [35.3]**	0.402 [0.8]	0.176 [2.1]

[a] *p-values and (F-values). The notation "<0.001" means that the p-value is smaller than 0.001. Bold values indicate significance.*

Finally, during the abort command (pre offset and post offset) the pupil diameter changed in the same complex pattern as found during the other task phases in that it reached the smallest pupil diameter while performing task 2 followed by an increase during tasks 3 and 4 ($p < 0.001$).

Post hoc analyses were performed to determine the total accumulated effects of performing repeated tasks, in terms of comparing the pupil diameter at the first and last of the four repeated tasks (**Figure 4**). The pupil diameter at post offset was significantly reduced between task 1 and test 4 ($p = 0.023$).

Post hoc regression analyses of pupil diameter development revealed a significant decrease in pupil diameter during pre onset before task 1 (rate of change = −0.018, $p < 0.001$), before task 2 (−0.013, $p < 0.001$) and before task 4 (−0.012, $p < 0.001$), whereas the pupil diameter increased significant pre onset before task 3 (0.009, $p < 0.001$) (**Table 7**). However, a significant pupil diameter increase was detected during post onset of task 1 (rate of change = 0.015, $p < 0.001$), task 2 (0.005, $p = 0.039$) and task 3 (0.009, $p = 0.002$), whereas a pupil diameter decrease was detected during post onset of task 4 (−0.007, $p < 0.001$).

The pupil diameter changes were disparate during task offsets. A significant pupil diameter decrease was found during pre offset of task 2 (rate of change = −0.009, $p < 0.001$). However, a significant pupil diameter increase was detected during post offset of task 1 (rate of change = 0.005, $p = 0.018$) and task 3 (0.004, $p = 0.029$), and a pupil diameter decrease was detected during post offset of task 4 (−0.006, $p = 0.003$).

DISCUSSION

Police officers are often exposed to stressful situations in their daily work. Little is, however, known about how repeated exposure to stressful situations that require police intervention influence physiological measures of stress. The heart rate and pupil size were measured in twelve experienced police officers while they performed policing tasks during four short scenarios containing stressful problems and threats to solve.

Effects of Repeatedly Performing Stressful Tasks on Heart Rate

Our results show that the heart rate of police officers gradually increased at the onset of the tasks across the four tasks, see **Figure 3**. Moreover, the heart rate was significantly higher just after the task onset compared to just before the task onset. However, the differences in heart rate before and after task onset decreased across the repetitions due to an increase in pre-task heart rate. Hence, the heart rate recordings suggest that the stress levels escalate when repeatedly performing stressful tasks, manifested mainly as a higher heart rate at the onset of the tasks. This said, after the initial escalation in heart rate during the first tasks, the heart rate seems to approach a new higher steady state level at task onset and offset already while performing task 3 and task 4.

That the first test scenario induced the largest increase in heart rate is similar to the findings by Kirschbaum et al. (1995), who reported an increased concentration of cortisol due to stress induced by speaking and solving numerical problems in front of an audience. However, regression analyses investigating changes in heart rate during the analyses windows suggest that during two of the tasks (task 1 and 4), the increase in heart rate started already before the task onset (Pre Onset) and continued to increase at an even faster rate after the door had opened (**Table 5**). This increase was observed while the participants were standing completely still (Pre Onset), or took a few steps into the scenario room at an average walking cadence not exceeding 0.9 steps/second (Post Onset) (see **Table 2**). For comparison, the moderate walking cadence for a healthy person is about 1.3–1.6 steps/s (Tudor-Locke et al., 2018). Moreover, the participants had been resting for at least 10 min, sitting down, prior to performing the four tasks. Hence, since all participants in the study had an above average physical strength and cardiovascular endurance level, it is unlikely that the low physical activity during the tasks would lead to heart rates of about 120 bpm in tasks 3 and 4, but instead likely reflect an induced stress response. Moreover, the average 106 bmp heart rate recorded during Pre Onset of task 1 compared with the average heart rate at rest of 71 bpm suggest that the participants were stressed already before performing any tasks. Nevertheless, that the average heart rate increase to 120 bmp during the sequence suggests that the participants experienced not more than a moderate threat from performing the tasks.

An unexpected finding was the close relationship between the heart rate at rest, just prior to performing the first task and heart rate across the tasks performed. These results suggest that the level of heart rate include a substantial individual component that persist also when affected by stress. Moreover, these findings also suggest that the changes recorded in heart rate before and while performing the tasks were not random but included a significant systematic behavior.

There were no significant changes in heart rate over the course of the tasks (Post onset vs. Pre Offset). However, the "abort" command, which terminated a scenario, was associated with an overall increase in heart rate across the repetitions. This heart rate response was more marked during the initial tasks but declined when reaching the last tasks 3 and 4. This response, predominantly found during the first tasks, might be a startle

TABLE 7 | Exponential regression analysis of temporal trends in pupil diameter for each task phase.

	Window	***p*-value[a]**	**Constant[b]**	**Time constant[c]**
Task 1	Pre Onset	**<0.001 [57.8]**	**5.02**	**−0.018**
	Post Onset	**<0.001 [39.2]**	**4.54**	**0.015**
	Pre Offset	0.912 [0.0]	4.74	0.000
	Post Offset	**0.018 [5.6]**	**4.76**	**0.005**
Task 2	Pre Onset	**<0.001 [18.3]**	**4.67**	**−0.013**
	Post Onset	**0.039 [4.3]**	**4.30**	**0.005**
	Pre Offset	**<0.0001 [16.4]**	**4.49**	**−0.009**
	Post Offset	0.913 [0.0]	4.38	0.000
Task 3	Pre Onset	**<0.001 [12.1]**	**4.53**	**0.009**
	Post Onset	**0.002 [9.9]**	**4.44**	**0.009**
	Pre Offset	0.150 [2.1]	4.66	0.003
	Post Offset	**0.029 [4.8]**	**4.83**	**0.004**
Task 4	Pre Onset	**<0.001 [39.3]**	**5.02**	**−0.012**
	Post Onset	**<0.001 [12.3]**	**4.90**	**−0.007**
	Pre Offset	0.780 [0.1]	4.52	−0.001
	Post Offset	**0.003 [8.8]**	**4.54**	**−0.006**

[a] p-values and (F-values). The notation "<0.001" means that the p-value is smaller than 0.001. [b] Pupil diameter starting value for window. [c] Exponential change in pupil diameter per second. Bold values indicate significance.

effect from that the instructor intervening in the scenario. When performing the last tasks, the participants knew that the scenarios would end this way, and the intervention therefore did not elicit a similar response.

Effects of Repeatedly Performing Stressful Tasks on Pupil Size

The interpretation of pupil activity was in general more complex compared to heart rate. During task onsets, there was a significant difference in pupil size across the task sequence. However, unlike heart rate, *post hoc* tests did not show a gradual increase in pupil size over tasks, but rather unsystematic variations from task to task, where the smallest pupil sizes were recorded during tasks 2 and 4. Similar patterns were found for the other task phases (Task execution, Abort command). It is difficult to explain why we see these differences in pupil size across tasks and task phases, and they may simply be related to the natural fluctuations in pupil size, which can reach up to 0.5 mm, in combination with changes in pupil size due to scenario-dependent differences in gaze direction (Centeno et al., 2011). However, the pupil diameter tended to respond differently to differences in the scenario content, e.g., the pupil diameter inclined to be larger when the threat more often appeared immediately, as in scenario 1 and 3 and smaller when the threat appeared delayed, as in scenario 2 and 4. Hence, the differences in scenario content suggests that the biomarkers heart rate and pupil diameter respond differently to different features in the tasks to perform under various levels of stress.

Moreover, the pupil diameter did not change to the extent expected in response to the changes in illumination. The average pupil diameter across all tasks was about 4.7 mm (SD 0.8 mm) at 4 lux, 4.6 mm (SD 0.5 mm) at 191 lux and 4.6 mm (SD 0.5 mm) at 385 lux. For reference, when investigating the effects of different illumination levels on pupil diameter under non-stressful conditions, Gholami et al. (2018), found that the average pupil diameter was about 6.4 mm (SD 1.0 mm) at 4 lux, 5.7 mm (SD 0.9 mm) at 40 lux and 4.3 mm (SD 0.8 mm) at 400 lux. When entering the scenario room (Post Onset), one would expect the pupils to constrict due the much larger illumination in the scenario room (385 lux) compared to the dimly lit anteroom (4.6 lux). Interestingly, however, during the first three tasks, the regression analyses revealed that the pupils dilated significantly during the post onset analysis window, which is contrary to what would be expected due to the sharp increase in illumination. A possible explanation to our findings could be that the parasympathetic pupillary light reflex was overpowered by a stronger sympathetic nerve response, causing the pupils to dilate in spite of the participants entering a room with much higher illumination (Beatty, 1982; Pedrotti et al., 2014).

Potential Role of Homeostasis

The stress response has a fast autonomic sympathetic part and a somewhat slower endocrine or hormonal part. The sympathetic response uses neural pathways to activate basic physiological functions such as increased heart rate, pupil dilation, blood pressure, breathing rate and vasoconstriction (Purves et al., 2018). A sympathetic pathway to the adrenal medulla starts the release of adrenaline and noradrenaline to the blood system, which will strengthen and prolong the stress response effects. However, it takes several seconds to increase the stress hormone blood concentrations. Yet another stress system is the hypothalamic-pituitary-adrenal cortex or HPA-axis that through release of hormones in the blood system activates the adrenal cortex to among others release the stress hormone cortisol in to the blood system, which increases the ability to maintain a stress response over longer time if necessary. If the stress response is not inhibited due to obvious threat removal within about 15–30 s the stress hormone levels in the blood system will have reached levels to a point that even if the threat disappears the effects will last up to an hour or more before homeostasis is reached. High levels of cortisol can take hours to reduce (Hallett, 2012; Bozovic et al., 2013; Osborne et al., 2015; Wilkinson and Imran, 2019). Thus, even if the first three tasks were performed within about 30 s, this duration might be too long to enable a reset of the stress response systems. Concomitantly, the anticipation itself of coming unknown problems and uncertainty about how their performance will be judged may also contribute and explain the apparent increase of heart rate after the given abort command. Moreover, the only about 30 s of rest between tasks would not suffice for a recovery from a stress response that progressed into its long-term stress hormone phase. Hence, the study findings of an accumulated heart rate increase from repeatedly performing stressful tasks are in line with a hypothesis of an incomplete homeostasis between tasks performed. However, more research is needed to determine the role of homeostasis processes during different stress levels and threat durations, and about whether extensive high stress training may influence the neurobiological properties of the stress response and the processes of homeostasis.

Practical Implications

Temporary increased strength and faster sensory information processing during threatening stressful events, can easily be recognized as beneficial from an evolutionary point of view. A similar stress response system can be found in most mammals (Nesse et al., 2016). Psychological stress is a reflexive response caused by threats affecting performance both positively and negatively. Moderate stress levels can heighten awareness and improve performance. Higher stress levels start to impair decision making, decrease shooting performance and is an important cause of friendly fire (Meyerhoff et al., 2004; Oudejans, 2008; Vonk, 2008; Kassam et al., 2009). It should be noted that the scenarios in this study evoked heart rates up to about 120 bmp, suggesting that only a moderate escalated stress response was induced by the used scenarios. However, already at these stress levels starts fine motor skills using smaller muscle groups to deteriorate, which may have implications on the ability to handle, e.g., safety mechanisms requiring precise finger and hand performance (Siddle, 1995). The more severe motor skill effects typically starts to appear at heart rates higher than 145 bpm (Siddle, 1995; Nieuwenhuys et al., 2009), affecting also the dilation of the pupils (Hollingsworth et al., 2009).

Our results show that being repeatedly exposed to stressful tasks can produce an escalation of psychological stress, this even prior to being exposed to the task to perform. In this study the scenarios evoked only moderate stress responses. However, the importance and effects of stress escalation while performing sequential tasks might be of much more marked role in real-life situations where police officers may encounter true risks of being injured or killed. During such circumstance, a further deterioration of perceptual, cognitive and motor performance caused by a stress accumulation might render police forces unable to complete their tasks and unable to handle equipment requiring fine and complex motor skills (Siddle, 1995). Hence, the findings highlight the importance of avoiding sustained exposure to high stress by allowing de-escalating rests between performing stressful tasks, even though this may be difficult to implement in everyday police work (Anderson et al., 2002). In protracted intense situations, e.g., riots or hostage situations, recording heart rate may here be a useful method to monitor for strong stress responses. Moreover, since police training and evaluation often include sequential tasks, the study results may have practical implications when developing police training, planning at strategical as well as operational or tactical levels. Here, it is important to use a suitable biomarker when determining the effectiveness of different scenarios, training programs, and tests, to induce the required levels of stress response to reach specific goals (Murray, 2004; Bertilsson et al., 2013). The knowledge can also be useful in after-action reviews of stressful police interventions.

In this study, the heart rate was found to be the most useful biomarker for monitoring stress levels. The heart rate was comparatively easy to measure with modern wireless equipment and the findings easy to interpret also by novice users. Thus, recording heart rate might be of marked practical value also during real-life incident and police training. Pupil size was also easy to measure in active scenarios, but was somewhat more difficult to interpret. This makes recording pupil size presently more useful in specifically designed experimental research settings. Hence, by developing custom-made equipment and software, objective physical biomarkers might in the future be of marked help as a vehicle to evaluate performance and operative tactics.

Limitations

The study was performed on a limited number of subjects (*n* = 12), which gives limited opportunities to explore the effects of, e.g., randomized scenario orders. Given the large heart rate increases compared with during rest, the power analyses performed suggest that the number of subjects was enough for performing statistical analyses. Moreover, that the scenarios were different in key aspects, e.g., in that a threat appeared immediately in scenario 1 and 3 and delayed in 2 and 4, had no noticeable effect on heart rate. The accumulated increase in heart rate continued in spite of differences between scenarios, see **Figure 3**. However, the pupil diameter tended to respond differently to differences in the scenario content, though a systematic response pattern across repeated task could still be determined, see **Figure 4**. Hence, the fixed scenario test order used in this study helped to reveal that the biomarkers heart rate and pupil diameter may respond differently to different features in an investigation design. That said, more research should be done on larger materials, e.g., using randomized test orders, to explore whether biomarkers systematically respond differently to specific scenario events or assignments.

Another limitation was that human figurants were used in the scenarios. The main reason for this choice was that human figurants would be able to interact with the test subject during the scenario, and thus, produce a more realistic context. However, this also means that although each scenario included the same task to solve, the events did not play out identically. Hence, detailed analysis of heart rate variability, response latencies and detection of startle reactions were difficult within the scope of this study.

Finally, the pre onset heart rate values just before performing task 1 were already then significantly larger than the heart rate at rest. This may have had implications on our results in that the heart rate effects of repeatedly performing stressful tasks if compared with the heart rate levels at Pre Onset of task 1. Hence, that the subjects were physically inactive for at least 10 min prior to performing the tasks did not make the heart rate levels approach the ones recorded at rest.

CONCLUSION

When participants performed a sequence of four stressful tasks and were only allowed a brief rest between tasks caused this a significant accumulated increase in heart rate. The pupil diameter also changed significantly but in a complex pattern likely more related to the contexts in the individual scenarios, e.g., whether the threat appeared immediately or was delayed in the scenario. Thus, being repeatedly exposed to stressful tasks can produce in itself an escalation of psychological stress, which highlight the importance of avoiding sustained exposures to high stress by allowing de-escalating rests between stressful tasks. In this study, heart rate was found to be the most useful biomarker for monitoring stress levels. The heart rate was found comparatively easy to measure with modern wireless equipment and the findings easy to interpret also by novice users. Thus, recording heart rate might be of marked practical value also during real-life incident and during police training. Pupil size was also easy to measure in active scenarios, but was somewhat more difficult to interpret. This makes recording pupil size presently more useful in specifically designed experimental research settings. Hence, by developing custom-made equipment and software, objective physical biomarkers might in the future be of marked help when evaluating performance and operative tactics.

DATA AVAILABILITY

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

ETHICS STATEMENT

Experiments were performed in accordance with the Helsinki declaration and the recorded data was handled according to the protocol approved by the Ethics Review Board at the Lund University, Sweden (Dnr 2014-36). All participants provided written informed consent.

AUTHOR CONTRIBUTIONS

JB, PJF, MN, and P-AF collected the data aided by MJM and OF. P-AF, MN, and DN carried out the statistical analyses and worked on the draft of the manuscript together with JB. JB performed the first literature search. JB, P-AF, MN, and DN worked on the several drafts of the manuscript. MD, SG, PJF, MM, OF, and MJM revised the manuscript and contributed with literature.

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REVIEW
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Complex Motor Learning and Police Training: Applied, Cognitive, and Clinical Perspectives

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The practices surrounding police training of complex motor skills, including the use of force, varies greatly around the world, and even over the course of an officer's career. As the nature of policing changes with society and the advancement of science and technology, so should the training practices that officers undertake at both central (i.e., police academy basic recruit training) and local (i.e., individual agency or precinct) levels. The following review is intended to bridge the gap between scientific knowledge and applied practice to inform best practices for training complex motor skills that are unique and critical to law enforcement, including the use of lethal force. We begin by providing a basic understanding of the fundamental cognitive processes underlying motor learning, from novel skill acquisition to complex behaviors including situational awareness, and decision-making that precede and inform action. Motor learning, memory, and perception are then discussed within the context of occupationally relevant stress, with a review of evidence-based training practices that promote officer performance and physiological responses to stress during high-stakes encounters. A lack of applied research identifying the neurophysiological mechanisms underlying motor learning in police is inferred from a review of evidence from various clinical populations suffering from disorders of cognitive and motor systems, including Alzheimer's and Parkinson's disease and stroke. We conclude this review by identifying practical, organizational, and systemic challenges to implementing evidence-based practices in policing and provide recommendations for best practices that will promote training effectiveness and occupational safety of end-users (i.e., police trainers and officers).

Keywords: procedural learning, motor learning, plasticity, training, stress, physiology, occupational health, police

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Law enforcement personnel including police officers rely on several types of information as they go about their duties and daily routines; external cues from the environment, internal physiology, declarative memory of laws and regulations, and implicitly learned tactical skills. Police are also entrusted to resolve potentially dangerous or violent encounters, in some cases necessitating the use of force. As a result, law enforcement personnel are exposed to high levels of occupational stress, which have been shown to pose risks to physical and mental health (Carleton et al., 2018, 2019; Planche et al., 2019). Policing skills, including physical capabilities and mental resiliency, are modifiable by training and experience and have an influence on police decision-making and performance in the field. To bridge the gap between empirical research and applied practice, we begin this review by describing initial learning processes (i.e., basic skill acquisition) before reviewing motor learning of specialized physical skills relevant to law enforcement. Specifically, we propose that situational awareness and decision-making are essential motor skills for policing that integrate sensory, motor, and cognitive functioning. The neurophysiological processes underlying procedural motor learning will be integrated throughout these discussions. Then, we show how occupationally relevant stress influences police performance, and has been adaptively integrated into state-of-the-art training to promote motor learning outcomes. Next, evidence from various clinical populations will be reviewed to identify cognitive and neurophysiological mechanisms that are important for procedural motor learning among police. Finally, we conclude our review by identifying practical, organizational, and systemic challenges to implementing evidence-based police practices and put forth recommendations to overcoming these challenges that will improve training effectiveness and direct future work.

Before we begin, the authors would like to emphasize that this review is not intended to criticize or condemn any current practices. Rather, the following review is intended to provide an accessible summary of what happens in the brain during complex motor learning (i.e., police training), as well as during real-world police encounters that induce physiological stress responses that directly influence whether training is recalled during in-the-moment decision-making. Our hope is that police trainers and curriculum developers will use this information to inform, update, or improve understanding of current training practices to maximize learning outcomes. As society, technology, and scientific knowledge continue to advance, so should police training practices for the purpose of maintaining public and occupational safety.

APPLIED MOTOR LEARNING IN LAW ENFORCEMENT

The manner by which police officers learn motor skills is no different from other humans simply because of their occupation– they have to progress from initial skill learning to high proficiency using the same neurophysiological processes as experts in other domains. To acquire this expertise, police officers must undergo rigorous training and acquire experience in the field. In addition to learning specific motor skills such as firearm handling and hands-on tactics, police officers must also train visuomotor networks involved in situational awareness. Together with past experiences (in training and on the job) and individual action competencies, an officer's perceptual assessments implicitly inform complex decision-making for choosing the most appropriate motor command during dynamic and unpredictable encounters. Neural mechanisms underlying effective police training methods remain unknown and will be inferred from fundamental science and research on clinical populations that experience breakdowns in the cognitive and neurological mechanisms that facilitate motor learning and memory.

Early Motor Learning: Basic Competency and Novel Skill Acquisition

Skill acquisition and motor learning come with experience, which includes problem-solving through individual trial-and-error or during training with supervisors, teachers, or colleagues. Using firearm skills training as an example, new recruits (presumably without any prior experience with firearms) will carefully observe and model the behaviors of their instructor. A crucial step in the process of motor learning is the ability to define, understand, and remember the ordered sequence of observed movements (**Figure 1**). In order to do so, sensory-motor and memory regions of the brain are recruited to help break down continuous streams of motion (as well as music and language, see Zacks et al., 2009a; Francois and Schön, 2011; Lerner et al., 2011) into component "chunks" (Zacks and Sargent, 2010). Motor chunks begin and end with event borders that are typically marked by distinct kinematic movement parameters, including changes in position or location, speed, and direction of movement and also perceived changes in goals and intentions (Zacks et al., 2009b, 2010; Hemeren and Thill, 2011).

To continue with our previous example, drawing one's firearm requires a set of discrete movements or chunks, including reaching down, releasing the gun from the holster, pulling the gun up from the holster to the chest and pushing it straight with the arms to the firing position, and aiming at a target. Segmenting motor sequences in this way facilitate early motor learning and gaining competence in smaller, more manageable units of information (Ericsson et al., 1980; Gobet and Simon, 1998; Bo and Seidler, 2009). With continued training, motor chunks can be grouped or "concatenated" into longer sequences (Sakai et al., 2003; Bläsing, 2015) that can be performed and recalled with less mental effort. Although it has not been directly investigated in police, one could hypothesize that experienced officers would identify fewer and larger chunks of component actions (e.g., a single motion for "pointing a firearm") based on these previous findings. Future applied research on police segmentation behaviors would clarify the relationship between multisensory perception, motor learning, and memory. All of these cognitive processes are especially relevant for police, whose decision-making (i.e., motor selection) is guided by assessment of the environment, current physiological status (e.g., stressed, fatigued), and prior experience.

Reinforcing Motor Learning in the Brain

Our brains have evolved a highly sophisticated and complex network of brain areas that facilitate imitation-based learning.

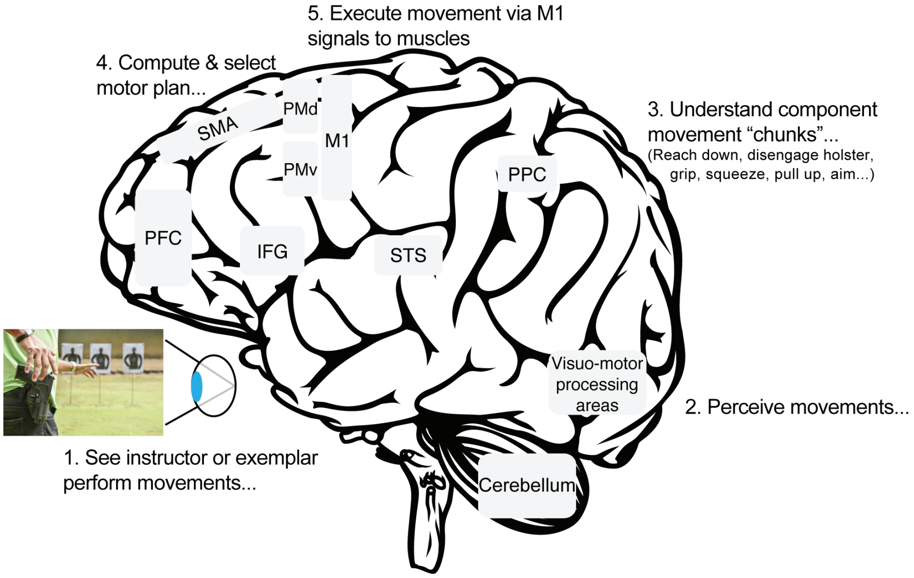

FIGURE 1 | Transforming vision into action. Regions of the mirror neuron network (MNN) are independently responsible for a myriad of functions, including sensory perception, language processing, transforming external information onto internal body-centered reference frames, and planning and executing movements. Through repeated practice, the neuronal pattern of activation (or "motor representation") underlying a novel movement is recalibrated and reinforced or consolidated into long-term memory. IFG, inferior frontal gyrus; M1, primary motor cortex; PFC, prefrontal cortex; PMd, dorsal premotor cortex; PMv, ventral premotor cortex; PPC, posterior parietal cortex; SMA, supplementary motor area; STS, superior temporal sulcus.

Giving credence to the old adage "monkey see, monkey do", researchers unintentionally discovered the "mirror neuron network" (MNN, **Figure 1**) during neurophysiological investigations on reaching behaviors in monkeys (Gallese et al., 1996; Rizzolatti et al., 1996). Based on subsequent research in both animals and humans, the MNN has been shown to facilitate imitation-based learning by way of transforming observed or verbally instructed movements into a physically embodied action (for contemporary critical review, see Kilner and Lemon, 2013). Behavior is typically associated with the ability to execute a given movement but also involves observing and thinking about movement(s) through visualization or planning. That is, an officer's MNN is activated while they are using their firearm, when they observe an instructor use their firearm, as well as when they visualize themselves using their firearm (Grèzes and Decety, 2001).

Based on common activation of the MNN during observation, visualization, and execution of movement, it begs the question: Can motor learning be achieved without physical practice? Several researchers have directly compared training gains across these paradigms for simple movement sequences (e.g., finger tapping). While similar performance gains (Hird et al., 1991), force gains, muscular motor-evoked potentials (Yue and Cole, 1992; Mattar and Gribble, 2005; Porro et al., 2007), and neural activation (Cisek and Kalaska, 2004) were found during observation- and visualization-based training paradigms, these measures and physical competency were less than movement-based training. Therefore, the neurophysiological connections enabling successful motor learning cannot be achieved to the same degree without physical practice[1].

Brain regions comprising the MNN in humans include ventral and dorsal premotor cortices (Binkofski and Buccino, 2006), intraparietal sulcus, superior parietal lobe (Filimon et al., 2007), inferior parietal lobule, inferior frontal gyrus (Broca's area), cingulate gyrus, cerebellum, superior temporal sulcus (Iacoboni et al., 2001), supplementary motor area (SMA), and primary motor cortex (M1). Individually, these nodes are functionally related to sensory, motor, language, attention, and memory processing (**Figure 1**). Together, the MNN transforms and maps externally perceived movement onto internal body-centered reference frames. Premotor cortices and SMA are primarily responsible for computing the desired motor plan, which is set into motion by triggering activation of M1 neurons that directly innervate corresponding muscle groups (for review, see Gallivan and Culham, 2015). There has been some debate regarding the activation of M1 and SMA during observation and visualization when motor output signals are inhibited and no overt movement occurs (Roth et al., 1996; Grèzes and Decety, 2001). Nonetheless, these nodes have shown reliable activation during all three types of movement processing to enable transformation of sensory and cognitive information into motor commands.

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[1] Some of the noted benefits of visualization (or mental imagery, motor imagery, or mental simulation) include the rehearsal of visual, motor/kinesthetic, spatial, and symbolic aspects of a given movement in the absence of overt movement (Sherwood and Lee, 2003). Visualization as a proposed component of intuitive decision-making and an effective training tool in the context of policing are discussed below.

A given movement, such as drawing one's firearm, is coded as a very specific pattern of neural activation in the MNN, referred to in the scientific literature as a "motor representation." Once a given movement is performed (e.g., drawing, aiming, and firing a firearm), there is immediate visual feedback regarding whether the outcome was successful or not. These "incoming" visual signals, or *reafferents*, are compared to predictive "outgoing" *efference copy* signals that are generated by the brain during movement preparation (Blakemore et al., 1998; Rizzolatti et al., 1998; DeSouza et al., 2003). When predicted and actual movement is successful, and incoming feedback signals are congruent with the predictive outgoing signals, the motor representation is reinforced. Specifically, neural connections between MNN regions for the successful movement are strengthened, in turn facilitating future successful performance and engraining motor learning (Rizzolatti and Craighero, 2004; Oosterhof et al., 2013). When predicted and actual behavioral outcomes do not match, motor planning signals are recalibrated and updated with subsequent attempts, a process referred to as "motor adaptation" (Cressman and Henriques, 2009; Salomonczyk et al., 2011; Neva and Henriques, 2013).

In order to forge the functional connections between brain regions that code a novel motor representation, researchers have identified a competitive mechanism whereby stronger pre-synaptic inputs weaken the inputs from other neurons to the same post-synaptic cell, resulting in learning-dependent plasticity (Song et al., 2000). Made famous by Hebb (1949), neurons that "fire together, wire together", known as spike-timing-dependent plasticity (STDP). In other words, the repeated and paired activation between neurons is reinforced with experience and training, forging stronger, and more reliable connections.

Just as training is intended to encode correct behaviors, it provides an opportunity to work through errors constructively (section "The Gold Standard for Complex Motor Learning for Police: Scenario-Based Training"). Our brains are equipped with specialized functions to ensure that those errors are not encoded over correct patterns of behavior. The precise timing of coordinated and long-range neural activation among regions of the MNN can induce states of anti-STDP, potentially blocking the encoding of new information that needs to be erased (Koch et al., 2013). For instance, anti-STDP processes could prevent the encoding of an officer's incorrect drawing of their firearm or movement pattern through a training scenario that resulted in them being shot by an armed suspect. Break-downs in learning-dependent STDP mechanisms are observed in clinical populations, including individuals with Alzheimer's disease (AD) and are discussed further in section "Seeing and Hearing is Believing: Superadditive Mechanisms of Multisensory Inputs".

Defining Expertise in Policing

Performance Enhancement

Initial motor learning is characterized by effortful practice and mastery of component actions or "chunks" (e.g., drawing, aiming, and firing) of larger action sequences (e.g., quickly reaching for one's firearm). With continued training comes a reduction and eventual plateau in performance errors, reaction times, and the effort needed to execute now-automatized behaviors. Such performance measures have often been used to define expertise in empirical research studies of various problem-solving tasks. Expert knowledge is organized in large scale, multilevel, and interconnected data structures that integrate sensory, motor, and linguistic functions of component "chunks" of information (Di Nota, 2017). Increasing the number of chunks in novice thinking does not make him an expert but requires a structured organization of knowledge (Rauste-von Wright and Wright, 1994). As a result, experts are characterized to have an excellent ability to perceive the overall picture in different situations, with an unconscious understanding of how to meet the needs of novel situations (Ropo, 1991).

Defining expertise as a progressive linear process that encompasses a finite set of physical skills has been met with criticism. Several researchers argue that the extent or duration of training time is less important to defining expertise than an individual's competence, with less experienced individuals outperforming experts in several domains (Doane et al., 1990; Vicente and Wang, 1998; Ericsson, 2004). One of the most prominent researchers in expertise is Ericsson, who proposed that the duration of training is positively correlated to improvements in performance that are tailored to typical situational demands. Once automaticity of behavior is achieved, additional experience will not significantly improve performance further or refine mediating neurological mechanisms, leading to arrested development (Ericsson et al., 1993; Ericsson, 1998). An appropriate example includes tying one's shoelaces; once this skill has been mastered, additional experience will not be related to higher levels of performance.

To develop high-level skills, including those relevant to policing, Ericsson defines expertise as an ability to apply one's skills adaptively to perform faster, more accurately, and with less effort under a wide variety of situational constraints and demands. Experts break through the ceiling of arrested development with deliberate practice, which involves effortful cognitive engagement in challenging tasks that may not commonly be encountered (Ericsson and Lehmann, 1996). According to this definition, experts attain higher levels of performance by challenging themselves to meet increasingly difficult demands, in turn developing a repertoire of increasingly complex motor representations. Ericsson's theoretical framework is especially relevant for police who train for highly dynamic, uncertain, and potentially dangerous encounters. Section "Bridging the Gap Between Science and Practice: Evidence-Based Police Training" will review the current state of the art for police training paradigms that consider the principles of deliberate practice, as well as the influence of physiological responses to occupationally induced stress, to promote motor learning and effective recall during critical incidents.

Through the overt (sensory reafferents) and covert (efference copy) feedback processes described above, expert sensorimotor networks facilitate decision-making, performance, and novel motor learning that is faster and more accurate than among novices. The refinement of complex networks that encompass sensory, motor, language, and cognitive (i.e., memory, decision-making) brain regions suggest a high potential for skill transfer across domains and bear important implications for the therapeutic application of motor learning and training for a variety of disorders (see section "Therapeutic Benefits of Complex Motor Learning").

Situational Awareness

By their very nature, high-stakes police encounters are highly complex and always changing. Among police instructors, it is understood that motor skill learning in and of itself is not sufficient to cope with the complex reality of police encounters. An example would be a situation in which the police have the conditions and necessity to use a firearm toward a target person, but there are many bystanders in the vicinity. In this case, using a firearm could be a serious threat to public safety. In addition to the basic motor competency and handling of the weapon, the officer must also be able to assess and change their positioning effectively so that discharging the firearm can minimize collateral damage and effectively resolve the situation. If an officer lacks knowledge (and training) in situational awareness and decision-making, the outcome of highly unpredictable, time-pressured, and stress-inducing encounters like the one described here is likely unfavorable. Therefore, situational awareness and subsequent selection of the best course of action are fundamental procedural skills for police that inform behavioral outcomes just as much as basic motor learning.

Although the conditions and circumstances to every situation are unique, police instructors and practitioners generally agree that situations can be understood as a whole, within which there are fundamental elements that can be separately understood and trained. An officer's perception and evaluation of a situation directly informs what motor skills they will employ. This online assessment of the environment is known as situational awareness. Several definitions of situational awareness exist for different fields but has been defined by Endsley (1995) as possessing three components: perception, comprehension, and projection. In other words, sensory perceptions signify elements of the environment, whose meanings must be understood in order to anticipate their future status in relation to the objectives of the action. Before we are able to understand our perceptions, it is important that we learn to make proper perceptions. Selective attention is an important function of the sensory system because all of the information received by the senses cannot be consciously perceived at the same time (Tiippana, 2006). Therefore, what part of the external environment is the subject of conscious awareness at any given time is controlled by attention, which is highly influenced by stress (see section "Stress-Induced Memory Deficits, Perceptual Distortions, and Performance Errors in Police"). According to this view, selective attention divides the external totality of a situation into meaningful and non-meaningful elements, the latter of which is ignored and the remaining essentials are attended (Varila and Rekola, 2003).

In the case of training aimed at developing situational awareness, it would be advisable to develop methods of visual exploration and subsequent processing of critical information (Salas et al., 1995). Once essential features of the environment have been identified, complicated situations can be broken down into smaller elements or "chunks." Just as with fundamental motor learning described above, situational awareness training can afford novices the opportunity to recognize chunk patterns in different contexts and combinations, and link them to appropriate motor strategies (Varila and Rekola, 2003). As shown by previous research (Bläsing, 2015), police experts may sum up several observations into larger entities that include both situational awareness and tactical elements. Indeed, an examination of police shooting strategies found significant overlap in stepping and shooting behaviors (Nieuwenhuys et al., 2017), reflecting concatenation of component motor and perceptual chunks during a high-threat shooting exercise. Without investigation, standardization, and validation of situational awareness training strategies, police officers may be learning wrong patterns and encoding stimulus-response tendencies instead of effective critical thinking skills.

Fast, Flexible, and Accurate Decision-Making

In both policing and basic science, actions are typically evaluated by the final outcome. In reality, human behavior is far more complex than a hierarchical, step-wise process that begins with a goal, is followed by a conscious motor plan, and concludes with an appropriate movement. Researchers in the field of computational neuroscience have provided an alternative school of thought that suggests multiple behavioral outcomes, or "affordances," unconsciously competes for final selection (Cisek, 2006, 2007). Based on current perceptions of the environment, the brain considers multiple potential motor affordances to achieve a desired outcome. For instance, a suspicious individual in a dark alley may elicit multiple behaviors from an officer, including verbal commands, change in positioning, and accessing one of multiple force options [e.g., baton, oleoresin capsicum (OC) spray, conducted electrical weapon, firearm]. As the situation unfolds over time, goals and available options for action selection are continuously updated by the prefrontal cortex (PFC) and basal ganglia, respectively.

In the current example, the suspect could charge toward the officer with a weapon necessitating a use of lethal force, or the suspect may comply with officer's verbal commands and allow for safe approach. Cisek's (2006, 2007) model suggests that updated sensory information biases competition among multiple motor affordances toward a single response that is released into execution. Further, there is evidence to suggest that high levels of threat narrow perceived and actual motor affordances for possible action (Pijpers et al., 2006). We propose that complex decision-making undertaken by police officers during high-stakes encounters involves several other factors, including stress-induced perceptual biases and prior experience acquired through training or in the field.

These considerations and their unconscious influence on police performance and motor selection will be discussed in detail in section "The Influence of Stress on Police Performance."

Once motor learning is engrained, and officers are adequately trained in situational awareness, how is this knowledge functionally used "in the moment"? Based on acquired knowledge from training and work experiences, officers make well-informed decisions very quickly under conditions of extreme time pressure, high stakes, and shifting conditions (Klein, 2017). However, they may not be able to describe how or why they chose to act (Ropo, 1991). Decades of investigations with experts in several fields, including emergency first responders and military personnel, support two prominent theories that characterize "intuitive" decision-making. In contrast to deliberate, slow, and controlled reasoning, Kahneman and Tversky's Two-System Model (Stanovich and West, 2000; Kahneman, 2003) stipulates that intuitive decision-making is automatic, effortless, and not available to introspection. Often emotionally charged, intuitive decision-making elicits habitual responses that are difficult to control or modify, highlighting the importance of cementing correct (or optimal) intuitions with police training.

Klein's Recognition-Primed Decision Model (RPDM) (Klein, 1989, 1993) characterizes proficient decision-making as a fusion of two mental processes – situational awareness and mental simulation (or visualization). Experienced officers recognize familiar cues and patterns of information in the environment and quickly identify what goals and actions are feasible or not. In contrast to competitive affordance models (Cisek, 2006, 2007), the RPDM stipulates that there is no concurrent deliberation of alternate options. Rather, a single action plan that is most likely to meet a sufficient outcome is mentally simulated. If any pitfalls are expected, the action plan is adjusted until a satisfactory outcome is realized and executed. Because there is no deliberation, decision makers often cannot explain their rationale.

The difficulty of articulating implicit decision-making also poses a problem for training and evaluation of police motor learning, which is largely outcome based. Steps should be taken to ensure that the physical tactics and cognitive thought processes leading up to (and including) the decision to act are adequately addressed in police training. Experts are also shown to make "rookie mistakes" when ignoring relevant cues for the sake of fast decision-making (Kahneman, 2003). Through more introspective pedagogical approaches, police trainers can use mistakes in both novice and expert officers' performance to recalibrate and reinforce correct intuitive cognitive and motor strategies.

Confidence and Action Competency

Finally, we suggest that the practical application of procedural motor skills, situational awareness, and expert decision-making might also be linked to the officer's individual perception of their own skills and abilities that precedes action. As reflected in military pedagogy, the concept of action competence refers to one's self-perceived ability to act, which includes physical (i.e., operational) and mental capability, competence, knowledge, and skills that are essential to an individual's survival in demanding situations (Toiskallio and Mäkinen, 2009). Action competence can also be defined with respect to social and ethical considerations, including ownership and justification of one's actions that undoubtedly influence police and law enforcement performance. Action competence is another aspect of complex motor learning that trainers and curriculum developers should be aware of when reimagining police training methods and approaches.

Changes to Brain Structure and Function With Long-Term Training and Expertise

Investigations of motor learning are typically examined in highly controlled experimental settings using simple tasks, including arm reaching, finger tapping, and eye movements. However, the physical skills of police and other law enforcement personnel require complex, whole-body movements that are highly dynamic and dependent on the unique situation at hand. To investigate learning-induced neural plasticity that is more applicable to real-world experiences, we look to other areas of research including sport psychology of athletics, dance, and music. These domains have served as ideal models for measuring ecologically valid, reproducible, sequential movements that have established standards for correct performance. Neurological evidence for motor learning among police is a largely unexplored area of study (see section "Live Versus Virtual Scenario-Based Training"), and the few empirical research studies investigating training-induced changes to police physiology (i.e., cardiovascular) and performance will be reviewed in section "The Gold Standard for Complex Motor Learning for Police: Scenario-Based Training."

To facilitate dynamic expert performance, neuroimaging findings of long-term training have shown greater structural organization and neural efficiency among brain regions involved in motor planning among experts relative to novices. Specifically, expertise has been linked to reduced gray matter volume in superior frontal gyrus, left PMC, SMA, and putamen relative to non-experts, and lower white matter volumes in bilateral corticospinal tracts and corpus callosum (Hänggi et al., 2010). Fractional anisotropy, which measures the extent of fiber integrity (Assaf and Pasternak, 2007), is also lower in white matter tracts underlying PMC among experts, reflecting less diffusion across white matter tracts (Hänggi et al., 2010).

Reorganization of expert brain networks also facilitate faster and less effortful learning of new information related to one's area of expertise (Shmuelof et al., 2012), lending empirical evidence to the old adage that "you can teach old dogs new tricks." Brain imaging studies of novel sequence learning among longstanding experts show initial increases in neocortical activation (SMA), reflecting effortful cognitive motor planning. Once the motor sequence has been automated and over-learned (i.e., practiced daily for several weeks with a high degree of accuracy), there is a dramatic decrease in neocortical activation and greater activation in subcortical regions including the striatum (Bar and DeSouza, 2016). The striatum is a critical part of the brain's motor and reward systems, is reciprocally connected to the PFC and thalamus, and coordinates numerous cognitive functions including action planning, decision-making, motivation, and goal/reward processing (Yager et al., 2015). These connections enable optimal expert performance and involve processes that directly inform police decision-making as discussed above. Despite the body of neuroimaging evidence reviewed here, there is a dearth of investigations examining training-induced changes to brain structure and function among police (see section "Future Directions for Evidence-Based Police Training: Neurophysiological Mechanisms" for current evidence and future directions).

THE INFLUENCE OF STRESS ON POLICE PERFORMANCE

Despite the comprehensive overview of occupationally relevant motor learning presented above, an important problem for police training remains: how can we promote recall of training during high-stress, time-limited encounters in the real world? By examining how physiological responses to stress influence police performance, perception, learning, and memory, we provide a framework for understanding effective training programs that use evidence-based principles to prepare police officers for the realities of the frontline.

Physiological Responses to Stress

The most scrutinized decisions made by police officers usually occur under highly stressful conditions resulting in a use of force and particularly lethal force. Despite expectations to perform in accordance with the law and their training, law enforcement personnel and other first responders are not immune to the body's automatic physiological responses to threat and stress (for detailed description, see Schwabe and Wolf, 2013; Ness and Calabrese, 2016). By initiating the "fight or flight" response, stress adaptively promotes survival by mobilizing individuals to escape threat (Lovallo, 2016). Stress can be measured by various objective physiological markers. Cardiovascular indexes of stress include heart rate (HR), heart rate variability (HRV), blood pressure, and galvanic skin response. Cortisol obtained through saliva or blood samples provide a neurochemical measure of stress. Very little research has been conducted on police using non-invasive brain imaging techniques, including magnetic resonance imaging (MRI) or electroencephalography (EEG) (see section "Future Directions for Evidence-Based Police Training: Neurophysiological Mechanisms"). Both neuroimaging techniques stand to illuminate structural and functional changes to the brain following acute and long-term exposure to stress, as well as learning-induced plasticity.

Seminal work by Yerkes and Dodson (1908) has been supported by basic and applied research in several fields to establish the stress-memory continuum (**Figure 2**), which demonstrates that low to moderate levels of stress "arousal" adaptively facilitate learning, memory, and cognitive performance (Jameson et al., 2010). The strength of a memory is proportional to the level of arousal it elicits (Thayer and Sternberg, 2006), with stronger encoding of new information with more robust stress responses. However, at extreme levels, stress is maladaptive for learning by blocking both encoding of novel information and memory retrieval.

Basic science and animal research shows that the precise timing of stress-induced release of neurochemicals is key to successful encoding of novel information. Improved learning outcomes are observed when epinephrine is administered immediately prior to or during learning (Cahill and McGaugh, 1998; Cahill and Alkire, 2003), and severe impairment in

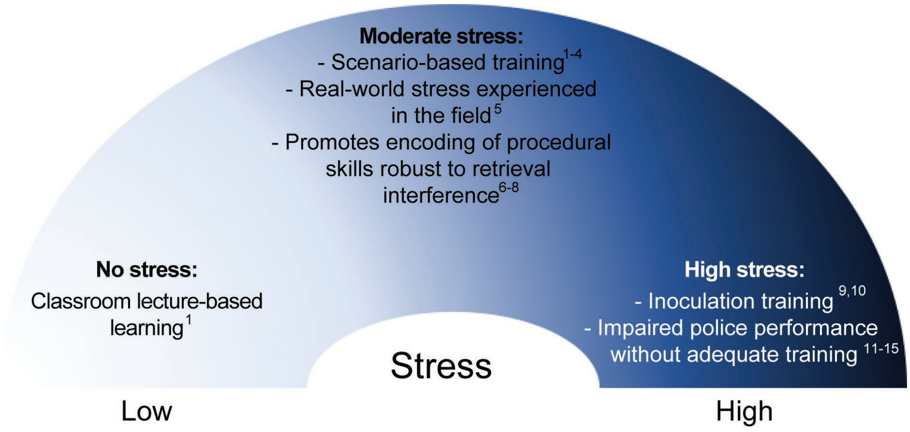

FIGURE 2 | The stress-memory continuum. As established by Yerkes and Dodson's (1908) seminal work, stress influences learning and memory processes on an inverted U-shaped continuum. At moderate levels, stress promotes attentional arousal and encoding (i.e., learning) of novel information. At extremely high levels, stress interferes with both encoding and retrieval processes and is maladaptive in training contexts. Based on empirical physiological evidence from police officers, scenario-based training lies at an optimal position of the continuum whereby ecologically-valid levels of stress are induced and result in measurable improvements in performance, including use of force decision-making. [1]Andersen et al., 2016a; [2]Andersen and Gustafsberg, 2016b; [3]Andersen et al., 2018; [4]Armstrong et al., 2014; [5]Anderson et al., 2002; [6]Jameson et al., 2010; [7]Cahill and Alkire, 2003; [8]Cahill and McGaugh, 1998; [9]Morgan III et al., 2004; [10]Taverniers et al., 2013; [11]Oudejans, 2008; [12]Nieuwenhuys and Oudejans, 2010; [13]Nieuwenhuys et al., 2012a; [14]Nieuwenhuys et al., 2009; [15]Nieuwenhuys et al., 2012b.

memory recall is observed when glucocorticoids are administered before retention testing (De Quervain et al., 1998, 2000; Diamond et al., 2006). These findings reveal unique influences of the various neurochemicals released during human stress responses on learning (i.e., memory formation). An important consideration for developers of police training programs is to identify an optimal level of stress that adaptively promotes learning without crossing the threshold for maladaptive stress that interferes with encoding and retrieval processes.

Stress-Induced Memory Deficits, Perceptual Distortions, and Performance Errors in Police

There is a limited yet growing body of research investigating the effects of stress on police performance, learning (see section "Bridging the Gap Between Science and Practice: Evidence-Based Police Training"), and memory (e.g., Yuille et al., 1994; Stanny and Johnson, 2000; Hope et al., 2016; Lewinski et al., 2016), with several insights offered from studies on military personnel (Morgan et al., 2004, 2006; Taverniers et al., 2013). These studies tend to focus on declarative memories of extremely stressful training and work situations, including prisoner of war exercises and police-involved shootings. Results consistently show stress-induced impairments to both immediate and delayed memory. For instance, officer recall of their path of travel during a simulated high-stress traffic stop significantly deviates from their actual path of travel, highlighting the influence of stress on officers' spatial memory (Lewinski et al., 2016). These outcomes bear greatly on the accuracy of police or eyewitness memory of traumatic encounters, as well as recall accuracy during stressful questioning procedures like evaluations, inquests, and trial proceedings. Considerations of stress on police memory lie beyond the scope of the present review (see Hope, 2016), which aims to clarify the influence of stress on police motor learning and performance.

Qualitative evaluation of police officers' accounts of encounters where they shot citizens reveal several consistent perceptual distortions, including diminished sound, slowed time, tunnel vision (i.e., narrowed attention), and heightened sense of visual detail (Klinger and Brunson, 2009). Even though officers are inherently aware of the temporal dynamics of action-reaction, they have been shown to systematically underestimate the distance between themselves and suspects in both low- and high-threat conditions (Nieuwenhuys et al., 2012a). In fact, research showing that an officer already pointing their gun at an armed suspect is unable to fire before the suspect does (Blair et al., 2011). These natural, untrained tendencies can lead to devastating outcomes unless stress-induced perceptual distortions are also considered and integrated into training procedural motor skills relevant to police (see section "Bridging the Gap Between Science and Practice: Evidence-Based Police Training").

Based on the significant overlap of brain networks involved in movement, learning, attention, and physiological stress responses, several psychological theories offer possible mechanisms for stress-induced impairments in police performance. Where an officer directs their attention informs their perception, evaluation, and available behavioral options for motor selection. To enable fast decision-making, the brain predictively "sees" before conscious perception (Barrett and Bar, 2009; Barrett, 2012). This phenomenon is known as affective realism, whereby external stimuli are assigned an emotional or affective "value" (i.e., gun = bad) that informs downstream physiological processes to approach or avoid the stimulus. As such, reporting negative emotions can increase the likelihood that a benign object like a wallet or cellphone is visually perceived to be a gun (Baumann and DeSteno, 2010). While this type of perceptual distortion rarely contributes to misinterpretation in violent police encounters, it has been reported in the past (e.g., 1999 police shooting of Amadou Diallo in New York City). An empirical research study on military cadets found faster and more accurate identification of a weapon versus a tool when visually primed with a threatening image but also an increase in "false positives" for weapons when presented with a tool under high anxiety conditions (Fleming et al., 2010). Training that integrates realistic levels of stress can help promote accurate perceptions over false positives that bear significant implications for occupational safety and security.

Applied research on police shooting performance has shown greater stress (self-report and HR), faster reaction times, and decreased shooting accuracy during high-threat conditions, where a live actor or canon shoots back at officers with simulated ammunition, versus low-threat conditions where officers shoot a static target (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010; Nieuwenhuys et al., 2012b). Stress-induced decrements in police performance have also been found for other complex procedural skills, including arrest and self-defense behaviors typically used in the field (Nieuwenhuys et al., 2009). According to attentional control theory (ACT), a stressful or threatening stimulus exerts both negative and positive influences on attention, respectively, by: (1) drawing attention away from task-relevant information toward distracting threat-relevant information and internal worries, leaving fewer attentional resources to effectively perform the task at hand and (2) increasing motivational cognitive or mental effort on task performance to counteract negative attentional effects (Eysenck et al., 2007).

Consistent with ACT principles, head and eye tracking reveal increased attention toward the suspect (i.e., threat) and away from task-relevant targets. Increased motivation is supported by higher reported mental effort during high-threat conditions, as well as faster reaction times to eliminate the threat but at the cost of shooting accuracy (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010; Nieuwenhuys et al., 2012a; for discussion on conflicting attentional mechanisms, see Hope et al., 2016). Similar to Fleming et al. (2010), Nieuwenhuys et al. (2012b) found a greater bias toward shooting unarmed targets in high-threat conditions, in addition to faster reaction times and decreased shooting accuracy to armed targets. Despite sampling highly trained police officers, the high-threat condition in these investigations influenced subconscious attentional and motivational processes that superseded officers' training to respond to a threatening situation, impairing task-related shooting performance. These findings highlight the urgent need to address occupationally relevant stress during police training to mitigate impairments in perception and subsequent decision-making and performance.

"I Don't Feel Stressed": Subjective Versus Objective Measures of Stress

Further contributing to the nuanced and highly complex relationship between stress, learning, and memory is the fact that stress is a highly individual experience. What may be perceived as extremely stressful for one individual may not be stressful at all to another. One's perceived level of stress may also differ from objective physiological measures, especially among police and law enforcement personnel who may be hesitant to admit "feeling stressed." Physiological stress responses in police have been shown to manifest in very similar ways during an encounter (e.g., physical use of force interactions) or in anticipation of an encounter (e.g., driving to event with lights and sirens; hand on gun) (Anderson et al., 2002). Stress can also be triggered by "real" external cues in the environment (e.g., presence of a lethal weapon) or by internal psychological states (e.g., fear or anticipation of observing a lethal weapon), further complicating the investigation of how stress impacts police performance. Recent evidence shows that law enforcement personnel have significantly higher baseline levels of cortisol relative to the general population, and that tactical officers exposed to greater occupational threat have even higher levels of cortisol than frontline police officers (Planche et al., 2019), bearing greatly on the long-term health trajectories for individuals in high-risk occupations. Thus, individual and occupationally mediated differences in stress responses confound the determination of where any single police officer (or individual) lies on the stress-memory continuum (**Figure 2**), and what level of stress meets the threshold for maladaptive arousal. Objective measures of behavior and physiological stress such as HR, HRV, and salivary cortisol are crucial in evaluating the true influence of stress on individual performance.

BRIDGING THE GAP BETWEEN SCIENCE AND PRACTICE: EVIDENCE-BASED POLICE TRAINING

In recent years, there has been significant development and progress in the field of evidence-based policing, which uses empirical research to validate the effectiveness of various training approaches. The most studied training, and relevant for our discussion on complex motor learning, is use of force training. Most investigations of police behavior examine firearm use (i.e., shoot/no-shoot decisions), accuracy, and timing, but a use of force can range from physical (i.e., hands-on) tactics to any tools available to police officers including baton, OC spray, conducted electrical weapon, or firearm. In addition, we have proposed that situational awareness and decision-making are essential procedural motor skills for effective policing that are also influenced by occupationally relevant stress. The following section will review the current state of the art in evidence-based training that attempts to find a balance in the stress-memory continuum (**Figure 2**) and promote effective motor learning for police.

The Adaptive Role of Real-World Stress in Police Training

Through occupational experience, police officers can learn to adapt and overcome the negative influences of stress on perception and performance described above. A study comparing novice and expert police officers found improved shooting behavior and gaze control in the expert group under high-threat conditions (Vickers and Lewinski, 2012). Police officers who have better regulation of their stress responses have been shown to use the associated physiological cues in an adaptive way to promote performance (i.e., fewer shooting errors, de-escalating potentially violent encounters) (Akinola and Mendes, 2012; Haller et al., 2014). These findings suggest that increased exposure to, and familiarity with, occupationally relevant stress can offset its interfering effect on performance.

In a series of investigations on athletes and police officers, Oudejans and colleagues have established efficacy for performance training that integrates occupationally relevant stress. Beginning with basketball and darts players, Oudejans and Pijpers (2009, 2010) found that training with mild levels of anxiety improved post-training performance under stressful conditions compared to control groups that did not train with stress and who showed stress-induced deterioration of performance. Expanding on the police performance studies mentioned previously (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010; Nieuwenhuys et al., 2012a,b), Oudejans and colleagues examined the efficacy of training police officers in high-stress (with a live actor or canon shooting back simulated ammunition) and low-stress (officer shoots at static target or mannequin) conditions. Officers completed pre- and post-training tests on firearms use of force performance under high- and low-stress conditions. All officers showed increased HR, poorer shooting accuracy, greater mental effort, and greater attentional fixation on threat- (versus task-) relevant stimuli during high-stress pre-training evaluations. Officers trained under high-stress conditions no longer showed impaired shooting performance during stressful post-training evaluations (Oudejans, 2008) or at 4-month follow-up evaluations (Nieuwenhuys and Oudejans, 2011).

Similar to the principles of motor adaptation described earlier in the section on "Applied Motor Learning in Law Enforcement", the researchers suggest that training-induced performance gains are facilitated by recalibration of officers' selected motor plans (Nieuwenhuys and Oudejans, 2011). Even though officers still exhibited physiological stress responses post-training, their performance improved as a result of training under the same high-stress conditions in which they were expected to perform. Further, there is a relationship between stress and an officers' motor selection strategy, such that inhibiting a preferred motor plan (e.g., shooting with a grounded stance) due to situational constraints results in greater reported anxiety and reduced shooting accuracy, even if the preferred motor plan is slower and puts the officer at greater risk (Nieuwenhuys et al., 2017). Therefore, integrating stress into a repetitive training paradigm not only promotes police performance during subsequent high-stress conditions but also facilitates motor learning that can override preferred movement strategies that would put the officer at risk.

The Gold Standard for Complex Motor Learning for Police: Scenario-Based Training

Consistent with scientific principles of motor learning (section “Applied Motor Learning in Law Enforcement”), police trainers generally agree that basic skills training should begin with learning the fundamentals, or component “chunks”, in order to develop proficiency, comfort, and safety with a given technique (Pryor, 1999). Once motor skills are overlearned and deeply encoded in long-term “muscle memory,” training approaches must evolve in order to ensure the motor skill can be flexibly applied to a variety of stressful circumstances that necessitate a use of force. Surveys from experienced police trainers (Aldred, 2017) and a growing body of empirical research support the efficacy of scenario-based training, which simulates the stress and complexity of real-world situations to a greater extent than classroom lecture-based learning or static drills (Armstrong et al., 2014; Andersen et al., 2016a).

Scenario-based training is fully immersive, utilizing real and artificially constructed environments (e.g., schools, communities, and housing complexes), props, sounds, and lighting to create realistic environments that require various behavioral strategies. Professional actors or experienced police instructors are used to role-play various types of encounters ranging from violent offenders to domestic disputes and individuals in psychological crisis.

In accordance with Ericsson’s framework for deliberate practice (Ericsson and Lehmann, 1996; Ericsson, 1998, 2004), scenario-based training promotes expert motor learning among police by engaging the following principles:

1. Once police officers acquire proficiency through basic skill training, expertise is developed through exposure to increasingly complex and demanding situations.
2. By affording officers the opportunity to “feel” the physical sensations that accompany high-stress encounters, arousal-based mechanisms promote encoding of the learning experience and also allow officers to work through the stress response to achieve outcomes.
3. Trainees are afforded integrated practice of verbal, physical, and cognitive (i.e., decision-making, situational awareness) skills, building a repertoire of varied experience that increases the likelihood that skills will be generalized to other situations (Barney and Shea, 2007).
4. With constructive and immediate feedback from qualified instructors, multiple behavioral options can be explored for successfully resolving an encounter through discussion and mental simulation. This is especially beneficial to novices (i.e., new recruits) that can work through errors and dangerous encounters in a safe environment (see section “Reinforcing Motor Learning in the Brain” for anti-STDP mechanism for erasing unwanted information).
5. Deliberate practice through repeated attempts or trials reinforces the neural pathways of mental and physical skills (section “Reinforcing Motor Learning in the Brain”).
6. Training is administered at an appropriate level of difficulty to challenge the learner but not to ensure failure (i.e., no-win situations) or be too easy.

Very few studies have investigated the efficacy of scenario-based training on police performance or attitudes but show significant improvements after even a single day of training. Krameddine et al. (2013) administered a 1-day scenario-based mental health training program and found significant improvements in verbal de-escalation, communication, and empathy with the public up to 6 months post-training. With respect to procedural use of force training, Andersen and Gustafsberg (2016b) and Andersen et al. (2018) have shown immediate and long-term efficacy of a 4-day performance and resilience program (iPREP). Officers use real-time HRV biofeedback (HRV-BF) during immersive live-action scenarios to modulate their individual stress responses and promote recovery from threat by engaging adaptive peripheral nervous system dominance (Thayer and Sternberg, 2006; Lehrer and Gevirtz, 2014). Officers condition adaptive autonomic stress responses through repeated practice of various breathing techniques and mental simulation during various scenarios that increase in complexity and stress. Investigations of special forces and frontline officers have shown significant reductions in use of force shooting errors, improved situational awareness (Andersen and Gustafsberg, 2016b), and faster autonomic recovery to baseline following stressful training scenarios up to 18-month post-training (Andersen et al., 2018).

By integrating pure motor skill practice with realistic environments, stress, and various decision-making options and outcomes, scenario-based training ensures cognitive motor skills (i.e., situational awareness, decision-making, visualization, breathing techniques) are adequately encoded and reinforced in learning and memory systems.

Mental Skills Training

The “mental skills” engaged during iPREP, including visualization and stress-reducing breathing techniques, are physically conditioned (i.e., become implicit and are performed without conscious effort) using HRV-BF. Other police training interventions that incorporate mental skills have shown efficacy in improving use of force performance, reported and objective (HR) measures of stress, and negative mood during high-stakes scenarios (Arnetz et al., 2009). However, this training paradigm spanned 10 weeks, and post-training evaluations were conducted 12 months later. Therefore, it is unclear whether significant findings are due to the specific training intervention or 1 year of training and field experience.

Another investigation on the efficacy of two 75-min breathing, imagery, and attentional control training sessions found improved memory for details during a stressful OC training drill compared to controls. However, training did not improve autonomic stress responses, and the authors did not report post-training performance results (Page et al., 2016). While these findings suggest a modest added benefit of mental skills training to motor learning paradigms, direct comparison of different learning strategies have shown that combined physical and mental practice is not as effective in training procedural skills compared to 100% physical practice (Hird et al., 1991).

Live Versus Virtual Scenario-Based Training

Despite the efficacy of the training interventions by Oudejans and colleagues discussed in section "The Adaptive Role of Real-World Stress in Police Training," the test and training conditions were not truly scenario based, such that officers were instructed to shoot at targets (or individuals) that were directly in front of them, and no other suspect engagement (i.e., verbal communication, other physical tactics) or decision-making (i.e., deciding whether or not to shoot the target) was involved. It is also unclear what duration of training, experimentally induced practice effects, or occupational experience could result in performance improvements, as the low-stress training group performed equally well during the high-stress condition at 4-month follow-up (Nieuwenhuys and Oudejans, 2011). One investigation also found no post-training improvements in performance or gaze control, which could be due to the use of a video presentation for the stimuli instead of live actors (Nieuwenhuys et al., 2015).

There is increasing investment in virtual simulation technologies for occupational training among police agencies and training institutes. However, there has not been any empirical validation of simulators for police training, specifically in the use of force decision-making. One validation study found that virtual emergency medical training failed to induce the same level of cardiovascular stress as a live training scenario (Baker et al., 2017). Despite the appeal of using advanced technologies in an applied setting, video or virtual simulators lack the perceptual depth cues present in live environments that inform police decision-making and motor selection strategies. Further empirical validation of simulator systems relative to live scenario-based training is needed before police agencies make the considerable investment in implementing these methods for the use of force training.

Future Directions for Evidence-Based Police Training: Neurophysiological Mechanisms

While the studies reviewed so far have helped reveal the peripheral cardiovascular physiological mechanisms of police performance under stress, investigations are lacking on the impact of stress on central neurological mechanisms underlying police behavior. Stress has typically been operationalized with measures of HR, HRV, and cortisol, but neurological patterns measured by EEG scalp electrodes can also indicate increased anxiety or threat. Asymmetry in the extent of activation in left versus right frontal cortex is related to emotional and motivational processing (for review, see Harmon-Jones et al., 2010) and may predict which officers are more (or less) susceptible to stress-induced impairments in perception or performance. In a single pilot study, Johnson et al. (2014) investigated the differences in psychophysiological measures of HR, HRV, EEG, and lethal force decision-making (i.e., correct responses and errors) between civilians and military or police experts during high-stakes video scenarios. In addition to significantly higher pass rates, researchers found expertise-driven differences in HR and EEG measures but not HRV or alpha asymmetry. Further, these effects were greater for experts with more experience (10+ years versus intermediate experts with 6–10 years of experience). In spite of the study's limitations, this preliminary investigation is an important step in the right direction toward understanding the complex relationship between training/experience and different biological systems to high-stakes decision-making by police.

Other brain signals that can shed light on the neural correlates of police learning and behavior include the error-related negativity (ERN), which occurs within milliseconds following motor execution to monitor action and detect errors, as with reafferent feedback during motor learning (see section "Reinforcing Motor Learning in the Brain"). ERNs are enhanced among highly anxious individuals (Hajcak et al., 2003) and are sensitive to internal appraisals of threat (Weinberg et al., 2016). Enhanced ERNs were also observed following false positive identification of tools as weapons by military cadets primed by a threatening stimulus (Fleming et al., 2010), establishing a clear link between brain signals preceding or generated by the use of force decisions (both correct and incorrect) under stressful conditions.

A single pilot study on athletes compared the effects of HRV-BF training on cardiovascular and neurophysiological measures of arousal but not physical performance. For the HRV-BF group only, results show reductions in reported anxiety, increased HRV amplitude indicative of increased vagal tone and enhanced parasympathetic activity, as well as reduced frontal asymmetry and improved emotional control (Dziembowska et al., 2016). Future studies investigating the efficacy of HRV-BF training on police including iPREP can perform similar analyses on the bidirectional communication between central neurological and peripheral physiological systems and compare these biological markers to objective performance measures.

CLINICAL APPLICATIONS OF COMPLEX MOTOR LEARNING

The neurophysiological mechanisms underlying motor learning in a law enforcement context have been summarized above from the lens of cognitive neuroscience, with a call for more applied research that investigates police in occupationally relevant settings outside of a laboratory. Further insights on how motor learning is facilitated and stored in the brain are provided by examining clinical populations that experience breakdowns in these mechanisms, including people with Alzheimer's disease (AD), Parkinson's disease (PD), stroke, and traumatic brain injuries. This review will not go into detail on the prevalence of, and therapies for, psychological injuries and mental health disorders common among law enforcement (e.g., Carleton et al., 2018) but rather will consider the brain-based therapeutic benefits of complex motor learning.

Motor Learning Mechanisms Revealed by Disease-Related Impairments

Several clinical populations have demonstrated various deficits in how they chunk or segment continuous streams of movement. These deficits result in significant impairments to the "online" or real-time perception, and subsequent learning and memory, of motor information. Research on individuals with PD (Tremblay et al., 2010) and stroke patients (Boyd et al., 2009) show impaired concatenation of motor chunks, suggesting a crucial role for the basal ganglia in understanding and consolidating movement sequences into long-term memory (Yin and Knowlton, 2006). Other clinical populations, including patients with schizophrenia (Zalla et al., 2004) and frontal lobe lesions (Zalla et al., 2003), show deficits in segmentation ability such that the location of event borders vary from normative ones. Individuals with mild dementia and AD also show poor recognition and order memory of segmented action (Zacks et al., 2006), demonstrating a clear link between online attention, visuomotor, and memory functioning.

Visuomotor deficits have been revealed in clinical populations using simple tasks (e.g., moving a cursor on a screen with one's finger) presented on touchscreen tablets that can record reaction times and movement accuracy as proxy measurements of motor recalibration and adaptation (section "Reinforcing Motor Learning in the Brain," e.g., Tippett and Sergio, 2006). Not only is this methodology useful in determining disease-related impairments in visuomotor functioning (for review, see Joddrell and Astell, 2016), modified reaction time and adaptation tasks could also be used as screening and/or training tools for policing skills similar to their application in athletics as performance and injury evaluation tools (Ventura et al., 2016).

Therapeutic Benefits of Complex Motor Learning

Based on the neurophysiological mechanisms underlying complex motor learning described above, the following section will review the therapeutic application of complex motor learning for movement and memory disorders. There is demonstrated efficacy for improved attention and memory following relatively short (18 min) training with simple eye movements (Di Noto et al., 2013), including eye movement desensitization and reprocessing (EMDR) therapy. While EMDR has shown significant neurological and clinical improvements in post-traumatic stress disorder (PTSD) among police officers involved in on-duty shootings (Lansing et al., 2005), the following sections go beyond traditional forms of simple movement therapy (i.e., physical, pharmacological) to review how multisensory dance and music practice facilitate perception, understanding, and learning of complex sequences of movement.

Various forms of music and dance practice have been employed as alternative forms of therapy for a wide variety of disorders (for comprehensive review of therapies and specific outcomes, see Dhami et al., 2015). Especially during the last 25 years, music therapy has become internationally recognized as part of health care maintenance and rehabilitation, with systematic developments in training and research during this time (Ala-Ruona, 2007). In addition to improving primary disease symptoms and increased functional connectivity between motor planning (SMA) and control (cerebellum) regions of the brain, music and dance therapy have proven social and emotional benefits, including improved reports of mood, anxiety, and quality of life among individuals with AD-related dementia and PD (Heiberger et al., 2011; Westheimer et al., 2015; King et al., 2019). The holistic benefits of dance and music therapy for general well-being are significant, as an estimated 35% of individuals with PD also exhibit symptoms of depression (Reijnders et al., 2008). Further, the social and emotional benefits of dance and music therapy are suggested to drive high rates of adherence, which in turn contributes to the efficacy of these types of therapy for individuals suffering from impaired motor and memory functioning.

Seeing and Hearing Is Believing: Superadditive Mechanisms of Multisensory Inputs

By their nature, dance and music engage multimodal (i.e., sensory, motor, and memory) regions of the brain that individually may be affected by disease or injury. Regular participation in dance or music therapy capitalizes on the neurophysiological mechanisms underlying complex motor learning to recover functioning in one of two ways: by promoting neural activation in damaged multimodal brain regions and/or by forging novel and alternate neural pathways among multimodal networks. Similar to Hebbian principles described in section "Reinforcing Motor Learning in the Brain," individuals with AD show impaired STDP between regions of the MNN (**Figure 1**). reflecting impaired learning mechanisms (Di Lorenzo et al., 2018). Just as research in healthy individuals reveal how the brain retains new information, investigations on clinical populations can demonstrate how neurological processes manifest in functional (i.e., cognitive, motor) impairments.

Therapeutic efficacy of music and dance are also potentially driven by additive (or superadditive) activation of multisensory neurons that fire equal to (or greater) than the sum of two unisensory inputs (Stevenson et al., 2007; Werner and Noppeney, 2010). That is, concurrent presentation of visual and auditory stimuli will elicit greater activation from the same neurons than when either stimulus is presented on its own. Just as in fundamental motor learning, the neural representations of novel dance and music-producing movements are reinforced by reafferent feedback. However, music and dance movements are additively reinforced by external musical (i.e., auditory) stimuli together with reafferent feedback signals from multiple sensory inputs, including vision, audition, and proprioception (sense of body position and movement). When there is a failure to distinguish self-generated efference copy signals from external sensory stimuli, it can lead to perceived hallucinations as seen in schizophrenia (Pynn and DeSouza, 2013). Multisensory cues are also present in and relevant to police contexts, especially for situational awareness (see section "Situational Awareness") and should be integrated into procedural training to reinforce motor learning.

Entrainment of External and Internal Rhythms to Promote Learning and Recover Disease-Related Functioning

Music and dance typically involve regular rhythmic patterns, which are also present in various physiological functions including heart rate, respiration, and gait (i.e., walking). The activation of billions of neurons also produces oscillatory brain rhythms of various frequencies, much like the different frequencies of radio stations. Internally generated biological rhythms can be paired to, or cued by, external rhythms by a mechanism known as "entrainment" (for review, see Thaut, 2015). Driven by basic principles in physics, entrainment causes two asynchronous frequencies to coordinate themselves into a common or synchronous period. A stronger or faster frequency, such as that provided by an external stimulus (e.g., metronome, musical beat), will lock a weaker or slower frequency (e.g., neural activity) into a stable rhythmic period.

A growing body of evidence on dance therapy for people with PD has shown almost immediate (i.e., after a single session) and lasting improvements in disease-related impairments to gait, rigidity, balance, and tremor (Heiberger et al., 2011; Westheimer et al., 2015; Bearss et al., 2017). Improvements in motor functioning following dance therapy are suggested to be mediated by entrainment mechanisms (Thaut et al., 1996; McIntosh et al., 1997), whereby dominant external musical rhythms offset the slowing of brain rhythms observed in people with PD (Soikkeli et al., 1991; Moazami-Goudarzi et al., 2008). These findings bear significant implications for the application of dance and music therapy for police officers and other individuals with PTSD, which has shown a breakdown in cross-frequency communication between emotional and sensory-motor brain regions (Cohen et al., 2013). By repairing neurophysiological rhythms through training with external rhythmic stimuli, research shows that improvements in motor functioning can potentially translate to improvements in emotional processing as well, reducing the lasting negative impact of disease, injury, and trauma.

Together, these findings synthesize seminal research from basic and clinical neuroscience to illuminate how learning-induced neuroplasticity facilitates the recovery of motor and cognitive functioning for various clinical disorders. Identifying the neurophysiological mechanisms underlying effective movement therapies provides significant insights for the development of police training programs that can withstand the realities of occupationally relevant situations.

CHALLENGES TO IMPLEMENTING EVIDENCE-BASED POLICE PRACTICES

Given the wealth of multidisciplinary empirical evidence presented thus far on complex motor learning as relevant to policing, there remain several practical, organizational, and systemic challenges to implementing evidence-based approaches. We will briefly review some of these challenges before providing recommendations for best practices in police training.

How Much Training Is Needed? Establishing Universal Standards

Basic Recruit Training Versus Continued Education at the Agency Level

A problem that exists in the practical application of motor learning research is the specification of precisely how many repetitions or hours of training are required to develop adequate competency. Individual differences in physical, cognitive, and learning abilities further complicate identifying a universally prescribed training regimen. This problem is especially relevant for policy makers and educators in all industries, who are challenged to balance finite resources with maintaining occupational safety and performance standards that are often highly variable and poorly defined.

Police training begins with an introduction to the basic skills that an officer will require and use in their day-to-day practice, which is subsequently expanded upon and specialized at the local agency or precinct level. There is no universal occupational standard for the duration or content of basic (or extended) police training and varies across jurisdictions. For instance, the Justice Institute of British Columbia (JIBC) delivers basic recruit training for 12 police agencies in Western Canada post-hire. In addition to a minimum requirement of 2 years of post-secondary education, officers partake in a 38-week basic training program that includes a middle block of field within their employers' police agency. In contrast, all police officers in Finland complete a 3-year Bachelor of Police Services at the national Police University College (PUC), qualifying them for full-time employment at any local precinct in the country. Trainees complete approximately 40 weeks of mandatory in-field training to develop professional competencies during the 3-year period. Reviewing and contrasting current training programs lie beyond the scope of this review (see also section "Cultural Challenges and Access to Information" regarding access to this information), but the two basic recruit programs described above reflect relatively long training durations. Relative to other occupations that require high-stakes life-or-death decision-making (e.g., surgeons, emergency medical personnel) and several years of basic and specialized training, even the JIBC and PUC programs are significantly shorter. Given the complexity and inherent stress associated with police work, training should adequately prepare officers from all backgrounds to safely meet occupational demands.

Learning Theory and the "10,000 h" Principle

One of the earliest theories quantifying the progression of motor learning is Galton's (1869) *lifespan development theory*, which states that this ceiling in performance is bound by immutable biological genetic factors including physical (i.e., height, weight, body composition) and mental attributes (i.e., intelligence). More recently adapted by Fitts and Posner (1967), it is suggested that expert-level performance can be reached with approximately 50 h of training, after which no additional amount of training will further improve an individual's performance. However, these training paradigms evaluated simplistic physical skills. As such, 50 h of basic firearms training may result in expert performance of this skill but is likely not sufficient for more complex physical and mental skills (i.e., deciding how and when to use a firearm, or any other tactical option, during a variety of stressful encounters).

Yet another estimate of prescribed training time to achieve expert-level skill is based on Simon and Chase's (1973) investigations of elite chess players, whose successful performance at international competitive tournaments was not possible without at least a decade of practice. These findings were popularized to form the "10,000 h rule" (Gladwell, 2008), but Simon and Chase (1973) posited that expertise arises from repeated exposure to an increased variety of chess combinations and strategies. Each of these unique scenarios created stored memories for successful or failed experiences that experts could rely on to promote future success in similar situations. Similar to the principles of intuitive decision-making described earlier, scenario-based training exposes officers to multiple varied encounters that can inform the best course of action in similar future situations. Many more hours of training and occupational experience are needed to develop a repertoire of high-level skills (e.g., use of force decision-making, situational awareness) that can be flexibly and accurately applied to a variety of circumstances, relative to basic skill competency.

Tracking Motor Learning in the Brain Through Neuroplasticity

Neuroscientists have tried to observe incremental changes to brain structure and function following novel motor skill learning. Observable increases in structural gray matter (i.e., neural cell bodies and synaptic connections between them) are evident as early as 1 or 2 weeks of daily practice, and decaying 2–4 months once training has stopped (Driemeyer et al., 2008). However, functional neuroimaging research suggests learning-induced plasticity or reorganization of synaptic connections in the brain as early as the very first training session. Karni et al. (1995) identified a switch between initial "fast learning" and consolidated "slow learning" that corresponds with improvements in performance speed and accuracy and less variability across movement trials (Shmuelof et al., 2012). Further, M1 activity increased over several weeks of daily practice and was maintained for up to 5 months with no additional training (Karni et al., 1995). Cross et al. (2009) conducted a neuroimaging study comparing physical and observational training of brief dance sequences among non-experts. After only 5 days of training, they found common gains in activation of premotor and inferior parietal MNN regions (**Figure 1**) but better performance and significant M1 activation for physically versus visually trained dance sequences (Cross et al., 2009).

Lending empirical evidence to the principle of "use it or lose it," these findings show fast initial training gains that decay relatively quickly once training ends. Although they did not measure neurological indexes of motor learning, Andersen et al. (2018) investigated skill decay following a 4-day iPREP training program. Officers' gains in performance (reduction of lethal force errors) and autonomic stress regulation (decreased maximum HR and faster recovery to resting HR) were maintained up to 12-month post-training, returning to pre-training levels at 18-month follow-up. Together with the neuroscientific evidence presented here, these findings underscore the importance of continued practice and regular refresher training to maintain learning-induced changes to performance, brain structure, and function.

Organizational Challenges

Leveraging Finite Training Resources: Funding and Qualified Personnel

Before adopting evidence-based training approaches, individual police agencies must leverage finite available resources, including time away from regular duties, funding, and qualified personnel. Scenario-based training is especially resource-intensive and educationally challenging, despite demonstrated efficacy. Many unique and relevant scenarios need to be developed and executed with a high degree of realism to preserve the value of the teaching opportunity. However, evidence-based training may facilitate cost savings in the long run. In an evaluation commissioned by the United States Department of Education of 77 educational interventions that were not evidence-based, 91% were found to have weak or no positive effects (Coalition for Evidence-Based Policy, 2014). The United States military also implemented a $125 million dollar program (Comprehensive Soldier Fitness) to enhance resilience and performance before evaluating its efficacy, which was found to have no objective improvements and at worst may actually cause harm (McCord, 2003; Eidelson et al., 2011). Krameddine et al. (2013) performed a cost-benefit analysis of their scenario-based mental health training program and found that savings incurred from a significant reduction in time spent on mental health calls exceeded the cost of the study and training program. These outcomes are especially significant given a higher incidence of subsequent mental health calls, further underscoring the compelling nature of an evidence-based approach to police training.

In addition to training content and method of delivery, trainers' skills, abilities, and approach are very important from both educational (i.e., during training) and professional (i.e., during regular police work) perspectives (Murphy, 2014), yet no standards or definitions exist for proficient trainers. Novel pedagogical approaches in policing have been explored, including an emphasis on group discussion and active debate

(Birzer, 2003) and the development of "train the trainer" programs (Hammerness et al., 2005, 2007; Darling-Hammond and Bransford, 2007). Qualified trainers are often "those that do" and may not have formal pedagogical training to identify or address the unique learning needs of their trainees. To address this gap in occupational training, Finland's PUC has introduced a 6-week teaching course specifically designed for use of force trainers. In addition to subject knowledge, the course covers general pedagogy including recognizing and solving challenges of the training group. Other learning outcomes include independently organizing a training event and training key issues related to the selection and use of force in a pragmatic and fundamental manner. In addition to a lack of empirical data on police training outcomes, there is a scarcity of research or data on teaching effectiveness. This has led to the definition of training objectives and quality criteria according to available resources over practical consideration of the skills intended for training. Therefore, the systematic evaluation and development of police pedagogy is limited and vulnerable to approaches that are not evidence-based, compromising the learning opportunity for trainees.

Cultural Challenges and Access to Information

There are strong differences in opinion surrounding police training and practices more general among various stakeholders, including policy makers, police supervisors, trainers, management, officers, as well as the public. Due to the sensitive nature of training content (i.e., specific tactical plans and maneuvers that involve lethal force), information is often kept secret from the public to maintain safety. However, the confidential nature of police training practices can also foster a culture of unwillingness to share ideas among stakeholders and creates an additional barrier to collecting and comparing useful information to promote best practices. Updating existing police training models is also met with a great deal of controversy, despite mounting empirical evidence for the benefits of various training approaches including problem-based learning (Makin, 2016) and a societal need for changes to various policing practices. However, newer motor learning models currently used in military training have adopted a more holistic approach and consider factors like environment, cognitive skills, and kinematic movement options on various continuums (Schmidt et al., 2019). The primary goal of effective training for stressful and unpredictable situations is to protect both public and police and should not be compromised due to extraneous factors (i.e., resources, personal, or political motivations).

Similarly, academic research is often inaccessible to police practitioners unless findings are published in open-access format at a significant financial cost to the researchers. This "silo effect" of information stunts knowledge exchange between sectors and is a barrier to disseminating useful research evidence to practical end-users. Despite containing very relevant insights for policing, scientific articles laden with jargon and field-specific terminology are often not translated into a language that is accessible or understandable to an applied audience or the general public. However, there are peer-reviewed journals and publications available that seek to combine academic and applied perspectives in policing, including *Police Practice and Research*, *Policing and Society*, and *Policing: An International Journal*. Evidence-based reports are also published in industry-specific periodicals such as *The Police Chief* and *The Blue Line*. Indeed, the purpose of this Special Edition of *Frontiers* is to disseminate relevant and timely knowledge across domains for the purpose of improving current practices in policing, identifying areas of future research and development, and saving time and resources by understanding what has already been done.

RECOMMENDATIONS: BEST PRACTICES FOR EVIDENCE-BASED POLICE TRAINING

Common practice should not be confused with best practice or evidence-based practice. The following recommendations are based on the empirical and applied research evidence summarized in this review and are intended to promote training effectiveness as well as occupational safety.

Training

1. Officers need to be prepared for the perceptual and physiological impacts of stress that they will experience on the job (section "The Influence of Stress on Police Performance"). An important consideration for developers of police training programs is to identify an optimal level of stress that adaptively promotes learning without crossing the threshold for maladaptive stress that interferes with encoding and retrieval processes (**Figure 2**).
2. In addition to the benefits outlined in section "The Gold Standard for Complex Motor Learning for Police: Scenario-Based Training," scenario-based training facilitates motor learning by inducing realistic levels of occupational stress that helps override perceptual distortions and preferred movement strategies that could put the officer at risk. In addition, the physiological arousal elicited by scenario-based training can promote adherence to and active engagement with training, maximizing the learning opportunity afforded during limited training time with finite resources.
3. Police work is similar around the world; regardless of the laws and regulations specific to their jurisdictions, officers are uniquely tasked with addressing the needs of people in crisis. Without investigation, standardization, and validation of training strategies, police officers may be learning wrong or ineffective patterns, and encoding stimulus-response tendencies instead of effective critical thinking skills. On a larger scale, standardization of minimal training requirements should align practices across jurisdictions, as is currently done in Finland and under development in Canada (Canadian Association of Chiefs of Police, 2018).
4. Training delivery (i.e., duration, methods) needs to be appropriate to the skills intended to be trained. As

such, complex motor, verbal, and cognitive skills including situational awareness, decision-making, and de-escalation should be trained in live environments with trained actors or instructors that can dynamically respond to officers' behaviors. Further empirical validation of virtual simulator systems relative to live scenario-based training is needed before police agencies make the considerable investment in implementing these methods for the use of force training. However, virtual technology can be useful as complimentary training tools (i.e., in addition to contextually relevant training settings) as well as for psychophysical performance screening similar to its application in athletics (section "Live Versus Virtual Scenario-Based Training").

5. Action competence and an officer's self-confidence should be considered by trainers and curriculum developers when reimagining police training methods and approaches (section "Confidence and Action Competency").
6. Through more introspective pedagogical approaches, police trainers can use mistakes in both novice and expert officers' performance to recalibrate and reinforce correct intuitive motor and cognitive strategies when training situational awareness and use of force decision-making.
7. By repairing neurophysiological rhythms through training with external rhythmic stimuli, clinical research shows that improvements in motor functioning can potentially translate to improvements in emotional processing as well (section "Clinical Applications of Complex Motor Learning"), reducing the lasting negative impact of disease, injury, and trauma. Officers are encouraged to seek out extracurricular activities that incorporate social engagement and rhythmic and/or multisensory components such as music, dance, or athletics to promote physical and emotional health.

Knowledge Dissemination

8. To facilitate knowledge exchange between academic and applied professionals, and police practitioners around the world and across jurisdictions, new research should be published in open-access journals, and practitioners should attend relevant conferences and workshops wherever possible, and when resources permit. Becoming involved and engaged with research will not only help generate new knowledge but will provide police practitioners with an understanding of the scientific process, from generating a research question, to implementing an experimental study, and observing and communicating the results.
9. Police management should recognize and accept the importance of evidence-based policing and offer their trainers and officers opportunities to access and/or engage in applied research with partnerships at local academic institutions.
10. More importantly, a systematic cultural change within policing needs to occur in which stakeholders from multiple levels and sectors can meet and openly share knowledge and be willing to accept evidence in favor of opinions fuelled by political, financial, or personal motives.

CONCLUSIONS

An elite athlete such as a javelin thrower has one precise task to perform under a narrow range of controlled conditions. In police work, even a simple motor skill is never standardized or used in isolation. Officers have to constantly evaluate, consider, decide, and update what is appropriate or possible given the unfolding situation. As such, motor skills cannot be considered without all other aspects of police encounters, including occupationally relevant stress, situational awareness, and complex decision-making.

The current review is a synthesis of empirical and applied research on the fundamental principles of motor learning as relevant to police. Insights from the fields of applied policing, cognitive and computational neuroscience, and clinical and health psychology lend empirical evidence to the knowledge inherently possessed by police trainers, officers, and practitioners through their first-hand experience. Especially relevant to law enforcement, we consider the influence of occupationally relevant stress on the physiological and neurological mechanisms underlying police learning and performance. Training policies and protocols should be updated accordingly to reflect current knowledge and to promote motor learning and skill retention.

Bridging research across fields and industries also provides solutions to several systemic challenges to evidence-based policing, including a lack of universal training standards and knowledge exchange. Ultimately, we hope that this review will inspire practitioner engagement with applied research, and spark open and productive debate among various stakeholders on best practices surrounding training the complex motor skills required in policing.

AUTHOR CONTRIBUTIONS

PD and J-MH wrote the manuscript, conducted all background literature research to inform the contents, and approve the submitted version.

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Understanding Police Performance Under Stress: Insights From the Biopsychosocial Model of Challenge and Threat

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We examine when and how police officers may avoid costly errors under stress by leveraging theoretical and empirical work on the biopsychosocial (BPS) model of challenge and threat. According to the BPS model, in motivated performance contexts (e.g., test taking, athletics), the evaluation of situational and task demands in relation to one's perceived resources available to cope with those demands engenders distinct patterns of peripheral physiological responding. Individuals experience more challenge-like states in which blood circulates more efficiently in the periphery when they evaluate their coping resources as meeting or exceeding the task demands. Conversely, individuals experience more threat-like states in which blood circulates less efficiently in the periphery when they view the situation or task demands as exceeding their coping resources. Patterns of response consistent with challenge and threat states have been shown to predict important performance and decision-making outcomes in stressful contexts, and repeated experiences of threat-like patterns of physiological activity are thought to have detrimental effects on long-term cardiovascular health. To date, however, research has not used the biopsychosocial model to understand police decision-making under stress. Here, we review relevant empirical work from the perspective of the BPS model concerning how minority status and power can shape challenge and threat responding and contribute to decision-making under stress. We then detail a research agenda aimed at improving the translational value of research being conducted within the BPS model for understanding complex performance and decision-making in the real world, including among law enforcement personnel.

Keywords: challenge, threat, biopsychosocial, police, shootings

Police work is often stressful and requires execution of difficult tasks where outcomes are of high consequence. In this paper, we propose that many situations involving police decision-making or performance can be understood as motivated performance contexts: the situations are goal-relevant, involve instrumental cognitive processing, have uncertain outcomes, and require active rather than passive responding (Blascovich and Mendes, 2000). Motivated performance contexts have been studied extensively in the health and social psychology literature using the biopsychosocial (BPS) model of challenge and threat (Blascovich and Tomaka, 1996; Blascovich, 2008a), which articulates the psychological and physiological mechanisms by which stress can sometimes lead to more optimal performance and decision-making (associated with greater challenge orientation) and sometimes lead to poorer performance and decision-making (associated with greater threat orientation; for a review, see Hase et al., 2019). Consistent with this theorizing, existing empirical data on police officers shows that greater physiological arousal in stressful situations is sometimes associated with improvements in performance and decision-making (e.g., Verhage et al., 2018; Arble et al., 2019) and sometimes with decrements (e.g., Andersen and Gustafsberg, 2016). The BPS model may offer novel insights into the mechanisms by which police performance and decision-making can be optimized even in the face of unavoidable physiological arousal or stress.

This article briefly introduces the BPS model of challenge and threat and reviews recent empirical work that may shed light on the different ways that stress can influence police performance [broadly defined as the ability to handle critical incidents, involving situational awareness, verbal/non-verbal communication, self-control, or control of the public, (e.g., Brimmell et al., 2018; Arble et al., 2019)] and decision-making [defined as critical judgments to engage or not engage in a target behavior, (e.g., Correll et al., 2007a; Verhage et al., 2018)] across varying contexts, for both better and worse. We conclude by describing a research agenda to enhance the translational value of BPS research to better understand, and ultimately intervene, to improve, complex performance and decision-making behavior in the real world.

THE BIOPSYCHOSOCIAL MODEL OF CHALLENGE AND THREAT

According to the BPS model, challenge and threat represent motivational orientations involving the interplay of affective and cognitive processes that result from the evaluation of situational and task demands relative to one's available resources to cope with them (Blascovich and Mendes, 2000, 2010). More challenge-like states are experienced when a person evaluates his or her coping resources as meeting or exceeding the demands of the situation or task, while more threat-like states are experienced when a person evaluates the situation or task demands as exceeding his or her coping resources (Tomaka et al., 1993, 1997; Blascovich and Mendes, 2000, 2010). These appraisals (sometimes called evaluations) occur on a more subconscious and automatic level, are not under conscious control, and change dynamically over time as perceived demands or resources shift (see, Quigley et al., 2002; Seery, 2013). Originally, the factors contributing to the evaluation of task demands (e.g., perceptions of danger, uncertainty) were hypothesized as independent from those governing the evaluation of coping resources (e.g., dispositional factors, social support). However, more recent theorizing suggests that several factors are likely implicated in evaluations of both demands and resources (e.g., required effort, knowledge and skills, safety/danger; see Blascovich, 2008b). This is consistent with the idea that challenge and threat are not fixed and dichotomous, but rather malleable states that exist as opposing endpoints of a continuum (Seery, 2013; Jamieson et al., 2016).

The BPS model's focus on appraisals of demands and resources developed out of Lazarus' theory of cognitive appraisal (see Lazarus and Folkman, 1984; Folkman and Lazarus, 1985; Lazarus, 1991), which has been utilized in the policing literature to explore the role of cognitive appraisals in stress and performance among law enforcement personnel (e.g., Larsson et al., 1988; Harris et al., 2017). Lazarus introduced the terms "challenge" and "threat" as part of his theory, emphasizing that stress was not a unitary construct, but a system of responses that could be altered by changing one's perception of a stressor (Lazarus and Folkman, 1984; Folkman and Lazarus, 1985). In Lazarus' theory, "challenge" and "threat" reflect valenced appraisals that contributed to perceptions of a situation's self-relevance and the potential for a situation to confer gains or losses, respectively (for review, see Jamieson et al., 2016). In the BPS model, challenge and threat responses *only* occur in self-relevant contexts and are associated with evaluations of the relative balance of demands and coping resources (Blascovich and Mendes, 2000, 2010). Critically, in the BPS model, unlike in Lazarus' theory, the patterns of cognitive appraisals associated with challenge and threat are posited to engender reliably distinct patterns of physiological arousal (e.g., Blascovich and Tomaka, 1996; Blascovich and Mendes, 2000).

The basis for using physiological responses as indicators of challenge and threat in the BPS model is derived from the work of Dienstbier (1989) who theorized that quickly mobilizing energy resources during motivated performance, *via* the sympathetic-adrenomedullary axis, or SAM (as opposed to slowly *via* hypothalamic pituitary axis, or HPA), was a marker of "physiological toughness" because it was associated with favorable outcomes like increased performance, more emotional stability, and lower anxiety, leaving individuals more likely to appraise situations positively (for review see, Seery, 2011). Both challenge and threat states are theorized to involve activation of the SAM axis, and thus are associated with increases in indices of cardiovascular arousal (e.g., increased heart rate) and sympathetic nervous system control of the heart (i.e., ventricular contractility, measured as the inverse of pre-ejection period, the time between the electrical stimulus initiating ventricular contraction and opening of the aortic valve). Increases in ventricular contractility and heart rate are frequently interpreted as indicators of task engagement in motivated performance contexts (Seery, 2011, 2013). Experiencing a more challenge-like orientation is also associated with increased cardiac output (CO; volume of blood circulated per minute) accompanied by decreased systemic vascular resistance, typically measured as total peripheral resistance (TPR), the extent of overall constriction in the peripheral vasculature (Dienstbier, 1989; Blascovich and Mendes, 2000). In more challenge-like states, the heart beats harder and faster and moves blood more efficiently to the periphery, benefiting organ function and motor activity. Threat-like states involve activation of the SAM axis and the HPA, which inhibits decreases in vasoconstriction in the periphery. Thus, experiencing a more threat-like orientation is associated with no change or even increases in vascular resistance combined with more modest increases in cardiac output and ventricular contractility (i.e., blood flow is unable to reach and circulate in the peripheral vasculature as efficiently). While challenge-like patterns of physiological responding are interpreted as beneficial for the body, threat-like patterns of physiological responding are considered detrimental to energy mobilization (Tomaka et al., 1993, 1997). Moreover, the pattern of cardiovascular reactivity associated with threat-like states is theorized to have deleterious impacts on long-term cardiovascular health if experienced repeatedly over time (Mendes et al., 2007a,b; Blascovich, 2008a; Major et al., 2013).

RESEARCH USING THE BIOPSYCHOSOCIAL MODEL

Although the BPS model has yet to be directly explored in real-world police decision-making contexts, challenge and threat orientations have been shown to influence decision-making and performance in other stressful, high-stakes environments. For example, challenge orientation (physiological and psychological) has been associated with better performance in situations that unfold over longer durations of time such as surgery (Moore et al., 2014), cricket and baseball seasons (Blascovich et al., 2004; Turner et al., 2013, respectively), flight simulation (Vine et al., 2015), negotiations (O'Connor et al., 2010), and semester grades (e.g., Seery et al., 2010). However, greater challenge orientation also confers benefits in visual attention (e.g., Moore et al., 2012; Vine et al., 2016), motor performance (e.g., Moore et al., 2012, 2013, 2014, 2015), attentional control (e.g., Vine et al., 2013, 2015, 2016), and working memory (e.g., Kelsey et al., 1999; Elzinga and Roelofs, 2005; Feinberg and Aiello, 2010). As such, the BPS model may offer unique insight for improving police performance under stress both in situations that unfold over longer durations of time (e.g., assessing danger during a robbery; Arble et al., 2019) and in rapid decision-making contexts (e.g., lethal force decisions; Correll et al., 2007a).

Although a complete review of the BPS literature examining performance under stress is outside the scope of this article, we briefly highlight empirical findings in content areas that are particularly relevant to police decision-making and performance given the current sociopolitical context in the United States.

Stigmatization and Minority Status

Empirical studies with lay people have consistently demonstrated that, relative to White targets, participants are significantly quicker to shoot armed Black targets, significantly slower to "not shoot" unarmed Black targets, and have a lower shooting threshold for Black targets (i.e., tend to favor the "shoot" response) in computer-based shooting simulations (Correll et al., 2007a,b, 2011; Plant et al., 2011; Mekawi and Bresin, 2015). Laboratory research with real police officers on comparable tasks has demonstrated similar biases in reaction times for Black targets, though police officers generally demonstrate less bias in behavior and make fewer errors than lay individuals overall (see Correll et al., 2007a). Critically, research suggests these biases may be mitigated by a number of contextual and personal factors (for discussion, see Jetelina et al., 2017). For instance, police officers are less likely to demonstrate biases on shooting simulation tasks when they report having more positive interactions with Black people in their daily lives (Peruche and Plant, 2006) or report less overestimation of crime rates for minorities (Sadler et al., 2012), and studies with lay individuals have demonstrated reduced biases on tasks where counter-stereotypical targets (i.e., unarmed Black targets) are encountered more frequently (Correll et al., 2007b).

These findings on shooting simulation tasks are consistent with empirical work from the BPS model on challenge and threat responding during interactions with individuals from stigmatized groups. For example, Blascovich et al.'s (2001) "stigma-threat hypothesis," posited that effort exerted during interactions with individuals from stigmatized groups increases because non-stigmatized individuals monitor their behavior more carefully to appear unaffected and avoid accusations of prejudice (Blascovich et al., 2001; Derks et al., 2011). Even for individuals who do not hold blatant prejudices, interactions with individuals from stigmatized groups can evoke knowledge of negative stereotypes, resulting in increasing efforts to monitor behavior and suppress stereotype-consistent thoughts (Devine, 1989; Wyer et al., 2000). Indeed, researchers have consistently demonstrated that participants show patterns of cognitive appraisal and cardiovascular activity consistent with more threatened orientations during interactions with individuals from stigmatized groups (Blascovich et al., 2001; Mendes et al., 2002, 2007a). For instance, White participants performed worse on a joint word-finding task and were more likely to produce cardiovascular patterns associated with threat-like states (e.g., increased TPR) when interacting with Black confederates or confederates of low socioeconomic status compared to White confederates (Mendes et al., 2002).

However, researchers have found that increased interaction with stigmatized groups is positively related to challenge-like physiological responses during intergroup interactions (Blascovich et al., 2001). These findings parallel those from studies involving police officers (Peruche and Plant, 2006) and lay individuals (Correll et al., 2007a), where increased exposures to individuals from stigmatized groups, in safe contexts, reduced racial bias in shooting simulation tasks. This suggests that interventions targeted toward increasing positive social interactions with individuals from stigmatized or minority populations may help increase the likelihood of exhibiting more challenge-like orientations during intergroup interactions to the benefit of performance and decision-making.

Power

Research on the BPS model has examined the nuanced ways in which social status and power influence patterns of biopsychological activity. Specifically, individuals high in social status or power tend to experience more challenge-like states during social interactions with people of lower status (e.g., Scheepers and Ellemers, 2005; Scheepers, 2009; Scheepers et al., 2012). For example, participants prompted to recall incidents in their lives where they had a lot of power or who were randomly assigned to a high-power role (e.g., given more leverage in a negotiation task) exhibited more challenge-like appraisals and cardiovascular activity than participants randomly assigned to low-power comparison conditions (Scheepers et al., 2012). Consistently, Akinola and Mendes (2012) found that police officers who self-reported higher social status exhibited more approach-oriented or challenge-like patterns of physiological reactivity, including increased heart rate, cardiac output, and testosterone reactivity, during a simulated interaction with a disgruntled citizen.

Critically, research suggests that the relationship between power and biopsychological responding relies on the stability of the power hierarchy; those high in status show more threat-like responses when their status is perceived as unstable or illegitimate (Scheepers and Ellemers, 2005; Scheepers, 2009). These findings may offer insight into why tense situations can escalate quickly depending on social dynamics. Specifically, when police officers feel secure in their status as an authority figure and do not believe they are being undermined by a suspect or civilian, they may be more likely to engender challenge-like orientations to the benefit of decision-making and performance in that context. Moreover, research suggests that, when individuals' social identities are threatened, engaging in self-affirmation strategies engenders more challenge-like patterns of physiological reactivity (Derks et al., 2011). Thus, it may prove beneficial to develop interventions to help police officers maintain stable perceptions of their status (e.g., by engaging in self-affirmation strategies) even when interacting with suspects or other civilians who are questioning their legitimacy or status.

THE BIOPSYCHOSOCIAL MODEL AND POLICE DECISION-MAKING: A RESEARCH AGENDA

Although the BPS model has proven useful in examining performance under stress across a variety of motivated performance contexts (see Behnke and Kaczmarek, 2018; Hase et al., 2019), there remains a critical need for translational research investigating its utility in real-world situations, specifically in the context of police interactions and decision-making. A recent field study demonstrated the viability of using the BPS model to examine and predict biopsychological responding among first responders, including police officers, in an ecologically valid, high-stress situation: a multi-faceted drill simulating the response to a plane making an emergency landing with a fire and injured passengers onboard (Wormwood, 2019). Consistent with the BPS model, more challenge-like appraisals among first responders were associated with better self-assessed performance during the drill (**Figure 1**).

Data from this field study highlight several critical theoretical and methodological considerations for researchers interested in pursuing translational research examining the relevance of the BPS model in realistic decision-making and performance scenarios. First, the vast majority of research using the BPS model has focused on group comparisons between samples of individuals exhibiting more threatened versus more challenged appraisals, failing to examine challenge and threat responses at the level of the individual (though see Quigley et al., 2002). As a result, little is known about why, given identical circumstances, one individual may be more challenged while another is more threatened (for review, see Kilby et al., 2018). Note the presence of robust individual differences observed in the recent field study, even within a highly evocative, personally-relevant context (**Figure 1**; Wormwood, 2019). According to Dienstbier (1989), exposure to repeated intermittent stressors could result in a proneness to challenge-like responding under stress, a pattern of response linked to both increased emotional stability and immune system enhancement (Seery, 2013). This is consistent with a number of clinical and therapeutic approaches (e.g., cognitive behavior therapy, desensitization therapy, stress inoculation training) which posit that trainings involving repeated exposure to small stressors that the individual can cope with successfully may bolster more effective, challenge-like performance in the face of future, unknown stressors.

In addition, research using the BPS model has focused almost exclusively on static assessments of challenge and threat responding and has not examined how patterns of

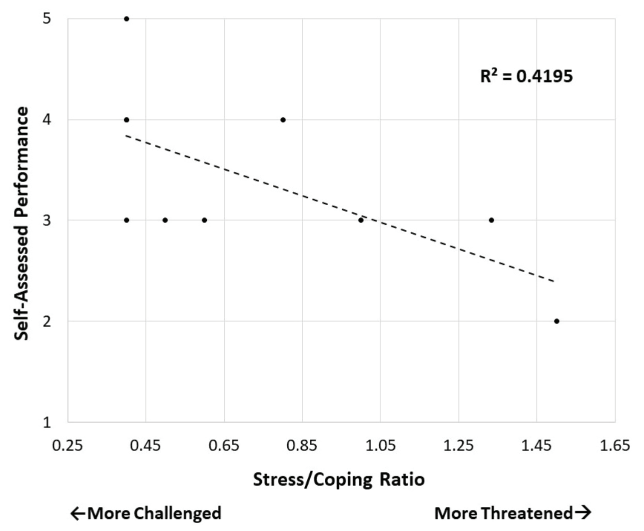

FIGURE 1 | Stress/coping ratios predict self-assessed performance (rated on a 5-point scale) during an emergency training drill. Ratio of self-reported stress to self-reported coping ability is shown on the *x*-axis, with higher numbers indicating more threat-like appraisals and lower numbers indicating more challenge-like appraisals. An estimate of R^2 is provided in figure, though should be interpreted with caution due to sample size.

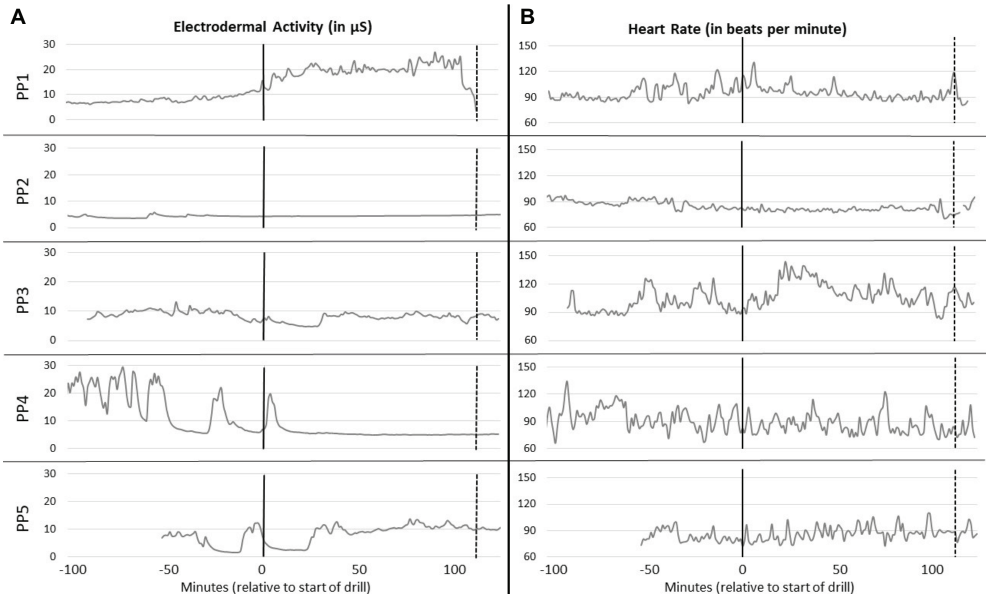

FIGURE 2 | Electrodermal activity and estimated heart rate for five individuals throughout emergency training drill. Time in minutes relative to the start of the drill is shown on the *x*-axis. The start of the drill is marked with a solid vertical line and the end of the drill is marked with a dashed vertical line on each graph. **(A)** shows electrodermal activity in microsiemens (µS) for the five participants (PP1, PP2, PP3, PP4, and PP5) throughout the study. **(B)** shows estimated heart rate (HR) in beats per minute for the same five participants throughout the study. Each row contains EDA and HR data for the same participant. For both physiological variables, an average value was taken for each 1 min of recording, and these averages are plotted here.

physiological activity or cognitive appraisals change dynamically over time as a stressful context unfolds. The recent field study revealed dynamic changes in physiological and SNS arousal over time throughout the training, and these patterns of change varied markedly across individuals (**Figure 2**; Wormwood, 2019). The focus on static assessment means important information about early detection and genesis of challenge-like and threat-like states in the face of stressors remain unknown. Information concerning the time course of psychobiological states might be useful for designing early intervention systems involving biofeedback or for identifying critical time points at which individual interventions might be most effective at mitigating threat-like physiological patterns as they unfold in real time.

Future translational work would also benefit from the inclusion of complementary methodological approaches used less frequently in research on the BPS model. For instance, audio-visual data recorded continuously during a motivated performance context would be invaluable for elucidating how and why challenge and threat orientations shift dynamically as a context unfolds. Qualitative interviews with participants could shed light on important individual differences related to the tendency to experience more challenge-like orientations under stress, or could suggest potential mechanisms for future exploration of factors contributing to appraisals of demands and/or resources. Considering the myriad contexts in which police officers must optimize performance and decision-making, future translational research would benefit from the inclusion of more diverse, real-world contexts (e.g., situations involving different combinations of cognitive, affective, social, and motoric features). Comparing diverse scenarios may offer insights on the psychological and physiological mechanisms by which challenge and threat orientations influence performance or decision-making across contexts.

CONCLUSION

The BPS model appears well-suited for studying the psychophysiology of police performance and decision-making because challenge- and threat-like states are relevant across a wide range of social evaluative and motivated performance domains (e.g., Behnke and Kaczmarek, 2018), are associated with consistent patterns of cognitive appraisal and cardiovascular reactivity (Blascovich, 2008a), and have been shown to predict important behavioral and decision-making outcomes in stressful contexts (see Hase et al., 2019). Moreover, while threat-like states have not been *directly* linked to health outcomes, prolonged physiological activation (particularly in the HPA) can result in profound negative health consequences (e.g., McEwen, 1998). Thus, research examining challenge and threat responding among police officers in the line of duty stands to improve early detection of individuals at risk for the negative health outcomes (e.g., cardiovascular disease) that are associated with careers in law enforcement (Hartley et al., 2011).

AUTHOR CONTRIBUTIONS

DK and JW drafted the manuscript. ES provided substantial edits and feedback on the manuscript.

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CONCEPTUAL ANALYSIS
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Applying the Theory of Constructed Emotion to Police Decision Making

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Law enforcement personnel commonly make decisions in stressful circumstances, where the costs associated with errors are high and sometimes fatal. In this paper, we apply a powerful theoretical approach, the theory of constructed emotion (TCE), to understand decision making under evocative circumstances. This theory posits that the primary purpose of a brain is to predictively regulate physiological resources to coordinate the body's motor activity and learning in the short term, and to meet the body's needs for growth, survival, and reproduction in the long term. This process of managing the brain and body's energy needs, called allostasis, is based on the premise that a brain *anticipates* bodily needs and attempts to meet those needs before they arise (e.g., vestibular activity that raises sympathetic nervous system activity *before* standing), because this is more efficient than responding to energetic needs after the fact. In this view, all mental events—cognition, emotion, perception, and action—are shaped by allostasis, and thus all decision making is embodied, predictive, and concerned with balancing energy needs. We also posit a key role for the autonomic nervous system (ANS) in regulating short-term energy expenditures, such that the ANS influences experience and behavior under stressful circumstances, including police decision making. In this paper, we first explain the core features of the TCE, and then offer insights for understanding police decision making in complex, real-world situations. In so doing, we describe how the TCE can be used to guide future studies of realistic decision making in occupations in which people commonly make decisions in evocative situations or under time pressure, such as in law enforcement.

Keywords: allostasis, predictive coding, autonomic nervous system, police decision making, theory of constructed emotion, law enforcement

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INTRODUCTION

Law enforcement personnel must commonly make high-stakes decisions in stressful circumstances where the costs associated with errors are high and sometimes fatal. The Justice Department found that in 15% of police shootings in Philadelphia over 8 years, the person who was shot was unarmed, but half of these unarmed individuals were perceived to have a weapon (Fachner and Carter, 2015). However, it would be a mistake to assume that decision making errors in stressful contexts are the result of any single feature of a complex situation. Rather, we theorize that decisions made by police officers in highly stressful, time-pressured circumstances are multiply determined by features of the decision making situation, including affectively driven perceptual effects, the current bodily state of the officer, and the officer's past history or prior experiences in similar contexts.

These high-stakes situations, termed "critical incidents," often involve witnessing, experiencing, or enacting violent behavior. Officers often describe having distorted perceptions, memory, and thinking both during and after such an incident (Alpert et al., 2012; Novy, 2012). The traumatic distress associated with these critical incidents also can lead to less effective coping and poorer decision making in similar future situations (Cox et al., 2018). Understanding and ultimately improving workplace decision making by personnel who must commonly act under such highly stressful circumstances is important, first and foremost, because their decisions affect the well-being of all those involved. Performance in stressful circumstances can also have important workplace performance and health consequences for law enforcement personnel long after a critical incident (Violanti and Paton, 1999; Franke et al., 2002; Arnetz et al., 2009; Gershon et al., 2009). These same concerns also arise for those in other high-stakes professions, such as military personnel (Johnson et al., 2005; Kavanagh, 2005; Bray et al., 2009; Smith et al., 2011; Rush et al., 2016), or corrections officers (Johnson et al., 2005; Ghaddar et al., 2008; Costello et al., 2015).

To understand and minimize errors in decision making in stressful, complex, real-world contexts, we need innovative experiments and field studies that leverage recent technological advances in ambulatory data collection, including measures of peripheral physiology, cognition, behavioral action, and context (e.g., Andersen and Gustafsberg, 2016; Andersen et al., 2016a,b, 2018). The increasing availability of wearable technologies that can support data collection in more ecologically valid stressful workplace scenarios provides a set of much-needed methodological tools for assessing the physiological changes, real-world behavior, and context of law enforcement officers when they are making mission-critical decisions in the line of duty.

This important translational empirical work must also be guided by current theory. Much of the prior work on decision making in high-stakes workplaces has borrowed from psychological theories derived from experimental evidence gathered in highly controlled, laboratory settings. Such theories often do not translate well to understanding more complex, multifactorial decision making situations, or to a decision-maker who is experiencing strong physiological and subjective arousal in a real-world scenario. In contrast, our recent theory, the theory of constructed emotion (TCE; Barrett, 2017a,b; Hutchinson and Barrett, 2019), can situate the features of multi-factorial, real-world decision making within a single theoretical framework. The TCE integrates evidence from neuroscience, physiology, evolutionary and developmental biology, computational modeling, and engineering to explain how humans construct mental representations (e.g., cognitions, emotions, perceptions, and actions). This framework generates testable hypotheses about how humans will behave and make decisions in real-world scenarios or highly realistic simulations and can guide future work aimed at understanding decision making in stressful occupational settings, like law enforcement. Using this theoretical framework to guide such work has strong potential to result in positive impacts on work performance, health outcomes, and potentially, even to enhance public trust in law enforcement (Jackson, 2015).

Here, we first explain the core features of the TCE, and then illustrate key insights arising from the TCE that are relevant for understanding police decision making in stressful, complex, real-world situations. In so doing, we describe how the TCE can be used to guide future studies of naturalistic decision making in law enforcement or other similar occupations in which people must commonly make decisions under time pressure in stressful or affectively evocative situations.

THE THEORY OF CONSTRUCTED EMOTION

Predictive Allostasis: Regulating Energy in the Service of Action and the Role of the Autonomic Nervous System

The theory of constructed emotion (TCE) posits that the primary purpose of an organism's brain is to coordinate (or regulate) all of the physiological resources required to meet the organism's imminent needs for action and learning in the short term, and for growth, survival, and reproduction in the long term (Barrett, 2017a,b; Hutchinson and Barrett, 2019). Extensive evidence from the neuroscientific and physiological literatures suggests that energy regulation is best optimized when the brain anticipates bodily needs (Sterling, 2004, 2012); it is more energetically efficient to prepare to meet anticipated needs than to wait and respond to needs after they arise (e.g., if your brain is going to stand you up, the vestibular system increases sympathetic nervous system activity before you stand, lest you faint, which would be energetically costly). This process of predictively managing energy needs is called *allostasis* (Sterling, 2004, 2012; Sterling and Laughlin, 2015). All activities of allostatic regulation—resource acquisition, allocation, and utilization—are posited to operate on a predictive basis to enhance metabolic efficiency. From an organism-level view, we theorize that all mental events—cognition, emotion, perception, and action—are predictive and subject to the constraints of allostasis. As a result, all decision making is embodied, predictive, and fundamentally dependent on how our brains anticipate energy needs.

For the brain to regulate the body, and for the body to maintain support for the brain's energy needs, there is bi-directional communication between the brain and the systems of the body (i.e., everything outside the brain). The brain sends control messages to organs in the periphery (referred to as efferent signals), and also receives messages from peripheral physiological systems [e.g., afferent signals from organs innervated by or influenced by the autonomic nervous system (ANS), the endocrine system (hormones), and the immune system], which indicate the current state of the body outside the brain (Cacioppo and Berntson, 2011). The ANS, the endocrine system and the immune system all play particularly critical roles in energy regulation because they are the systems that most quickly and directly marshal oxygen, glucose, and other necessary energetic mediators to tissues where they are needed (Bray, 1986). The ANS, which can change organ function on the order of milliseconds to seconds to support imminent action, is especially critical in supporting decision making and related behaviors under stressful circumstances and time pressure. Thus, the ANS is a critical short-term mediator of how the brain achieves allostasis and supports human decision making and action.

The Brain Creates an Internal Predictive Model to Achieve Allostasis

Recent neuroscientific evidence and computational modeling both converge on the idea that to maintain allostasis, a brain constructs an internal predictive model of the world, and this model includes its own body (Pezzulo et al., 2015; Sterling and Laughlin, 2015; Seth and Friston, 2016; Corcoran and Hohwy, 2017; Barrett, 2017a; Hutchinson and Barrett, 2019). From this perspective, sometimes termed predictive coding (Clark, 2013), Bayesian inference (Deneve, 2008), active inference (Friston, 2010), or predictive processing (Hutchinson and Barrett, 2019), the brain does not simply react to incoming sensory inputs from the world (or from the body); rather it anticipates these inputs by constructing a model of its body in the world. Mental events (i.e., cognitions, emotions, perceptions, and actions) arise from the dynamics of the brain's "predictions" about the assumed causes of sensory events. These predictions are constantly checked against incoming sensory input ("prediction error"). When prediction error is sufficiently large, the brain updates its internal model, which results in more accurate predictions for similar future situations. The brain aims to construct a model of itself and the body in the world so that fewer unexpected events are encountered in the world, minimizing adverse effects on the organism's short- and long-term allostasis.

Affect Is Central to the Brain's Internal Model

Thirty years of anatomical research (based on tract-tracing studies in primates and other mammals) (Barbas, 2015) indicates that cortical limbic regions are at the top of the brain's predictive hierarchy (Barrett and Simmons, 2015; Chanes and Barrett, 2016; Barrett, 2017a,b). These regions, which include portions of the cingulate cortex, ventral anterior insula, posterior orbitofrontal cortex, and entorhinal cortex, have the least laminar differentiation, meaning that cytoarchitecturally, they are agranular, with larger layers V and VI, no defined layer IV, and undifferentiated layers II and III (Barbas, 2015; Chanes and Barrett, 2016). These regions are hypothesized to issue, or send, predictions to more differentiated granular cortical areas, including primary motor and sensory cortices (Barbas and García-Cabezas, 2015; Barrett and Simmons, 2015; Finlay and Uchiyama, 2015; Chanes and Barrett, 2016), as seen in **Figure 1**. These same cortical limbic regions both support allostasis (Kleckner et al., 2017) and receive relayed sensory inputs from organs, joints, and skin in the periphery, which is called interoception (Vaitl, 1996; Cameron, 2001; Craig, 2002, 2003a,b, 2009, 2014; Berntson et al., 2018). Interoceptive visceral afferents from organs innervated by or influenced by the autonomic nervous system (ANS), the endocrine system (hormones), and the immune system carry relatively low-resolution information, and we hypothesize that these inputs are experienced as low-dimensional affective feelings (i.e., general feelings that vary in pleasantness/unpleasantness and activation/deactivation; Barrett and Bliss-Moreau, 2009; Barrett, 2017a; Hutchinson and Barrett, 2019). As such, interoceptive sensations from the periphery and their representation as affective feelings are at the core of the neural architecture which issues the brain's internal model (Craig, 2014; Chanes and Barrett, 2016; Barrett, 2017a,b; Hutchinson and Barrett, 2019). Your brain is always trying to maintain allostasis, and so it is always modeling the interoceptive state of the body. Therefore, affective feelings are a property of consciousness, and affect is at the core of all mental events that your brain constructs.

Accurate Predictions Require Variability Across Mental Instances

A critical feature enabling a brain to operate predictively is its ability to generalize or create higher level summaries from particulars. That means that the organism must constantly query its existing model about the current sensory array and what it is *most like* from its prior experience. Generalizations, also called abstractions, are constructed as an organism updates its internal model based on a wide range of highly variable instances over time. Predictions issued from limbic cortices to sensory and motor cortices are constructed from the organism's past experience with similar internal and external contexts. However, these contexts are never exactly the same twice. This means that the brain must quickly generalize from one situation to another even when they are somewhat different, creating *ad hoc* generalizations in the moment to categorize a given instance as more similar to one prior experience than to another. Predictions underlying particular instances of cognitions, emotions, perceptions, and actions will, therefore, be highly context-bound. Because predictions are context-bound, and the contexts in which humans find themselves can vary widely, we expect there to be substantial variability across *instances* of experience within a person, even when the instances are categorized and labeled as belonging to the same *category* of experience (e.g., anger). Instances labeled with the same category will have variable features—including affective features, physiological features, action or movement-related features, and brain features. For example, fear in the context of taking a rollercoaster ride has different features than fear in the context of hearing footsteps following you while walking in a dark alley. Both the common and the divergent features across each of the variable instances of a category are hypothesized to become part of the generalization (or abstraction) for that category as constructed by the individual as part of their internal model. The internal model will reflect that some subset of the features of one instance of the category will be similar across instances, but that the exact subset of features, including contextual features, will vary across different instances labeled as belonging to the same category.

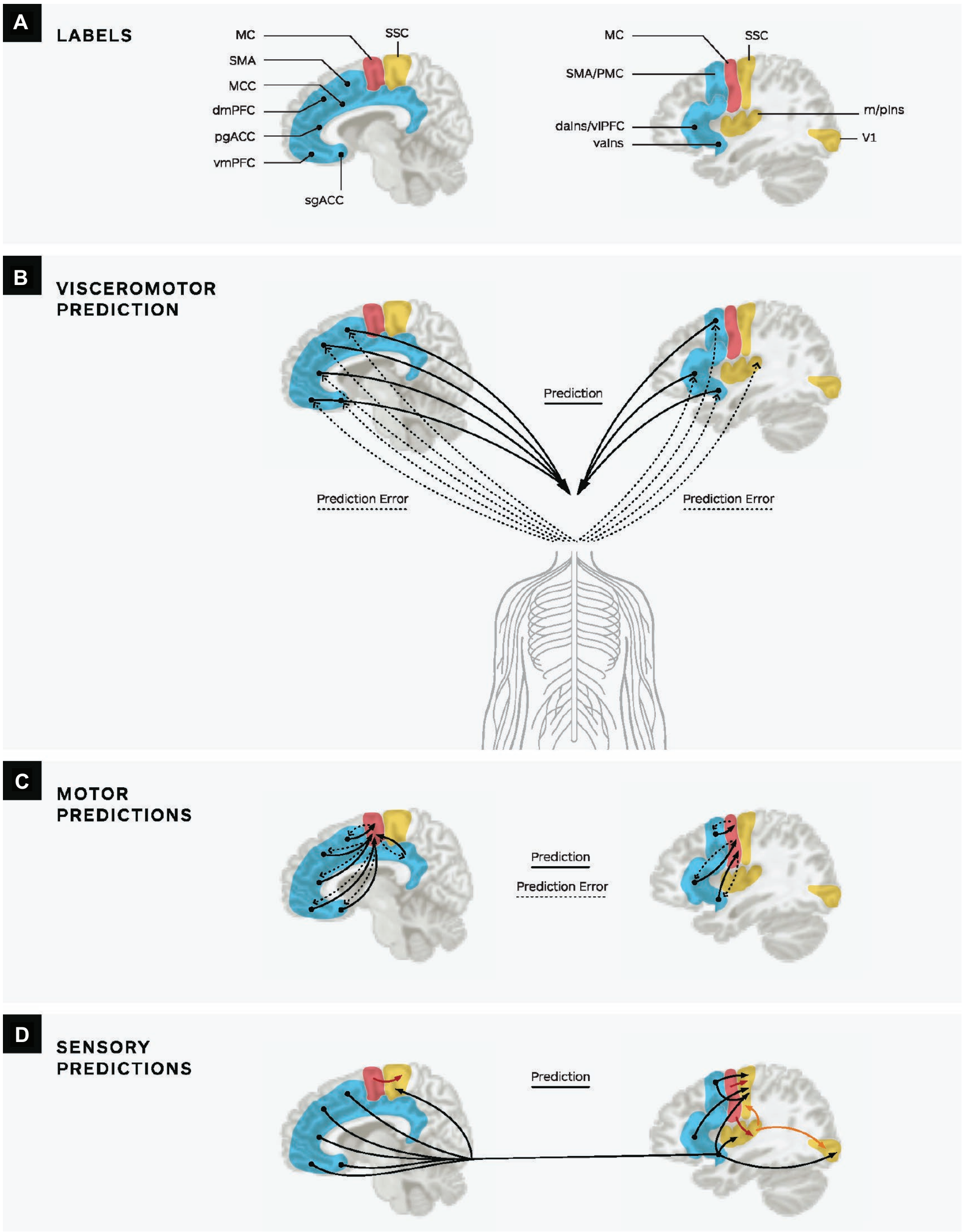

FIGURE 1 | Reproduced with permission of Oxford University Press from Barrett (2017b). A depiction of predictive coding in the human brain. **(A)** Key limbic and paralimbic cortices (in blue) provide cortical control of the body's internal milieu. Primary MC is depicted in red, and primary sensory regions are in yellow. For simplicity, only primary visual, interoceptive, and somatosensory cortices are shown; subcortical regions are not shown. **(B)** Limbic cortices initiate visceromotor predictions to the hypothalamus and brainstem nuclei (e.g., PAG, PBN, nucleus of the solitary tract) to regulate the autonomic, neuroendocrine, and immune systems (solid lines). The incoming sensory inputs from the internal milieu of the body are carried along the vagus nerve and small diameter C and Ad fibers to limbic regions (dotted lines). Comparisons between prediction signals and ascending sensory input result in prediction error that is available to update the brain's internal model. In this way, prediction errors are learning signals and therefore adjust subsequent predictions. **(C)** Efferent copies of visceromotor predictions are sent to MC as motor predictions (solid lines) and prediction errors are sent from MC to limbic cortices (dotted lines). **(D)** Sensory cortices receive sensory predictions from several sources. They receive efferent copies of visceromotor predictions (black lines) and efferent copies of motor predictions (red lines). Sensory cortices with less well-developed lamination (e.g., primary interoceptive cortex) also send sensory predictions to cortices with more well-developed granular architecture (e.g., in this figure, somatosensory and primary visual cortices, gold lines). For simplicity's sake, prediction errors are not depicted in panel D. sgACC, subgenual anterior cingulate cortex; vmPFC, ventromedial prefrontal cortex; pgACC, pregenual anterior cingulate cortex; dmPFC, dorsomedial prefrontal cortex; MCC, midcingulate cortex; vaIns, ventral anterior insula; daIns, dorsal anterior insula and includes ventrolateral prefrontal cortex; SMA, supplementary motor area; PMC, premotor cortex m/pIns, mid/posterior insula (primary interoceptive cortex); SSC, somatosensory cortex; V1, primary visual cortex; and MC, motor cortex (for relevant neuroanatomical references, see Kleckner et al., 2017).

The nature and extent of this immense variability has been a significant point of contention, for example, among theorists who disagree about whether the variability in features that is observed among instances labeled as belonging to the same emotion category is meaningful (as the TCE suggests) or simply random error (as other theories posit). Emotions traditionally were, and in some quarters still are, commonly assumed to have an essence, meaning that all instances of a given emotion are presumed to have a core similarity either at a neural or physiological level (Barrett, 2006, 2017a,b). However, empirical evidence reveals a striking lack of consistency in emotional experience and expression, such that specific emotional instances (e.g., an experience categorized as anger or fear in a specific time and place) are highly variable across contexts, even within a person. Empirically, there are no biological "fingerprints" for specific emotion categories in the brain (Lindquist et al., 2012; Clark-Polner et al., 2017), in the face (Barrett et al., 2019), in the body (Siegel et al., 2018a), or in experience (Lindquist et al., 2013). That is, an emotion does not have unique and consistent physical features across individuals, or even within the same individual across instances. Thus, quite distinct experiences can be categorized (or labeled) as belonging to the same emotion category but still vary considerably in their features (e.g., whether anger is associated with a heart rate increase or decrease, or whether it is associated with a scowl on the face or not). Likewise, very similar affective experiences can be categorized and labeled as belonging to different emotion categories across instances (Lindquist et al., 2013). For example, it can be difficult to tell if you are feeling fear or excitement in advance of an important event (e.g., a marriage, the birth of a child, a major sporting event of your favorite team). According to the TCE, and consistent with decades of empirical evidence, variability within and across instances of different emotion categories (including distress) is the norm, and this variability is functionally important and relevant for allostasis, because allostatic needs will vary across situations that have different energetic consequences even for instances labeled as the same emotional or affective experience.

NOVEL IMPLICATIONS FROM THE THEORY OF CONSTRUCTED EMOTION FOR DECISION MAKING IN LAW ENFORCEMENT

In this section, we use law enforcement examples to demonstrate how the TCE offers a unique perspective from which to examine decision making under stress among law enforcement personnel. The TCE offers several key insights that may shed new light on energetic, brain, and/or bodily processes that underlie decision making under stressful circumstances or that could be leveraged to design interventions to improve decision making in such contexts. We provide examples of (1) how allostasis and affective feelings predictively shape perception and action; (2) the central role of interoception and related peripheral physiological arousal in cognition, emotion, perception, and action; and (3) the role of individual differences and variability in cognition, emotion, perception, action, and thereby, decision making in law enforcement settings.

The Role of Affective Feelings in Predictively Shaping Perception and Action

Between 2007 and 2014, 49% of "officer-involved shootings" in Philadelphia in which the victim was unarmed were attributed to "threat perception failures," meaning a non-threatening object or movement led the officer to perceive the subject as being armed (Fachner and Carter, 2015). Despite having roughly the same population of White and Black citizens, 80% of the suspects in officer-involved shootings in Philadelphia during this time period were Black, with the US Justice Department reporting that Black suspects were most likely to be the subject of a threat perception failure (Fachner and Carter, 2015). This is consistent with other findings showing that individuals from racial minority groups experience more force in encounters with police (Fryer, 2016), are treated less respectfully during traffic stops (Voigt et al., 2017), are more likely to be shot at, even when unarmed (Brown and Langan, 2001; Ross, 2015), and that further, these effects remain even when suspect behavior is controlled for (Scott et al., 2017). This is also consistent with other empirical work demonstrating that social categories like race have a pronounced impact on threat perception (Payne, 2001; Correll et al., 2002, 2007; Eberhardt et al., 2004; Payne et al., 2005), and that affective feelings are integral to how we perceive and respond to others across a range of social categories (Cuddy and Fiske, 2002; DeSteno et al., 2004; Russell and Fiske, 2008). The racial and cultural stereotypes thought to underlie these biases in threat perception are imbued with affective features, and some data suggest that more general beliefs concerning the likelihood of encountering interpersonal threats may partially explain race-based shooter biases, even in the absence of racial or cultural stereotypes (Miller et al., 2012).

The TCE, at its heart, posits that brains use predictive processing in the service of optimizing energy regulation. The agranular limbic brain areas involved in implementing allostasis and the experience of affect are both central to energy regulation, and anatomically speaking, reside at the top of the brain's predictive hierarchy. As a result, affect and affective predictions critically shape perception and behavior (see, e.g., Chanes et al., 2018). In previous research, we have proposed that you "perceive what you feel," a phenomenon we have termed "affective realism" (Anderson et al., 2011, 2012; Barrett and Wormwood, 2015; Wormwood et al., 2018; Siegel et al., 2018b). This means that affective experience critically shapes what we *expect to* and *actually do* see, hear, and smell. In this way, affect infuses all perception and action, including decision making in the time-pressured, stressful situations encountered by police officers.

We have demonstrated that both experimental affective inductions and naturally occurring evocative situations evoking intense affect can significantly shape perceptions of social and threat-related information (Baumann and DeSteno, 2010; Wormwood et al., 2016, 2017, 2019; Siegel et al., 2018b). For example, individuals induced to experience an instance of anger were more likely to exhibit biased perceptual decision making in a gun detection task, such that they were more likely to make misidentification errors "seeing" unarmed individuals as armed than vice versa (Baumann and DeSteno, 2010). Critically, this biased perception was causally explained by anger's influence on predictions: angry participants expected to encounter more armed suspects, and controlling for these expectancies mitigated the impact of anger on threat perception. In another experiment, participants in Boston tested about 1 month after the Boston Marathon bombings completed a threat perception task where they attempted to shoot armed targets and avoid shooting unarmed targets (Wormwood et al., 2016). Prior to the threat perception task, participants viewed images taken from news coverage of the bombings that were either accompanied by threat-related headlines (e.g., "Not Since 9/11") or more affectively positive headlines focused on the community's resilience following the attack (e.g., "Boston Strong"). Participants made more errors shooting unarmed targets if they had viewed the negatively framed terror attack images than if they viewed the positively framed images. Critically, we showed that the observed increase in shooting of unarmed targets was caused by decreased perceptual sensitivity (i.e., a reduced ability to distinguish targets holding a gun from those who were not), and perceptual sensitivity was also impacted by how strongly the participant reported having been affected by the bombings when they occurred.

Taken together, theoretical and empirical work suggest that feeling significantly distressed or threatened can predictively contribute to perceiving the world as more stressful or threatening in a very literal sense. This work also suggests that an officer's experience of danger or threat can be "affectively real" even when the situation is non-threatening in other ways (i.e., there is no weapon). Affective realism also has implications for how bystanders think about misperceptions in police decision making: when feeling threatened or affectively aroused, officers could "see" a gun in the hand of a suspect or perceive a suspect as behaving aggressively whereas someone who is not feeling threatened or not affectively aroused would not. This is not a *post hoc* justification for errant behavior, but the perception of danger can be objectively incorrect even while being "affectively real." This perspective strongly implies that police officer trainings should (1) help police officers learn to be more attentive to their bodily feelings, (2) help officers recognize when their perceptions could be shaped by their predictions, and (3) help them learn to consider alternative interpretations before a situation becomes a critical incident or a critical incident becomes even more dire.

Interoception Predictively Shapes Cognition, Emotion, Perception, and Action

Consider a police officer nearing the end of a busy, stressful 12-h patrol shift. The officer steps back into their cruiser after drinking two cups of coffee when a dispatch call comes in about a nearby prowler. Driving over to investigate, the officer's heart is racing, palms sweating, stomach clenching, and face flushing. Minutes later, in the same neighborhood, the officer encounters a teenage loiterer on the phone, who, when seeing the officer, scowls and turns away. The officer loudly instructs the teenager to end the call, turn around, and answer some questions. From the perspective of the TCE, the officer's internal sensations of greater peripheral physiological arousal predictively shape their experience and actions in this situation, and do so regardless of whether the officer is consciously aware of these sensations. If the officer is not consciously aware of these changes—in this case a quickly beating heart, sweating, clenched stomach, and facial flush—this physiological arousal may instead be incorporated into the officer's internal model of the current situation as threatening (i.e., the heightened bodily arousal shapes affective predictions concerning the presence or likelihood of threats that would necessitate the current bodily arousal, directing perception and action accordingly). In fact, those sensations are internal to the officer and very likely created by other features of the context: the two cups of coffee just consumed, the recently received call to be on the lookout for a prowler, and the rest of the officer's day having been busy and stressful. The officer who is unaware of the possible range of sources for these feelings is very likely to construe the situation with the loitering teenager as tense, the teenager as surly, and as a result, the officer might act harshly. The TCE highlights the importance of making police officers aware of the ways in which internal sensations, which can arise from many different sources, can color our experience and our actions. Indeed, several of the newest officer training protocols specifically make officers more aware of their physiological arousal by enabling them to measure and track it over time using wearable devices, and then training officers to use strategies to reduce this arousal (Arnetz et al., 2009, 2013; Andersen and Gustafsberg, 2016; Andersen et al., 2018).

The peripheral physiological systems that are responsible for feeling aroused or activated, most notably the cardiovascular, respiratory, and gastrointestinal systems, are the very same systems that support attainment and movement of energetic resources (such as oxygen and glucose) around the body to where they are needed to enact allostasis. Indeed, we meet most of our most basic short- and long-term allostatic needs by moving the body—this includes respiration, consumption (of water and nutrients), communication, copulation, and ambulation and associated changes in posture. Thus, allostasis requires action planning, which itself requires very context-specific assessments of predicted metabolic needs and environmental affordances that must be tightly coupled with changes in peripheral physiological activity which prepare for and enable these upcoming actions. The idea that the cardiovascular system operated predominantly in the service of action was earlier posited by Paul Obrist and colleagues, as the concept of "cardio-somatic coupling" such that cardiac activity changed in advance of expected action (Obrist et al., 1969, 1970). From this perspective, we propose that future research aimed at improving police decision making under stressful situations would benefit from robust measurement of physiological changes during both training scenarios as well as real-world law enforcement situations. Tracking these measures may help officers learn to attend to the myriad possible sources of physiological activation and feelings of arousal so that they can consider alternative explanations for the felt arousal. Police training that incorporates peripheral physiological measures and can demonstrate these effects for officers may help make very real the importance of such bodily changes in a law enforcement context.

Future research is needed to examine how allostasis and interoception together create mental experiences, especially in dynamically changing real-world contexts. Although technologies enabling the collection of affective, physiological, or contextual information could be useful as training feedback, there are obstacles to deploying self-monitoring technologies in the field. For one, despite the increasing prominence of body camera surveillance and calls within the profession to implement biometric monitoring of police officers (Bedford, 2019), there is still reticence among first-responders to continuous monitoring of their physiology, perhaps because such initiatives are still nascent and not in common use. Others are unconvinced that the benefits of such sociotechnical tools outweigh potential accompanying downsides which could negatively impact decision making and performance—for example, inadvertently inducing anxiety or panic in officers or distracting from the processing or awareness of critical exteroceptive sensory information. Still, some researchers have been able to build collaborative partnerships with police officers to test the use of techniques like portable heart rate variability biofeedback to reduce lethal force errors (see, e.g., Andersen et al., 2018).

Another key feature of these bodily sensations that is highlighted by the TCE framework (and noted above) is that the sensory signals from the organs, joints, and skin of the body (interoceptive signals; Craig, 2002, 2003a,b, 2009) have lower fidelity (low signal-to-noise ratio) than those coming from the exteroceptive senses (Barrett and Simmons, 2015; Chanes and Barrett, 2016; Khalsa et al., 2018; Hutchinson and Barrett, 2019). We propose that the low fidelity of interoceptive signals is a key reason why it can be difficult to pinpoint the source or meaning of low-dimensional affective feelings, which are proposed to be the experiential sequelae of interoceptive signals. These diffuse interoceptive signals provide a source of prediction error to the brain, which can alter the brain's internal predictive model, and in turn generate new predictions.

Interoceptive signaling from the heart *via* the baroreceptors has been shown to be one interoceptive signal influencing behavior and action. Interoceptive information from the heart arrives in phases because the pressure-sensitive baroreceptors fire at systole, when the heart is ejecting blood into the aorta, and are less active during diastole. This phenomenon provides a unique opportunity for exploring state-related changes in affectively mediated prediction because researchers can synchronize the presentation of exteroceptive stimuli with systole or diastole to vary the interoceptive context concurrent with a constant exteroceptive stimulus. Time-locked presentation of stimuli with cardiac interoceptive information can enhance or inhibit aspects of perception, memory, and action. For example, baroreceptor stimulation reliably decreases pain ratings (Dworkin et al., 1994). Likewise, Garfinkel et al. (2013) have shown that memory for target words presented at high speeds suffered from interference when presented during systole compared to those presented during diastole, whereas detection, learning, and even exposure therapy for fearful stimuli are enhanced by presentation of stimuli at systole (Garfinkel et al., 2014; Pfeifer et al., 2017; Watson et al., 2019). This paradigm has been adapted to show that race-driven misidentifications of threat during a weapons identification task and a first-person shooter task were significantly increased by presentation during systole (Azevedo et al., 2017). These findings demonstrate the importance of developing methodologies to investigate the influence of particular interoceptive contexts on perception and action.

Critically, there are striking individual differences in sensitivity for detecting internal sensations from the body (i.e., Jones, 1994; Knapp et al., 1997; Barrett et al., 2004), or interoceptive sensitivity. Further, interoceptive sensitivity can be altered using either pharmacological methods (Khalsa et al., 2009; Hassanpour et al., 2018) or environmental stimulation (Feinstein et al., 2018). Thus, individual differences in interoceptive sensitivity could critically underlie differences across people in affective experience and behavior under stressful circumstances. Previous work also shows that interoceptive sensitivity moderates the relationship between peripheral physiological activity and self-reported experience (Barrett et al., 2004; Pollatos et al., 2007; Garfinkel et al., 2014; Pfeifer et al., 2017), such that physiology and experience or behavior are more tightly coupled in those with higher interoceptive sensitivity. In a related study, Dunn and colleagues (Dunn et al., 2010) found that participants' ability to track their heartbeats was positively correlated with the strength of the association between anticipatory bodily signals (electrodermal activity and heart rate) and decision making in an intuitive reasoning task. (However, the tracking task used in the Dunn et al. study does not permit a strictly interoceptive interpretation of the findings; for a discussion of the limitations of the heartbeat tracking task, see Ring et al., 2015; Desmedt et al., 2018). Further, higher interoceptive sensitivity does not necessarily mean that one is more interoceptively aware of or more likely to notice one's bodily states (Chentsova-Dutton and Dzokoto, 2014; Garfinkel et al., 2015, 2016; Critchley and Garfinkel, 2017). Thus, individual differences in this psychological facet of interoception may not reflect individual differences in the strength or patterning of afferent neural signaling coming from the periphery (Critchley and Garfinkel, 2017).

One implication of these findings is that police officers may also benefit from trainings that promote greater awareness of their interoceptive signals. For example, prior empirical work showed that mindfulness interventions may foster long-term increases in an individual's ability to attend to interoceptive sensations (Farb et al., 2013), and similar interventions have been shown to improve cognitive performance in a sustained attention Go/No Go task in a high-stress military cohort (Jha et al., 2017). Recent exploratory work with law enforcement personnel suggests that officers would be willing to undertake similar evidence-based training that focused on the effects of distress and trauma (Andersen et al., 2015). These findings suggest that new interventions could target interoceptive sensitivity training for police officers. Finally, we note that augmenting interoceptive awareness may not always be useful, and in some moments or contexts, higher interoceptive awareness could distract from other more pressing incoming sensory information. Thus, one needs to take this issue into account when designing an interoceptive intervention.

The Role of Individual Differences and Variability in Cognition, Emotion, Perception, and Action

To execute physical feats in stressful situations, professionals in fields such as car racing, civil aviation, medicine, and law enforcement now commonly train using realistic, and sometimes stressful, situations. Although classroom preparation can help professionals to understand work goals, interpret training feedback, and learn some tasks, no one can learn to drive a race car, do surgery, land a plane, or become a police officer just by reading or talking about it. It takes experience to detect and assess goal-relevant signals in perceptually complex environments, to know which strategy to deploy to mitigate the chances of catastrophic failure, and to successfully complete physically demanding tasks under highly time-pressured or stressful circumstances.

The TCE specifically addresses how context-specific work-oriented predictions can drive experience and behavior. In the case of police officer training, the TCE emphasizes the importance of recognizing that each instance or experience of "distress" can be quite different from every other one, and that sensations from the body also can vary considerably depending on the affective or performative (action-oriented) context of the situation. Because officers will experience a wide range of stressful situations in the field, including critical incidents, the TCE suggests that trainings must also occur across a range of diverse and highly realistic scenarios, which we propose would hasten the process of gaining needed experience and reduce the chances of real-world errors. Consistent with this perspective, a study by Arnetz et al. (2009) using realistic training scenarios provided evidence of better performance, less negative mood, less cardiovascular reactivity, and less distress in those who received real-world, in-the-moment training (termed resilience training by these authors), than in those who did not take this training (Arnetz et al., 2009). Such training also can enable an officer to focus attention on important features of the external environment and, at the same time, reduce physiological arousal that could lead to poor decisions.

Engaging in more realistic and variable training scenarios also should better prepare police officers to recognize, and potentially overcome, affective realism effects in the case of biased perceptions of threat under stressful conditions in the field. To be maximally effective, these trainings must reliably induce affective experiences with similar potency to those they may experience on the job, which can be assessed using ambulatory technology. Because prior research has demonstrated that affective feelings can shape not only actions in a threat perception task (Wormwood et al., 2016), but perceptions of social others as well (Cuddy and Fiske, 2002; DeSteno et al., 2004; Russell and Fiske, 2008), we recommend that these training situations also involve learning to consider potential alternative interpretations of others' affective states and intended actions, especially in highly evocative contexts. Officers can also be trained to consider alternative interpretations of their own affective states, which in some theoretical perspectives would be called emotion regulation, but in the TCE is simply part of the process of creating another emotional experience (see Gross and Feldman Barrett, 2011 for further discussion).

These training scenarios should also utilize other people, including other officers, to increase the realism, unpredictability, and variability in the behaviors observed in the scenarios. Inclusion of team members within the same training scenarios also can enhance cohesion especially among team members who have little prior experience with one another. Organizational science has consistently documented that building social cohesion is critical to effective teamwork (e.g., NTSB, 1994), particularly at a new worksite, or when the composition of the team is changed (Huckman and Pisano, 2006; Groysberg et al., 2008). These findings are also consistent with proposals of the TCE that unfamiliarity with or lack of predictability in the behavior of social others may lead to errors in prediction (Theriault et al., 2019), which we suggest could be corrected through ecologically valid, team-based training.

CONCLUSION

According to Barrett (2017a,b), a person's *affective niche* comprises whatever "objects and events will impact [their] body budget, changing [their] affect" (Barrett, 2017a, p. 73). Our affective niche is shaped by the state of our bodies and our expectations about our bodies. These expectations are informed by our past experiences and our culture, which includes our prior work experiences. The affective niche of police officers and other first responders are rich and complex, involving civilians and suspects, superiors and colleagues, and a wide variety of stressful and potentially traumatic situations or events. Police officers also have to consider how their performance will be evaluated by the public, governmental groups that set policy, oversight bodies, and the media. Despite the relatively large and rich affective niche of police officers, there are strong professional pressures to avoid attending to or conceptualizing sensations as feelings or emotions, or what one survival guide for officers called the "biological rollercoaster" of policing (Gilmartin, 2002). Drodge and Murphy (2002) noted: "[i]t is ironic that police personnel are socialized to curb their own emotions, and there are strong cultural norms aimed at controlling this, whereas on the other hand, they are trained to be vigilant about other people's emotional displays, particularly criminal suspects" (Drodge and Murphy, 2002, p. 426). This report and others also describe how these norms can have long-term negative mental and physical effects on police officers and their families (Pogrebin and Poole, 1991; Galatzer-Levy et al., 2013). Some of the physical effects could arise as sequelae of the repeated autonomic nervous system and endocrine system activation that occurs over a work career characterized by frequent, stressful situations (Planche et al., 2019).

Police officers also are at increased risk for more distal possible health consequences (e.g., cardiovascular disease, links between PTSD & cardiovascular health risk, metabolic syndrome, obesity) than those in less stressful occupations (Violanti et al., 2006a,b). Many of these chronic health conditions are characterized by allostatic dysregulation and are exacerbated by police work schedules that disrupt circadian rhythms (Vila et al., 2000; Vila, 2006; Violanti et al., 2009). Critical incident exposure specifically has been found to be associated with increased occurrence of nightmares and poor global sleep quality (Neylan et al., 2002). Additionally, poor sleep in police officers mediated the relationship between traumatic stress symptoms and health functioning (Mohr et al., 2003). Finally, even though police suicides tend to be under-reported (Violanti et al., 1996), police officers are significantly more likely than the general public to die of suicide (Violanti et al., 1998), with more police officers dying of suicide in the past 3 years than in the line of duty (Lohr, 2019). In short, police officers bear major chronic health burdens that we propose are due in part to allostatic dysregulation that could be mitigated by training that focuses more on attending to, and learning to reduce, the physiological arousal that commonly occurs in the law enforcement workplace.

The TCE offers a unique perspective from which to examine the affective niche of police officers, along with other first responders, military personnel, and corrections officers, all of whom have similarly stressful occupations. Importantly, our framework suggests there are important neurobiological and energetic mechanisms that support decision making among personnel who must make high-stakes decisions under extremely stressful conditions on a regular basis. The TCE also points to novel future interventions aimed at improving decision making and cognitive performance in stressful situations. Understanding that human brains use predictive processing to enact allostasis and create cognition, emotion (including affective feelings), perception, and action will not only lead to better models of individual behavior across contexts, but to better training regimens and other occupational interventions to reduce negative health outcomes for police officers. Applying findings from contemporary affective science to policing could improve the accuracy of police decision making in stressful contexts and increase the mental and physical resilience of law enforcement officers.

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All authors contributed to manuscript drafting and revision, and read and approved the submitted version.

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MINI REVIEW
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Basic Processes in Dynamic Decision Making: How Experimental Findings About Risk, Uncertainty, and Emotion Can Contribute to Police Decision Making

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In this paper, we review basic findings from experimental studies in judgment and decision making that could contribute to designing policies and trainings to enhance police decision making. Traditional judgment and decision-making research has focused on simple choices between hypothetical gambles, which has been criticized for its lack of generalizability to real world contexts. Over the past 15 years, researchers have focused on understanding the dynamic processes in decision making. This recent focus has allowed for the possibility of more generalizable applications of basic decision science to social issues. We review recent work in three dynamic decision-making topics: dynamic accumulation of evidence in the decision to shoot or not shoot, how previous decisions influence current choices, and how the cognitive and neurological processing of fear influences decisions and decision errors. We conclude this review with a summary of how basic experimental research can apply in policing and training.

Keywords: police decision making, decisions from experience, dynamic decision making, fear conditioning, first person shooter

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INTRODUCTION

Police decision making is dynamic. Decisions unfold over time with information (often incomplete) becoming known at different rates. The same type of decision may be made multiple times, allowing for a police officer to base a future decision on past outcomes. And decisions are made in uncertain and often changing environments. While the early pioneers of judgment and decision-making (JDM) research highlighted the importance of uncertainty and changing dynamics in decision making (i.e., Simon, 1955; Edwards, 1961), this focus was largely ignored for many years in favor of studying simple one-time decisions which could easily be represented in controlled experiments using choices between monetary gambles such as choose between a sure gain of $5 or a 50/50 chance of getting $11 or nothing (i.e., Lichtenstein and Slovic, 1971; Kahneman and Tversky, 1979). One reaction to this focus on simple decision contexts was the field of *naturalistic decision making* (NDM) which focuses on describing and understanding how people make decisions in real contexts with real world constraints (Lipshitz et al., 2001). NDM typically focuses on highly specialized experts in high stake decision circumstances, such as firefighters, military personnel, and police. This extremely successful tradition of research has grown largely from the work of Klein (1989, 1993, 1997) and is often seen in contrast to traditional JDM research programs (more concerned with the experimental control of laboratory studies) and has had more relevance to topics such as police decision making than traditional JDM research (e.g., Klein et al., 2014). In this article, we review recent experimental work in JDM that has brought dynamic decision making back into focus and discuss some of the experimental findings from this work that could contribute to improving police decision making. We begin by reviewing recent research on the decision to shoot or not shoot which analyzes the decision to shoot or not as a dynamic accumulation of evidence over time. We then review recent research on repeated experiential decisions and how they differ from one-time decisions typically studied in the lab. Finally, we review the neurocognitive mechanisms of fear in decision making. The primary goal of this article is to review recent experimental JDM research that has more fidelity with applied settings relevant to police decision making. A secondary goal of this article is to prompt future research incorporating findings from dynamic decision making to applied settings in a police context.

DYNAMIC ACCUMULATION OF EVIDENCE IN THE DECISION TO SHOOT OR NOT SHOOT

The experimental paradigm most closely analogous to a consequential decision made by police officers is likely the decision to shoot or not shoot. Shooting decisions have been researched extensively in a simulated video game task (Correll et al., 2002, 2006). In this task, participants are presented with a series of background and target images (e.g., **Figure 1**). Each image contains a target holding various objects. In the task, participants are usually instructed to decide – as quickly as possible – whether the target is holding a gun. If a gun is identified, the participant is instructed to shoot as quickly as possible by pressing a button on the computer. In the context of police shooting decisions, the target may vary in sex, race, and appearance.

A large body of research has relied on this paradigm to examine factors (situational, individual, and contextual) of both weapon identification and shoot (vs. do not shoot) decisions. A majority of the early research focused on the shooting decision as a function of the decision maker and target's race. Correll et al. (2002), for example, found that White participants made more correct decisions to shoot an armed target who was African American, than when the target was White. Participants were also more likely to correctly decide to "not shoot" an unarmed target who was White. Correll et al. (2007) found that police officers were on average more accurate than community participants in their shooting decisions, whereas community members made more errors by setting a lower decision threshold for shooting a Black target. Decisions to shoot, however, were influenced by a number of other factors such as the mode of the presentation (video vs. picture, Cox et al., 2014), training (Correll et al., 2007), and contextual cues (neighborhood safety) (Kahn and Davies, 2017).

Cognitive factors also play a role in the accuracy of shooting decisions. For example, decision makers under high working memory load were more likely to shoot an unarmed target and more likely to make errors (e.g., shooting an unarmed target) (Kleider and Parrott, 2009; Kleider et al., 2010). Relatedly, physical fatigue – as operationalized by sleep – also had a negative effect on shooting accuracy (Ma et al., 2012). Although a large body of work on police shooting decisions has focused on the difference between Black vs. White targets, some scholars have begun examining the role of gender, SES, and other racial and ethnic backgrounds (e.g., Latino, Asian, Muslim: Fleming et al., 2010; Plant et al., 2011; Sadler et al., 2012; Moore-Berg et al., 2017).

Arguably, the classic police shooting task, which relied on statistical analysis of correct and incorrect decisions, has overlooked important temporal dynamics of the decision-making process (Pleskac et al., 2018). Pleskac and colleagues noted that the typical approach assumes that "all the information used to make a decision is extracted from the scene in a single sample" (p. 1302). Under a dynamic model of decision making called the drift diffusion model (DDM), the decision to shoot (or not shoot) can be modeled as a dynamic process where the police officer accumulates momentary evidence over a short period of time and makes a rapid decision (Ratcliff and Rouder, 2000; Klauer and Voss, 2008). The DDM describes how decisions unfold over time as a function of accumulated evidence, and it can be used to predict both choice and response time. Based on the DDM, decision makers extract information from the decision context, which is accumulated as evidence for or against the decision to shoot.

FIGURE 1 | Example stimuli of the first-person shooter task (http://psych.colorado.edu/~jclab/FPST.html).

By integrating the dynamic drift diffusion model to the classic first-person shooting task, Pleskac et al. (2018) found that the race of the target did not affect the prior bias of decision makers to shoot Black targets. However, when examining the specific decision processes under the dynamic drift diffusion model, the authors found a quicker rate of evidence accumulation when faced with a Black target. In other words, participants gathered evidence toward their decision quicker when the target was Black. Moreover, the authors found that some participants were more conservative in their decision, such that they set higher evidence thresholds when faced with a Black target. In other words, participants required more information before making a decision to shoot a Black target. Extending this work, Johnson et al. (2018) also found that untrained civilians gathered evidence quicker when faced with a Black target. This bias, however, was not observed in trained officers. The authors also found that providing decision makers with prior information – similar to police dispatch calls – eliminated racial bias at both the process and behavioral level.

The novel application of the dynamic drift diffusion model on the classic police shooting task affords future research to more finely examine how race, experience, and training combine to affect the decision-making process. Specifically, this research suggests that the various components of the decision process may be compensatory in producing the final decision. For example, a slower accumulation process and a low decision threshold may produce similar final decisions than a quick accumulation process but a more stringent decision threshold. Moreover, the presence of a decision bias may be attributed to different psychological processes (e.g., initial bias, rate of evidence accumulation, decision threshold). Taken together, under the dynamic drift diffusion model, it is possible to observe similar decision outcomes between different decision processes.

DECISIONS FROM EXPERIENCE

Traditional research in the field of human judgment and decision making relied on experimental paradigms where participants would make a choice between two options, usually monetary gambles where the outcomes and associated probabilities were presented (e.g., Kahneman and Tversky, 1979; Kahneman et al., 1982). For example:

Which of the following would you prefer?

A: a 0.8 chance to get $4 and 0.2 chance to get $0.

B: get $3 for sure.

This work was very influential and led to codified "knowledge" about how people react to the prospect of risks. One of the main findings from this line of work is that people overweigh or overreact to the potential of rare but serious outcomes. More recently, researchers have realized that these one-time choices with full information (referred to henceforth as decisions from description: DFD) do not accurately model how most of our decisions (and police decisions) are made. More typically, we face choices that we have made previously and will make again and we rarely have full knowledge of the exact risks associated with different possible outcomes. Likewise, typical police decisions such as whether to pull someone over are not analogous to the DFD example above. To address this, researches created new experimental paradigms where people make repeated decisions and learn about the likelihood or risks of different outcomes primarily through their experience (decisions from experience: DFE; Hertwig et al., 2004). For example, instead of choosing between options A and B above with their full description, participants would make repeated choices between two unmarked buttons, each time they chose one option they would receive $3 and when they choose the other button they would receive $4 80% of the time and $0 otherwise. Results from these new paradigms have found that choice behavior is quite different and sometimes in the opposite direction when made repeatedly with experience when compared to one-time choices with full information. These systematic and robust differences between decision behavior from experience and from description have been labeled *the description-experience gap* (Hertwig et al., 2004; Hertwig and Erev, 2009). This gap makes explicit the differences in decision behavior when outcome relevant information is acquired through experiencing sequential outcomes from choice options as opposed to from a descriptive summary of the choice options.

In context, underweighting rare events through experience could explain anomalies such as low levels of flood insurance in areas where flood insurance is advised (if not mandated). When someone decides to purchase flood insurance, he/she is protecting himself/herself from the possible devastating consequences of a flood. How much this rare possibility motivates decision makers depends on how they evaluate the risk. If they were making a one-time hypothetical choice with full information of the actual likelihood of a flood along with the potential costs, they would likely fall in line with traditional findings from DFD and react strongly to the risk of floods. If however, they had lived in the same location for a long time without experiencing a flood (or even experiencing a flood but very rarely), they would react less strongly to the same objective risks. Key to this example is a key finding by Larraharge and Gonzalez (replicated over several conditions by Erev et al., 2017) that when making repeated decisions while you are presented with descriptions of risk leads to behavior early in an experiment akin to DFD (i.e., overweighting of rare events), but after only a few rounds of feedback these descriptions are largely ignored and behavior is identical to typical DFE choices (underweighting of rare events). One important caveat to the DFE finding that rare events are underweighted was found by Harman and Gonzalez (2015). Their research which combined behavioral choice data and computational cognitive modeling found that reactions to rare negative outcomes change depending on the recency of a negative rare outcome but more importantly by how often a person has experienced a positive outcome in the same circumstance. In other words, a person's likelihood of renewing flood insurance will vary depending on when the last flood was and more so, how long they have owned their house (with long time residence being more likely to cancel flood insurance).

As critical decisions made by police are typically faced repeatedly, we believe insights from DFE may be more informative than typical DFD research. Most notably, reactions to rare negative events are different and more complex than the traditional finding from DFD that people overweigh or overreact to rare consequential outcomes. Several DFE studies have demonstrated that people act as if they underweigh the probability of rare events compared to defined probability when making decisions based on repeated experienced outcomes (Hertwig et al., 2004). For example, when choosing between a safe option and a risky option with a high or low outcome, participants prefer the risky option when the high outcome is likely, but they prefer the safe option when the high outcome has a probability of around 0.2 or less. This pattern is reversed when the same options are presented with full written descriptions (Erev et al., 2010). The *description-experience gap* has been found to be a robust phenomenon (Barron and Erev, 2003; Hertwig et al., 2004; Gonzalez and Dutt, 2011) with the reversal in reactions to rare outcomes being the most consequential finding.

In terms of police decision making and use of force in particular, we believe that JDM's recent focus on dynamic experiential decision making is an important step in bringing laboratory research closer to real world applications for police decision making and training. In terms of the focus of this special issue, we think of the use of lethal force as a reaction to a rare consequential event. A vast majority of encounters made by police officers result in a non-violent outcome on both sides. On very rare occasions, police find themselves in situations that may warrant the use of force while situations which warrant the use of lethal force are even more rare. Error rates in the use of lethal force then would represent the overweighting or overreaction to the actual risks in the environment. The results from Harman and Gonzalez (2015), that the overreaction to rare events is dynamic and depends on the frequency of non-consequential outcomes experienced, would predict that seasoned officers with years of experiencing encounters resolved without the use of force would be less likely to overreact to low likelihood risks than newer officers. This hypothesis however may only capture part of risk perceptions when making repeated decisions. As will be outlined in the next section, our perceptions of risks may not be influenced solely by actual outcomes experienced in the past, but also by the outcomes of others (through social communication or media coverage), imagined outcomes, expectations, or simulated outcomes (i.e., training). All of these taken together could easily create a decision context where the rare outcome that warrants the use of lethal force is perceived as not that rare at all. Therefore, simply educating officers of actual base rate risks would be ineffective. Rather, repeated experiences of positive outcomes – either imagined or in training, may be an effective way to moderate the weighting of rare events, thus reducing error rates. Thus, the literature would recommend creating more positive outcomes in training scenarios, rather than a central focus on lethal force outcomes.

NEUROCOGNITIVE INFLUENCE OF FEAR ON DECISION MAKING

Police as a group have significantly more exposure to traumatic events, such as being assaulted, viewing assault, or viewing a dead body, than those in the general population (Haugen et al., 2012; Federal Bureau of Investigation, 2017; Morgan and Kena, 2018), which appears associated with psychological distress and worry (Leino et al., 2011). They also appear to be more likely to experience post-traumatic stress disorder than the general population (Kessler and Chiu, 2005; Maia et al., 2007; Klimley et al., 2018) and may be at greater risk for death by homicide and suicide compared to the general population (Violanti, 2010). How might either having such experiences or even simply learning about them affect one's emotional state and subsequently one's decision making?

One likely important factor in police decisions involves the impact of emotions on decision making, particularly fear. For example, a state of fear has been associated with increased processing of aversive information (Robinson et al., 2011). On the other hand, a state of fear has also been found to improve response inhibition. Specifically, participants made fewer commission errors on no-go trials of a go/no-go task while under threat of shock versus safe (Robinson et al., 2013). One avenue for potentially bettering our understanding of how emotions affect decision making for police officers is to first consider the basic science of fear (or threat) conditioning.

One of the most common ways of studying fear (or the anticipation of threat) is fear conditioning *via* classical conditioning. In classical fear conditioning, a neutral stimulus such as an auditory tone or a visual object (i.e., the conditioned stimulus with reinforcement, CS+) is paired with an inherently aversive stimulus such as a mild shock or the sound of nails on slate (i.e., the unconditioned stimulus, US). Successful classical fear conditioning has occurred if the CS+ elicits a measurable conditioned response (CR), such a skin conductance response (SCR), similar to, though often of lesser magnitude than, the unconditioned response (UR) elicited by the US alone. Often, classical fear conditioning involves having participants differentiate the CS+ from a second neutral stimulus that is never paired with the US (i.e., the conditioned stimulus without reinforcement, CS−). In cases of differential fear conditioning, one will observe a significantly greater CR for the CS+ compared to the CS−. Based on recent meta-analytic evidence of brain imaging data (Fullana et al., 2016), a greater response to the CS+ versus the CS− is found in several brain areas, most notably bilateral anterior insula (aIn) and bilateral dorsal anterior cingulate cortex (dACC).

Relevant to the current topic, humans can acquire fear conditioning in two additional scenarios, neither of which involves the actual experience of the US. The first is vicarious fear conditioning (which has also been observed in non-human primates) in which participants develop a fear CR by observing another person undergo a classical fear conditioning experiment. In such cases, participant who never experienced the CS+ paired with the US nevertheless evinces a CR when viewing the CS+ versus CS−, such as a differential SCR (Olsson and Phelps, 2004) and differential activation of the aIn and dACC (Olsson et al., 2007). The second method by which humans can acquire fear associations is *via* instructed fear learning. In such experiments, participants are first told explicitly that one of the conditioned stimuli will be paired with the US and the other will never be paired with the US. Later, participants are shown both the CS+ and the CS−, though neither is ever physically paired with the US. As with both classical and vicarious fear conditioning, instructed fear conditioning has been observed as both a greater SCR and more activation in the aIn and dACC when viewing the CS+ compared to the CS− (Olsson and Phelps, 2004; Mechias et al., 2010). Taken together, to the extent that a fear response can affect one's decision making at any one moment, not only are the fear-related experiences one has had important, but of potential concern are the fear-related experience has one seen or heard about.

Finally, when considering the potential role of fear in police decision making, one should also consider what might broadly be called context-dependent fear conditioning. This includes fear conditioning to environmental cues *per se* or the role of environmental cues as "occasion setters" (i.e., when a certain context qualifies the significance of a given CS) (Maren et al., 2013) and non-reinforced stimuli with semantic or conceptual connections to the CS+. Regarding the former, physical environments that are paired with the US elicit greater SCRs and activation of the aIn than environments never paired with shock (Alvarez et al., 2008; Marschner et al., 2008). Other research has found that environmental information modifies participants' response to conditioned stimuli. When the environmental context predicts that a cue will be paired with the US, then participants have a larger CR, compared to when the environmental context predicts that the cue is not associated with receiving the US, though in both conditions, participants receive the same number of USs (Indovina et al., 2011). In the case of decisions to shoot, one recent study found that participants were more likely to make decisions to shoot in perceived threatening neighborhood compared to a perceived safe neighborhood (Kahn and Davies, 2017). Other contextual factors that appear to impact fear conditioning include semantic similarity and conceptual connections. For example, participants who are fear conditioned to a specific word display generalized fear conditioning (i.e., conditioning to a non-reinforced CS) to an orthographically distinct yet semantically related word (Boyle et al., 2016; Grégoire and Greening, 2019a). Additionally, conceptual factors such as category membership can lead to generalized fear conditioning. For example, pairing 50% of animal pictures in a set with shock produced a generalized CR to the other animal pictures in the set that were never paired with shock (Dunsmoor et al., 2012).

It is possible that police experience legitimate states of fear, while nevertheless overestimating the relative risk present in any one situation. Such fear can be acquired from experience, observation, or word-of-mouth, and can potentially affect decision making. On the other hand, however, civilians may underestimate the degree of legitimately fear-producing experiences that police draw upon, implicitly or explicitly, during any given situations. This may be because civilians have relatively few fear-related instances to draw upon when imagining how they would have reacted in a given situation. Regarding police, one potentially beneficial strategy might be to intervene in the attenuation of fear associations and the calibration of fear reactions to contextual factors.

One of the common treatments used in disorders associated with fear, such as PTSD, is imaginal exposure therapy (Holmes and Mathews, 2010), which has also been used for police officers (Haugen et al., 2012). To date, there is little experimental evidence detailing the most important factors and mechanisms by which imagery can be used to attenuate fear-conditioned associations, though this has recently begun to change. For example, either repeatedly imagining or viewing the CS+ without the US produced a similar degree of fear extinction (Reddan et al., 2018). Another way to attenuate fear is *via* reconsolidation. In fear reconsolidation, a memory probe of the CS+ is presented followed by a brief (10 min to 1 h) waiting period, followed by extinction trials. This procedure may produce more durable fear attenuation such that the fear-conditioned response is less likely to spontaneously recover (Schiller et al., 2010; Agren et al., 2012). Recent research has found that mental imagery can be used in fear reconsolidation procedures, for example by having participants simply imagine the memory probe to open the reconsolidation window (Grégoire and Greening, 2019b) or having participants imagine the CS+ during the extinction trials once the reconsolidation window is opened (Agren et al., 2017). Additionally, there are situations in which one might experience a fear response acutely. In such situations, active down-regulation of the fear response can be attempted using strategies of cognitive control or reappraisal. For example, Delgado et al. (2008) had participants down-regulate (i.e., suppress) their fear response to a CS+ by diverting their thoughts to "something calming in nature." This attenuated both the SCR to the CS+ and brain activity in parts of fear conditioning network including the insula.

Police attend annual recertification training in which they undergo many varied "police call" simulations and interactions, either *via* video or live with individuals acting out a scene. Police officers are required to resolve the situation while their performance is being assessed. The results of the assessment either requalify the officers to handle their gun and go back out in the field, or they would not. While it may not be desirable for training to excessively suppress fear responses to threat, there could be a legitimate need to improve the accuracy of the fear response. Can this training help to improve the calibration of the fear-conditioned response? There is no clear answer to the question, but if one were to undertake in answering it, here are some factors one might want to consider. The goal of such training could aim to improve the discriminability of the fear response, with the aim that this improvement would also improve decisions to use force. In terms of the fear response, the goal could be to maintain "hits" of the fear response (i.e., fear when threat is present) while reducing "false alarms" of the fear response (i.e., fear when threat is not present). Furthermore, we may want to reduce "misses" of the fear response (i.e., no fear when threat is present) and maximize "correct rejections" of the fear response (i.e., no fear when threat is not present). In order to determine how police training affects the fear response, however, we need to consider the multiple factors that have been described above. In terms of decisions to use force, we might ask how the presence of a fear response affects the parameters involved in making a shoot/no-shoot decision.

The training of police officers might wish to employ a selection of scenarios that considers the calibration of the fear response. This might involve practicing proportionately fewer scenarios in which a threat is actually present. Additionally, there could be a need to facilitate positive learning such that it modifies the various contextual factors that can influence one's fear response. Such positive experiences could involve aspects of community in addition to training simulations. For example, community engagement including both formal (e.g., organized social gatherings) and informal (e.g., day-to-day social encounters such as door-holding or gestures "good-morning") positive encounters could help with the accurate calibration of the threat response by minimizing the influence of misleading contextual factors. Finally, such calibration through training and community engagement can never be perfectly achieved. In practice, officers can also practice threat regulation strategies such as cognitive reappraisal in potentially threatening situations.

CONCLUSION

Though the criticism that traditional judgment and decision-making research (focused primarily on simple one-time choices between hypothetical gambles) lacks generalizability to consequential real world decision making has some validity, recent trends have focused on the dynamics of decision making which provide more fidelity with real world decision contexts. We reviewed recent findings that highlight dynamic pre-decisional processes that influence the type of consequential decisions police face in the line of duty. Work by Pleskac et al. (2018), applying drift diffusion modeling to decision to shoot or not, highlights how bias to shoot is not a singularly straightforward variable, but instead could influence how evidence in favor of a decision is accumulated or how much evidence is needed to make a decision. Likewise, the emerging topic of decisions from experience illustrates that reactions to risk and possible outcomes are strongly influenced by previous decisions made in similar contexts. And the review of the neurocognitive mechanisms of fear adds the insight that these previous experiences may be as subtle as imagined or vicarious scenarios.

While the focus on dynamic processes in decision making is an improvement in terms of generalizability, there is still a long way to go before laboratory-based decision-making researchers can offer concrete prescriptive suggestions for police training and operation. Any worthwhile intervention or policy should be theory driven, which the research above could assist in, but also needs to be empirically tested and validated. Some possibilities drawing from the research reviewed could be increased training of typical police scenarios that have positive outcomes as well as post incident interventions to moderate the neurological conditioning of fear responses with particular contexts.

AUTHOR CONTRIBUTIONS

JH organized the writing of this manuscript and wrote sections "Introduction," "Decisions From Experience," and "Conclusion." DZ wrote section "Dynamic Accumulation of Evidence in the Decision to Shoot or Not Shoot." SG wrote section "Neurocognitive Influence of Fear on Decision Making."

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Stress-Activity Mapping: Physiological Responses During General Duty Police Encounters

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Policing is a highly stressful and dangerous profession that involves a complex set of environmental, psychosocial, and health risks. The current study examined autonomic stress responses experienced by 64 police officers, during general duty calls for service (CFS) and interactions with the public. Advancing previous research, this study utilized GPS and detailed operational police records as objective evidence of specific activities throughout a CFS. These data were then used to map officers' heart rate to both the phase of a call (e.g., dispatch, enroute) and incident factors (e.g., call priority, use-of-force). Furthermore, physical movement (i.e., location and inertia) was tracked and assisted in differentiating whether cardiovascular reactivity was due to physical or psychological stress. Officer characteristics, including years of service and training profiles, were examined to conduct a preliminary exploration of whether experience and relevant operational skills training impacted cardiovascular reactivity. Study results provide foundational evidence that CFS factors, specifically the phase of the call (i.e., arrival on scene, encountering a subject) and incident factors (i.e., call priority, weapons, arrest, use-of-force), influence physiological stress responses, which may be associated with short-term performance impairments and long-term health outcomes. Implications of research findings for operational policing, police training, and health research are discussed.

Keywords: police, occupational stress, physiological reactivity, heart rate, use-of-force

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INTRODUCTION

Policing is a highly stressful and dangerous profession that involves a complex set of environmental, psychosocial, and health risks (Pinizzotto et al., 2006; Gershon et al., 2009; Chopko and Schwartz, 2012; Violanti, 2014; Andersen et al., 2016a). Against a background of less dangerous tasks, officers are required to respond to violent and life-threatening situations, often encountering novel, ambiguous, and rapidly unfolding events (Fridell and Binder, 1992). It is under these conditions that officers are required to make decisions, sometimes in a split-second, and act to protect the public and themselves (Artwohl, 2002). The current study examines physiological responses experienced by police officers, during general duty calls for service (CFS) and interactions with the public. The aim of the study is to provide novel evidence of how frequently officers experience high physiological stress responses and examine the influence of the phase of the call (e.g., dispatch, enroute) and incident factors (e.g., call priority, use-of-force) on physiological arousal.

The study will also explore whether experience and relevant operational skills training impact cardiovascular reactivity.

When presented with a threatening stimulus (whether real or perceived) the body engages in a series of automatic physiological processes (LeDoux and Pine, 2016). Ledoux and Pine described two pathways to the threat, or "fear" response, more colloquially known as the "fight-or-flight" response. The pathways are: (1) behavioral and physiological stress responses and (2) fearful feelings in higher order cognitive processing. Under elevated levels of stress, the engagement of the first path, automatic physiological processing, happens within sub-cortical structures of the brain's limbic system. The second path engages higher order cortical cognitive processing, generating conscious feelings, such as fear or other related emotions, in response to a threat (Fenici et al., 2011; LeDoux and Pine, 2016). The fight-or-flight response is implicit (i.e., below conscious awareness) and is the default human response to threat in order to maximize survival by immediately preparing the body to fight or flee without the need for higher-order cognitive processing (Thayer and Sternberg, 2006; LeDoux and Pine, 2016).

During the fight-or-flight response, two central physiological processes are engaged to mobilize the body to meet the demands of the situation and suppress unnecessary functions (e.g., reproduction, growth; McEwen, 1998; Kemeny, 2003). As described in detail by McEwen (1998) and Lovallo (2016), the sympatho-adrenal response results in a wide-spread, powerful reaction, which includes the release of neurotransmitters and hormones. The other physiological process is the engagement of the autonomic nervous system (ANS), which is made up of two branches – the sympathetic (SNS) and parasympathetic (PNS) divisions.

Perceived threats are associated with an increase in SNS activation and, typically, the suppression of the PNS, which is associated with relaxation, focused attention, and stabilization (Berntson and Cacioppo, 2004). As reviewed by Lovallo (2016), when the SNS is activated, catecholamines such as norepinephrine and epinephrine (i.e., adrenaline) are released. Simultaneously, the hypothalamic-pituitary-adrenal (HPA) axis is activated, which results in the rapid release of epinephrine and cortisol from the adrenal glands (Lovallo, 2016). Cortisol stimulates glucose production and mobilizes fatty acids to encourage higher blood sugar and prepare for energy expenditure (Anderson et al., 2002; Sharps, 2016). The surge of these catecholamines, stress hormones, and glucose through the bloodstream stimulate increased respiration, heart rate, and blood pressure (Tsigos and Chrousos, 2002; Chrousos, 2009). The increased blood flow, oxygenation, and energy are then directed in the highest concentration to the brain, heart, and large muscles (Tsigos and Chrousos, 2002). Conversely, blood flow to other areas (e.g., digestive system), which are not required to respond to a threat, are inhibited. Thus, activation of this stress system leads to an increase in strength, resistance, and attention to improve chances for survival in the short-term (Tsigos and Chrousos, 2002; Fenici et al., 2011). However, chronic, or maladaptive autonomic activation can be detrimental to health over the long-term (McEwen, 1998). The ways in which chronic stress may be detrimental to the health of police officers has been examined (Violanti et al., 2006a,b). Longitudinal studies indicate that police officers experience dysregulation in HPA axis functioning associated with occupational stressors (Violanti et al., 2017). Furthermore, police officers are more likely to be diagnosed with chronic health conditions such as heart and metabolic disease than their civilian peers (Violanti et al., 2006b). However, there is a lack of studies examining the impact of acute stress on health among police officers.

Research has suggested that SNS arousal that matches situational demands (not too high or too low) is beneficial for performing optimally during threatening situations, as it can result in heightened sensory perceptions, rapid decision-making, and improved cognitive functioning (Cahill and Alkire, 2003; Hansen et al., 2009; Jamieson et al., 2010; Lambourne and Tomporowski, 2010). However, under conditions of extreme stress, such as when police officers encounter life threatening situations, performance may be impacted in various ways, some of which can be detrimental to performance (e.g., Westmoreland and Haddock, 1989; Artwohl and Christensen, 1997; Morrison and Vila, 1998; Klinger, 2006).

When considering performance generally, maladaptive stress arousal can result in increased task errors and degradation of task accuracy (Driskell and Salas, 1996). These adverse effects primarily involve cognitive functions, such as attention, perception, and decision-making (Driskell and Salas, 1996). Attention is a limited capacity resource, in that only a certain amount of information-processing capacity exists, making it difficult to focus attention on two things at the same time (Vickers, 2007). When attending to a threat, less attention is available for cognitive processing and cognitive overload is more likely to occur, which can result in inattentional blindness (Eysenck et al., 2007; Chabris et al., 2011; Nieuwenhuys and Oudejans, 2011a). Similarly, higher levels of arousal are associated with perceptual narrowing (e.g., tunnel vision, auditory exclusion) because the perceptual field tends to shrink under stress (Vickers, 2007; Honig and Lewinski, 2008). These attentional and perceptual deficits mean that individuals can miss relevant cues (e.g., a subject dropping their weapon; Easterbrook, 1959; Vickers, 2007) and be unable to recall aspects of a situation (Yuille et al., 1994; Hope et al., 2016). Maladaptive stress arousal is also associated with hypervigilant decision-making, which is often impulsive, disorganized, and inefficient (Johnston et al., 1997). Accordingly, Keinan et al. (1987) found that under threat of shock in a laboratory setting, participants completing a computer task tended to offer solutions prior to assessing all alternatives, abandoning their systematic approach of scanning relevant decision options. Research has also demonstrated that police decisions and behaviors, including aggression, during training were found to be associated with maladaptive heart rate (HR) arousal rather than situational factors presented in the scenario (Haller et al., 2014).

Perceptual-motor performance is also degraded by stress, although not to the same extent as cognitive performance (Staal, 2004; Nieuwenhuys and Oudejans, 2011a). For example, a study examining the execution of arrest and self-defense skills demonstrated that under stress, officers were less able to inhibit threat-related processing (e.g., perceptual narrowing) and achieve task-relevant processing (e.g., attentional control), thus leading to poorer task performance (Renden et al., 2014). In line with the default survival response, fine motor skills, such as manipulating a firearm, also tend to be at greater risk for impairment under stress than gross motor skills, such as running (Staal, 2004).

Several studies have examined officer-involved shootings (OIS) to determine how stress may have impacted performance in naturalistic settings. The findings are consistent with the broader stress and performance research. For example, hit rates in annual firearms requalification on the range are near 90% (Anderson and Plecas, 2000), but deteriorate rapidly in the real-world (i.e., hit rates ranging from 14 to 38%; Morrison and Vila, 1998; Morrison and Garner, 2011; Donner and Popovich, 2018). Moreover, under such conditions, officers can experience perceptual distortions, reduced motor dexterity, and impaired cognitive function (e.g., Honig and Sultan, 2004; Artwohl, 2008; Klinger and Brunson, 2009). Artwohl (2008), for example, had 157 police officers complete a survey within a few weeks of being involved in an OIS to examine perceptual and memory distortions that they may have experienced during the high stress incident. The results indicated that the majority of officers experienced perceptual narrowing (i.e., 84% experienced diminished sound and 79% experienced tunnel vision). Most participants (74%) also reported that they responded with little or no conscious thought (i.e., automatic pilot) and many (52%) reported memory distortions or loss. Approximately 7% of the sample reported temporary paralysis, though the author indicated that this may be related to the fleeting freeze response when startled (see LeDoux, 2003), which seems prolonged in high-stress shooting conditions (i.e., 62% reported slow motion time). Similar reactions have been reported in other studies as well (e.g., Honig and Sultan, 2004; Klinger and Brunson, 2009). These effects can be particularly detrimental during a critical incident, when officers are expected to demonstrate sound judgment, proficient performance, and provide accurate recall of their actions.

Manipulating stressful real-world encounters for research purposes would be unethical (Giessing et al., 2019); thus, much of the knowledge that exists today about the physiological impact of stress on performance among police officers come from scenario-based experiments. For example, several studies have found that high stress and anxiety scenarios resulted in impairments to shooting performance (Nieuwenhuys and Oudejans, 2010; Taverniers and De Boeck, 2014; Landman et al., 2016a), quality of skill execution (Renden et al., 2014, 2017; Nieuwenhuys et al., 2016), proportionality of force applied (Nieuwenhuys et al., 2012; Renden et al., 2017), memory (Hope et al., 2016), and communication (Renden et al., 2017; Arble et al., 2019). However, recent studies on police officers demonstrate that the impact of acute stress on performance is complex. For example, stress appears to have differential effects on cognition and physical movement in that rehearsed and automated skills are influenced to a lesser degree (Vickers and Lewinski, 2012; Renden et al., 2017; Arble et al., 2019). Experimental research with simulations is extremely important to not only draw conclusions about what 'might' happen to performance in real-world stressful encounters, but also to inform police training to improve public and police safety (Giessing et al., 2019).

While there is no single "best tool" for measuring stress, real-world demands outline the choice of appropriate measures given situational and environmental constraints. Common measures of reactivity to stress capture SNS and HPA axis activation and PNS suppression. Heart rate variability (HRV) is thought to capture changes in the balance between SNS and PNS activity (Thayer et al., 2012), and salivary cortisol is used to capture HPA anticipation and reactivity to stress (Hellhammer et al., 2009). However, during real-world police encounters these measures are highly sensitive to movement (i.e., HRV) or cumbersome to collect without confounds, such as time of day (i.e., salivary cortisol), rendering these methods inappropriate for continuous monitoring throughout police active duty shifts (Dickerson and Kemeny, 2004; Smyth et al., 2013). Current research specifically discourages the collection of HRV while participants are moving because data is highly inconsistent, erroneous, and may lead to false conclusions (Heathers and Goodwin, 2017). Alternatively, HR averaged across time, while controlling for movement, is a robust, ecologically valid, objective, and easily obtainable proxy measure for stress among highly active participants (Vrijkotte et al., 2000).

Previous research supports the feasibility of measuring the stress reactions of officers using HR as they complete their operational duties. Anderson et al. (2002) fitted 76 officers with HR monitors, which were worn prior to and during shifts, and had research assistants record their actions on a minute-by-minute basis during ride-alongs. The results provided HR profiles for various activities. For example, HR became elevated on average to 99–124 beats per minute (bpm; i.e., 40–65 bpm above resting rate) when involved in a use-of-force (UoF) encounter (e.g., physical control, fight, hand on pistol) with a suspect, with maximum HRs reaching 112bpm above resting rate. Similarly, Andersen et al. (2016b) monitored tactical officers during 11 active duty shifts. Researchers matched activities from the officers' shift notes with their physiological profiles. Study observations revealed that active duty tactical officers operated, on average, at 146 bpm, and ranged from 160 to 180 bpm during UoF incidents, such as pointing a firearm at suspect and warrant executions (Andersen et al., 2016b). Taking a novel approach, Hickman et al. (2011) conducted a pilot study where one officer wore a Garmin global positioning system (GPS)-enabled wrist-watch equipped with a HR monitor. Using GPS data and information from the calls the officer responded to, HR could be visually mapped and associated to specific aspects of CFS. For example, the officer's heart rate spiked to 165 bpm (69 bpm higher than the officer's average HR throughout the shift) when conducting a high risk vehicle takedown (i.e., firearm drawn) of an impaired hit-and-run driver who failed to stop for police.

In the current study, continuous ambulatory cardiovascular reactivity was measured on multiple active duty shifts. This was done to develop a "profile" of physiological responses associated with various aspects of police encounters that may influence call outcome. Specifically, this novel approach mapped autonomic stress responses to both the phase of a call (e.g., dispatch, enroute) and incident factors (e.g., call priority, UoF). Advancing previous research, this study utilized GPS and detailed operational police records (e.g., police notes, dispatch records) as objective evidence of specific activities throughout a CFS to be cross-referenced with cardiovascular reactivity data. Furthermore, physical movement (i.e., location and inertia) was tracked and assisted in differentiating whether cardiovascular reactivity was due to physical or psychological stress. It has been argued that, as moderators, experience and training can serve to 'intervene' immediately following the presence of a stressor (i.e., blunting the stress response due to previous exposure) or after the stress response occurs (i.e., through the threat appraisal process; Driskell and Salas, 1996; Kavanagh, 2005; Wollert et al., 2011). Results from a UoF simulation study provided some evidence for this moderating effect, with officers on a specialized arrest unit displaying lower HR during a high-pressure scenario, compared to general duty officers (Landman et al., 2016b). Accordingly, individual variables, including an officer's years of service and training profiles, were examined to conduct a preliminary exploration of whether experience and relevant operational skills training impacted cardiovascular reactivity. Together, these data will provide foundational evidence of what CFS factors are associated with physiological stress responses and to what degree and frequency. This is an important investigation because maladaptive stress responses may be associated with short-term performance impairments (Driskell and Salas, 1996; Nieuwenhuys and Oudejans, 2011a) and long-term health outcomes (Chopko and Schwartz, 2012; Violanti, 2014).

With the use of HR as an indicator of physiological arousal, we tested whether officers' cardiovascular reactivity uniquely varied as a function of call priority, the phases of a call, incident factors, demographics, experience, and training. We hypothesized the following:

> Hypothesis 1: Officers' cardiovascular reactivity would increase throughout the phases of a call (e.g., from dispatch to encounter).
>
> Hypothesis 2: CFS dispatched with a higher priority level (i.e., very urgent), that involved an arrest/apprehension, UoF, and/or a weapon being reported or accessible, would result in officers experiencing elevated physiological arousal.
>
> Hypothesis 3: Officers with more experience (i.e., years of service) would experience lower cardiovascular reactivity during CFS.
>
> Hypothesis 4: Officers with more relevant operational skills training would experience lower cardiovascular reactivity during CFS.

MATERIALS AND METHODS

Participants

Over a period of nine days, 69 active duty frontline police officers from a large Canadian police agency volunteered to participate in our study. The inclusion criteria for participants were that they were considered 'fit for duty' by their police agency and currently on active duty. Screening for diseases was based on self-report. As this is not a diagnostic clinical study, we did not perform medical examinations, however, we did examine self-reported diseases in relation to the data. One participant reported cardiovascular disease and another reported being on medication that affects HR, but their cardiovascular measures (i.e., HR_{rest}, $HR_{average}$, and HR_{max}) did not significantly differ from other participants and they were thus retained in the study.

A total of 125 shifts were recorded. Data from nine shifts were unusable because the HR data was corrupted (n = 3, 2.4%), the HR monitor became dislodged (n = 3, 2.4%), or the officer did not respond to any CFS (e.g., scene security; n = 3, 2.4%). This resulted in a final sample size of 64 officers over 116 shifts. Over a third of the officers (n = 25, 39.1%) participated during one shift, while a large number participated in two (n = 29, 45.3%) or three shifts (n = 8, 12.5%). One officer participated during four shifts and another during five. In total, approximately 1,200 h of recording time captured HR data for 754 participant responses to 593 CFS. Accordingly, almost a quarter of the CFS (n = 142, 23.9%) involved a response from multiple participants.

Table 1 shows the basic sociodemographic characteristics of the sample (n = 64). The majority of participants were male (79.7%) and had an average age of 31 years (*SD* = 6.4). Most (87.5%) had obtained post-secondary education. All of the participants were general duty constables with between 1 month and 12 years of service (*M* = 2.06 [years], *SD* = 2.08). Over a quarter (27%) of the participants had previous experience with another law enforcement agency or the military. Training records indicated many participants had received agency training on the conducted energy weapon (CEW; 60.9%), carbine (73.4%), and responding to active threats (81.3%). There were five participants (7.9%) who reported having been involved in a lethal force encounter, as either the officer discharging their firearm, or a witness officer on scene.

Materials

Demographics and Shift Questionnaires

A short demographics questionnaire was used to collect age, gender, years of service, law enforcement experience, and training. A pre-shift questionnaire was used to collect basic information on general health factors (e.g., exercise, sleep), while the UoF and level of fatigue during the shift were captured with a post-shift questionnaire.

Operational Police Records

Operational police records were obtained and reviewed to categorize officers' activities throughout their shift. Operational records included: (1) police notes, which are typically prepared during or shortly after a police occurrence and are used by officers as an aide memoire for court purposes; (2) occurrence files, which are created for the officer(s) to add reports (e.g., general, supplemental) and outline details concerning the circumstances of the call, individuals involved, actions taken, and whether charges were laid; (3) UoF reports, which an officer completes to articulate the use of an intervention

TABLE 1 | Participant demographics.

Demographic factors	*n*	%	*M*	*SD*
Sex				
Male	51	79.7%		
Female	13	20.3%		
Age	64		31	6.4
Height (in)	64		73	13.8
Weight (lb)	64		182	28.6
Highest level of formal education				
High school diploma or equivalent	8	12.5%		
Registered Apprenticeship or other trades certificate or diploma	2	3.1%		
College or other non-university certificate or diploma	18	28.1%		
University certificate or diploma below bachelors level	12	18.8%		
Bachelors degree	20	31.3%		
Post graduate degree above bachelors level	4	6.3%		
Current rank				
Constable	64	100.0%		
Current duty type				
General duty	64	100.0%		
Years of service with the agency	64		2.06	2.08
Prior service with another police agency or the military	17	27.0%		
Training experience				
Instructor experience in the area of use-of-force	3	4.8%		
Specialized training in the area of use-of-force (outside of the agency)	15	23.8%		
Martial arts	23	36.5%		
Active shooter	52	81.3%		
Conducted energy weapon	39	60.9%		
Carbine	47	73.4%		
Involved in a lethal force encounter	5	7.9%		

and describe the officer's risk assessment; and (4) computer-aided dispatch (CAD) records, which provide time-stamped radio communications (e.g., contact with subject, arrest), officer status (e.g., dispatched, enroute, on scene), and messages to mobile workstations.

Monitoring Devices

HR, GPS, and physical movement were captured with a Polar V800 watch, H7 chest strap HR sensor, and Stride sensor, which is a foot mounted inertia sensor (Polar Electro Oy, Kempele, Finland). The H7 is paired through Bluetooth with the Polar V800 to record cardiovascular reactivity at one second intervals. Polar HR monitors are regularly used to measure HR in police research (Barton et al., 2000; Anderson et al., 2002; Meyerhoff et al., 2004; Hulse and Memon, 2006; Hope et al., 2012; Kayihan et al., 2013; Renden et al., 2015; Hope et al., 2016; Landman et al., 2016a) and the technology has been validated against electrocardiograms (ECG; Gamelin et al., 2006; Nunan et al., 2008, 2009; Weippert et al., 2010; Quintana et al., 2012; Wallén et al., 2012; Giles et al., 2016; Barbosa et al., 2016). The Polar V800 is equipped with an integrated GPS that tracks speed (kilometers per hours; km/h), pace (min/km), cadence (steps/min), distance (m), location (latitude and longitude), and route. The Stride sensor automatically calibrates with the V800's GPS to capture more accurate and detailed physical movement. The battery duration of the V800 is up to 13 h with continuous GPS recording, which covers the typical police shift.

Measures

Heart Rate

Consistent with previous research, the HR monitors attached to officers were used to collect several measures of cardiovascular reactivity: resting HR during the shift (HR_{rest}), maximum HR (HR_{peak}) reached during each phase of the call (see below for more details), and average heart rate throughout the shift ($HR_{average}$) (Anderson et al., 2002; Andersen and Gustafsberg, 2016; Andersen et al., 2016b). HR_{rest} is best determined immediately upon waking in the morning, as HR measures taken before or during a shift may include anticipatory stress regarding the upcoming shift or potential events that might be encountered during the current shift and therefore be slightly higher than actual resting HR (Plowman and Smith, 2013). Resting HR can also be affected by body position and is reported to be higher when sitting, as opposed to when lying supine (Miles-Chan et al., 2013). However, for logistical reasons, HR_{rest} in this study was based on the lowest 1-min HR while an officer was on shift. Similar methods for determining HR_{rest} have been used in previous research (Anderson et al., 2002; Andersen and Gustafsberg, 2016). HRrest during sleep was collected for a small subsample ($n = 10$) for comparative purposes. HR_{max} and HR_{min} represented the highest and lowest HR during the officer's shift. To provide a standardized measure for between-subject analysis, the difference ($HR_{peak\ above\ resting}$) between the officers' HR_{peak} during phases of the call and their HR_{rest} was calculated (Anderson et al., 2002; Andersen et al., 2016b).

Movement

Speed (km/h), which was captured by the GPS and the inertia sensor, was collected to control for physical movement throughout an officer's shift. This assisted us in determining whether cardiovascular reactivity resulted from physical or psychological stress. For example, a large increase in HR absent of physical movement would suggest a psychological stress response. For reference purposes, average walking speed is approximately 5 km/h (Bohannon, 1997). A slow or average jogging pace is 8 km/h and a fast jog is 11 km/h (Schnohr et al., 2015). Research on law enforcement cadets has also found that average sprint speeds are approximately 23 1/2 km/h (Lewinski et al., 2015; Crawley et al., 2016).

Phase of the Call

Using GPS data and operational police records, HR_{peak} and movement were broken down temporally into four phases of the call: (1) dispatch, (2) enroute, (3) arrival on scene, and (4) encounter, UoF and/or arrest (see **Figure 1**). The first three phases were determined using GPS data and officer status

HRaverage: 75 bpm
HRmax: 163 bpm
HRmin: 55 bpm
HRrest (lowest one minute on shift): 58 bpm

Arrival on scene HRpeak above resting: 103 bpm
Physical movement: 12.6 km/h

Enroute HRpeak above resting: 57 bpm
Physical movement: 0 km/h

Dispatch HRpeak above resting: 53 bpm
Physical movement: 0 km/h

Arrival on scene

Officer ran from police vehicle to scene. Peak physical movement speed directly preceding HRpeak recorded.

Encounter HRpeak above resting: 105 bpm
Physical movement: 0 km/h

Encounter and subject arrest

No physical movement speed directly preceding encounter HRpeak (40 seconds from last movement)

FIGURE 1 | A disturbance CFS provides a graphical representation of how stress-activity mapping was conducted using HR, GPS, and inertia data in Polar Flow. The left vertical axis **(A)** presents HR (bpm), in red on the horizontal axis. The left vertical axis **(B)** presents speed (km/h) from the GPS, in blue on the horizontal axis. The left vertical axis **(C)** presents cadence [rpm] from the Stride sensor, in green on the horizontal axis. A tracking meter **(D)** identifies HR and movement measures at a specific point in time, which is linked to the corresponding GPS position on the map. Physiological data can be highlighted and zoomed in for detailed examination. Imagery 2019, CNES/Airbus, DigitalGlobe, IMTCAN, Landsat/Copernicus, McElhanney.

timestamps from the CAD (e.g., dispatched, enroute, on scene). The fourth phase was established by cross-referencing GPS data, inertia sensor data, time-stamped radio communications (e.g., contact with subject, arrest), officer notes, occurrence files, and UoF reports.

Incident Factors

CFS were classified based on dispatch priority levels (1 through 3). To ensure CFS are dispatched in a consistent manner, dispatchers adhere to standard operating procedures to assign priority levels. Priority levels are defined as:

> Priority 1 – Very Urgent – Immediate Dispatch. A major incident or incident in progress that requires immediate police presence, assistance or service. Involves the report of a loss of life or a need for police to prevent a loss of life.
>
> Priority 2 – Urgent – Dispatch as soon as possible. There is an urgent need for police presence, assistance or service. While there is no loss of life involved, the potential for escalation of violence exists.
>
> Priority 3 – Routine – Dispatch as soon as reasonably possible. Reports that do not require immediate police presence, assistance or service.

From the post-shift questionnaires and operational records, CFS were also coded for whether weapons were reported or accessible (0 = no, 1 = yes) during any phase of a call, if there was an arrest or apprehension (0 = no, 1 = present while other officer conducted arrest, 2 = *Mental Health Act* apprehension, 3 = arrest), and whether the encounter involved UoF (0 = no, 1 = non-firearm, and 2 = firearm). UoF included the use of physical control techniques, both soft (e.g., joint locks, soft takedowns) and hard (e.g., stuns and strikes, hard takedowns), less lethal options (e.g., CEW), and firearms, with or without a subject present. For example, clearing an empty building with a firearm drawn was categorized as UoF.

Training

Officers' training records and the training information captured in the demographics form were used to identify the following six experience criteria: (1) instructor experience in the area of UoF, (2) specialized training in the area of UoF (outside of the agency), (3) martial arts, (4) active shooter, (5) CEW, and (6) carbine. All officers had taken the agency's mandatory crisis intervention and de-escalation training. To create a composite training variable, the sum of the training experience criteria for each officer was calculated. A score was assigned to each participant to indicate the number of experience criteria the officer had (0 = least and 6 = most; see **Table 2**). While the categorization does not take into account the recency and frequency of training experience, nor

TABLE 2 | Composite training score, indicating the number of experience criteria the officer possessed (0 = least and 6 = most).

Level of training	*n*	%
1	9	14.1%
2	13	20.3%
3	29	45.3%
4	9	14.1%
5	3	4.7%
6	1	1.6%
Total	64	100.0%

weight types of training differently, it provides a basic measure that enabled us to examine the effect of training on cardiovascular reactivity during CFS.

Procedure

To improve the likelihood of capturing physiological responses to high-stress encounters, the selection of the study location and collection period were informed by an examination of UoF trends and violent crime severity indexes in Canadian cities. The urban city that was selected had approximately 700 operational officers and five policing districts. The two districts that were targeted have a population of approximately 220,000 and an area of 86 km^2. Work shifts were 12 h in length with staggered start times. Early morning shifts started at 0600 h and late morning shifts started at 0930 h. Early night shifts started at 1700 h and late-night shifts start at 1900 h. Participants were recruited by having the District Watch Commanders send a callout message via internal e-mail. Researchers also recruited at the pre-shift briefings.

Those interested in participating in the study completed a written informed consent form and were asked to take standard notes throughout their shift, indicating the time and call for service/activity that they were involved in. Participants were then equipped with a Polar V800 watch, H7 chest strap HR sensor, and Stride sensor. Following this, officers completed a demographics and pre-shift questionnaire. Monitoring devices were worn for the entirety of their shift. At the end of their shift, recordings were stopped, equipment removed, and the officers then completed a post-shift questionnaire. A copy of each officer's notebook notes for the shift were obtained. Each participant received a debriefing form and \$50 financial compensation. A small subsample (n = 10) volunteered to wear a HR monitor during their normal sleep cycle so that we could obtain their resting HR while sleeping. These participants received an additional \$50 in financial compensation.

After the field work was completed, the researchers accessed operational files, UoF reports, dispatch logs for the CFS, as well as training profiles for all the participants. Anonymized HR, GPS, and Stride sensor data were uploaded to the Polar Flow web application (Polar Electro Oy, 2016) where they were integrated with maps and charts for visual analysis and coding (see **Figure 1**). All procedures were approved by Carleton University's Research Ethics Board (REB #17-106853) and the agency's Research Review Board (RRB).

Data Analyses

Data from the stress-activity mapping (i.e., officer HR and movement data for corresponding phases of the call), along with incident factors and demographic data, were entered into SPSS v.22 (IBM Corp, 2013, Released) for quantitative analysis. All data were checked for expected ranges, presence of outliers and abnormal values. The Shapiro–Wilk test was used to assess normality (no assumptions were violated). The descriptive data are presented as frequencies, rates (%), means, and standard deviations. Paired-samples t-tests are used to test the mean difference between paired observations. The reported statistical tests are one-tailed, and the significance value is set to $p < 0.05$. Descriptive statistics for $\text{HR}_{\text{peak above resting}}$ across CFS are reported for each phase of the call as a function of incident factors (e.g., call priority).

To examine how the standardized measure of cardiovascular reactivity ($\text{HR}_{\text{peak above resting}}$) varied as a function of the phases of the call, demographics, incident factors, and training, linear mixed models (LMM) for repeated measures are used. LMM is a flexible approach for the analysis of repeated measures data and has several advantages over traditional methods (e.g., ANOVA). LMM can appropriately handle missing data and therefore does not exclude cases with a missing time point (Gueorguieva and Krystal, 2004). Moreover, the LMM can account for uneven spacing and correlation between repeated measurements on the same subjects and does not assume homogeneity of variance across groups and time points (Gueorguieva and Krystal, 2004; Blackwell et al., 2006). Time-varying covariates may also be included in the LMM (Blackwell et al., 2006); allowing for speed (km/h) at each phase of the call to be used as a covariate to control for movement. The LMM model will use a two-level hierarchical data structure: CFS as level-1 and participants as level-2. The model will include a random intercept to accommodate correlations in the outcome variables across CFS for each participant. All other predictors and covariates, including phase of the call, were specified as fixed effects. To compare fixed effects across models, maximum likelihood (ML) estimation was used (Zuur et al., 2009). The Bonferroni correction was used as a *post hoc* test to control for type I errors.

RESULTS

Shift HR

Table 3 presents HR data for officers across their shifts. A subsample (n = 10) wore a HR monitor to sleep to obtain an off-shift resting heart rate for comparative purposes. A paired-samples t-test was conducted to compare HR_{rest} at the lowest 1 min while on shift and while the officer was sleeping. There was a significant difference in HR_{rest} at the lowest 1 min while on shift (M = 64.60, SD = 6.74) and while the officer was sleeping (M = 55.40, SD = 6.60), $t(9) = -4.261$, p = 0.001, d = 1.35. Therefore, as expected, the resting rate in this study was slightly higher than actual resting HR during sleep. This may be attributed to factors such as anticipatory stress while on-shift or the officer's body positioning during the recording (e.g., sitting in police vehicle). As such, HR_{rest} in this study reflects the

TABLE 3 | Descriptive statistics for officer HR across shifts.

	N	*M*	*SD*	*Min*	*Max*
HR_{rest}	64	63.1	9.7	40.0	85.0
$\text{HR}_{\text{average}}$	64	82.7	10.7	54.0	102.4
HR_{min}	64	59.3	8.8	38.0	81.0
HR_{max}	64	147.6	19.6	109.0	203.0

HR_{rest} is the lowest one minute on shift.

TABLE 4 | Frequency of call type by priority level.

Call type	**Priority level**				
	1 – Very Urgent	**2 – Urgent**	**3 – Routine**	**Total**	
	n	***n***	***n***	***n***	**%**
Disturbance	3	65	2	70	9.3%
Abandoned 911	4	58	5	67	8.9%
Check wellbeing	0	53	1	54	7.2%
Bylaw	0	4	35	39	5.2%
Domestic in progress	7	23	0	30	4.0%
Assault report	0	26	3	29	3.8%
Assist police/fire/ambulance	0	26	2	28	3.7%
Alarm	0	27	0	27	3.6%
Unwanted person	0	14	11	25	3.3%
Suicidal person	5	19	0	24	3.2%
Fight	2	20	0	22	2.9%
Weapon	12	9	0	21	2.8%
Assist general public	0	9	12	21	2.8%
Suspicious person	0	14	4	18	2.4%
Motor vehicle incident	0	16	2	18	2.4%
Drugs	0	12	5	17	2.3%
Suspicious circumstances	1	12	3	16	2.1%
Suspicious vehicle	0	7	7	14	1.9%
Mischief	0	4	10	14	1.9%
Threats	0	5	7	12	1.6%
Shots fired	9	0	0	9	1.2%
Break end enter in progress	0	9	0	9	1.2%
Theft of vehicle	0	3	5	8	1.1%
Theft in progress	0	8	0	8	1.1%
Assault in progress	7	1	0	8	1.1%
Animal	0	6	2	8	1.1%
Other call types (<1%)	9	74	55	138	18.3%
Total	59	524	171	754	100.0%

realities of an officer being at rest while on-shift and provides a context relevant baseline measure to standardize increases in HR ($\text{HR}_{\text{peak above resting}}$) between the officers.

Call for Service

The types of calls responded to by participants, along with their associated dispatch priority level, are presented in **Table 4**. Disturbances (9.3%) and abandoned 911 calls (8.9%) were the most common calls that participants responded to. CFSs were most frequently dispatched as urgent (n = 524/754, 69.5%), followed by routine (n = 171/754, 22.7%), and very urgent (n = 59/754, 7.8%). Calls for weapons, shots fired, and assaults in progress were most commonly dispatched as very urgent.

Stress Reactivity

To examine the participant's cardiovascular reactivity during CFS, descriptive statistics for $\text{HR}_{\text{peak above resting}}$ as a function of incident factors (e.g., call priority) and phases of the call (e.g., dispatch) are displayed (see **Table 5**). Average $\text{HR}_{\text{peak above resting}}$ was lowest during the dispatch phase (M = 25.94, SD = 13.62), and increased while enroute (M = 32.50, SD = 13.42), and when arriving on scene (M = 46.37, SD = 16.32). Average $\text{HR}_{\text{peak above resting}}$ was highest during the encounter/UoF/arrest phase of the call (M = 55.30, SD = 20.25). Throughout all phases of the call, average $\text{HR}_{\text{peak above resting}}$ increased with the urgency of the priority level and the report or accessibility of a weapon(s) (n = 43/754, 5.7%). As expected, arrest (n = 68/754, 9%) and apprehension (n = 26/754, 3.4%) of a subject resulted in more pronounced increases in average $\text{HR}_{\text{peak above resting}}$ during the latter phases of the call, compared to the earlier phases. As the level of force increased from none, to non-firearm (n = 71/754, 9.4%), to firearm (n = 27/754, 3.6%), average $\text{HR}_{\text{peak above resting}}$ also increased. Interestingly, elevated average $\text{HR}_{\text{peak above resting}}$ can be observed during all phases of the call when force was used. For example, incidents where officers drew their firearm were those with the highest average $\text{HR}_{\text{peak above resting}}$ during dispatch (M = 38.5, SD = 20.4), while enroute (M = 44.2, SD = 21.1), when arriving on scene (M = 57.9, SD = 18.7), and during the encounter (M = 67.5, SD = 14.5).

To examine how cardiovascular reactivity ($\text{HR}_{\text{peak above resting}}$) varied as a function of the phases of the call, demographics, incident factors, and training, the results of the LMM for repeated measures are presented (see **Table 6**). Two models are displayed: one with speed (km/h) at each phase of the call as a covariate to control for movement and one without movement. Results for the model without movement will be presented and contrasted when differences appear in the model including movement. Based on this sample of officers and CFS, estimates (B) from the models (see **Table 6**) can be used to approximate average stress reactivity experienced by officers during CFS. For example, the following formula can be developed for a male officer responding to a priority 1 call with a weapon reported, where the officer clears a residence with his firearm drawn (at an average walking speed – 5 km/h), resulting in the location and arrest of a subject:

146 bpm (estimated HR) = HR_{rest} (63.1) + intercept (28.66) + priority 1 (5.61) + weapon reported/accessible (4.11) + average walking speed (5 km/h × 2.53) + officer use of firearm (7.64) + encounter phase (18.15) + arrest (6.49).

Phase of the Call

Our first hypothesis, that officers' cardiovascular reactivity would increase throughout the phases of the call (e.g., from dispatch to encounter), was tested using a repeated measures analysis. The repeated measures analysis without speed as a covariate determined that $\text{HR}_{\text{peak above resting}}$ significantly differed across the phases of the call [$F(3,567.455) = 384.390$, $p < 0.001$].

TABLE 5 | $\text{HR}_{\text{peak above resting}}$ as a function of incident factors and phases of the call.

Incident factors	**Dispatch** $\mathbf{HR}_{\textbf{peak above resting}}$[a] **(*n* = 741)**				**Enroute** $\mathbf{HR}_{\textbf{peak above resting}}$ **(*n* = 697)**				**Arrival on scene** $\mathbf{HR}_{\textbf{peak above resting}}$ **(*n* = 681)**				**Encounter/use-of-force/arrest** $\mathbf{HR}_{\textbf{peak above resting}}$ **(*n* = 272)**			
	M	***SD***	***n***	**%**	***M***	***SD***	***n***	**%**	***M***	***SD***	***n***	**%**	***M***	***SD***	***n***	**%**
Call priority																
(1) Very urgent	32.7	15.2	59	8.0%	39.5	18.5	54	7.7%	53.1	20.5	52	7.6%	56.9	25.3	22	8.1%
(2) Urgent	26.0	14.0	518	69.9%	33.0	13.3	490	70.3%	46.4	15.9	475	69.8%	55.5	19.7	207	76.1%
(3) Routine	23.2	10.8	164	22.1%	28.5	9.9	153	22.0%	44.1	15.4	154	22.6%	53.6	20.6	43	15.8%
Weapon(s) reported/accessible																
Yes	36.3	16.4	42	5.7%	39.9	20.4	43	6.2%	54.2	19.7	40	5.9%	55.5	24.7	26	9.6%
No	25.3	13.2	699	94.3%	32.0	12.7	654	93.8%	45.9	16.0	641	94.1%	55.3	19.8	246	90.4%
Arrest/apprehension																
Arrest	29.7	14.2	63	8.5%	38.8	16.8	66	9.5%	58.3	17.0	66	9.7%	62.9	24.5	63	23.2%
MHA apprehension	30.2	16.8	26	3.5%	32.9	14.6	25	3.6%	50.5	16.2	25	3.7%	55.0	26.3	23	8.5%
Present while other officer conducted arrest	29.0	13.1	21	2.8%	38.3	17.1	21	3.0%	51.7	12.1	21	3.1%	46.4	13.1	19	7.0%
No	25.3	13.4	631	85.2%	31.6	12.6	585	83.9%	44.6	15.8	569	83.6%	53.5	17.3	167	61.4%
Use of force																
Firearm	38.5	20.4	27	3.6%	44.2	21.1	27	3.9%	57.9	18.7	27	4.0%	67.5	14.5	25	9.2%
Non-firearm	29.0	15.4	68	9.2%	37.9	17.0	69	9.9%	55.6	16.4	70	10.3%	63.2	26.4	63	23.2%
No	25.1	12.8	646	87.2%	31.3	12.1	601	86.2%	44.7	15.6	584	85.8%	50.9	16.8	184	67.6%

Sample size decreases across phases of the call, since for various reasons, not all dispatched officers travel to the scene, attend the scene, and/or come into contact with the subject of the call (e.g., officer called off, subject gone upon officer's arrival). [a]*Resting heart rate was 63 beats per minute.*

In support of the hypothesis, the Bonferroni *post hoc* correction revealed that $\text{HR}_{\text{peak above resting}}$ during the encounter ($M = 59.46$, $SE = 1.75$) was significantly higher than when being dispatched to the call ($M = 35.07$, $SE = 1.54$, $p < 0.001$), while enroute ($M = 41.48$, $SE = 1.53$, $p < 0.001$), and when arriving on scene ($M = 55.35$, $SE = 1.57$, $p < 0.001$). Results remained significant at the $p < 0.001$ level when controlling for movement. See **Figure 2** for a line chart of estimated marginal means for phase of call.

Incident Factors

Recall that our second hypothesis was that CFS dispatched with a higher priority level (i.e., very urgent), that involved an arrest/apprehension, UoF, and/or a weapon being reported or accessible, would result in officers experiencing elevated physiological arousal. Results for the incident factors show that $\text{HR}_{\text{peak above resting}}$ significantly differed as a function of call priority [$F(2,713.764) = 10.221$, $p < 0.001$], reported/accessible weapon(s) [$F(1,690.781) = 5.594$, $p = 0.018$], arrest/apprehension [$F(3,666.173) = 4.884$, $p = 0.002$], and UoF [$F(2,671.957) = 9.5$, $p < 0.001$]. Results remained significant when controlling for movement. Specifically, results indicate that very urgent calls were associated with a 7 bpm increase in heart rate compared to routine calls ($p < 0.001$), while the report/accessibility of a weapon(s) increased heart rate by 3.8 bpm ($p = 0.018$). An incident involving an arrest resulted in a 6.5 bpm increase in heart rate, compared to one that did not ($p < 0.001$). Similarly, responses involving a participant's use of their firearm elevated heart rate by 8.3 bpm compared to a response that involved no UoF ($p < 0.001$). Incidents involving non-firearm UoF did not result in a significant increase in HR (0.58 bpm, $p = 0.784$), however, this can be attributed to the collinearity between arrest/apprehension and UoF (i.e., most arrests involve some level of force, such as soft physical control techniques). In fact, when the arrest/apprehension factor was removed from the model, non-firearm UoF resulted in a 5.6 bpm increase in heart rate ($p < 0.001$). Overall, our hypothesis was supported and, with the exception of call priority, results remained consistent when controlling for movement.

Demographics and Experience

Results for the demographic and experience characteristics show that $\text{HR}_{\text{peak above resting}}$ did not significantly differ as a function of gender [$F(1,65.255) = 2.216$, $p = 0.141$], age [$F(1,66.842) = 1.259$, $p = 0.266$], or years of service [$F(1,61.406) = 0.028$, $p = 0.867$]. Results remained non-significant when controlling for movement. Due to collinearity between age and years of service, models were run that retained one variable, while excluding the other. Neither age ($B = -0.191$, $p = 0.169$) nor years of service ($B = -0.344$, $p = 0.412$) became significant with this approach. The results did not support our third hypothesis, that officers with more experience (i.e., years of service) would experience lower cardiovascular reactivity during CFS.

Training

Our fourth hypothesis, that officers with more relevant operational skills training would experience lower cardiovascular reactivity during CFS, was also not supported. In both models, with and without movement, the composite training variable created from the sum of the training experience criteria for

TABLE 6 | Linear mixed-effects model for repeated measures with $HR_{\text{peak above resting}}$ as a function phases of the calls, officer characteristics, incident factors, and training with and without movement as a covariate.

	Without movement				With movement			
	B	***SE***	***t***	***p***	***B***	***SE***	***t***	***p***
Fixed effects								
(intercept)	28.61	5.40	5.30	< 0.001	28.66	5.23	5.48	< 0.001
Phase of call[a]								
Encounter/use-of-force/arrest	24.39	1.04	23.52	< 0.001	18.15	1.02	17.72	< 0.001
Arrival on scene	20.28	0.65	31.36	< 0.001	11.58	0.67	17.32	< 0.001
Enroute	6.41	0.45	14.11	< 0.001	7.33	0.40	18.20	< 0.001
Dispatch	–				–			
Sex								
Female	3.39	2.21	1.54	0.130	2.71	2.14	1.27	0.209
Male	–				–			
Age	−0.18	0.16	−1.12	0.266	−0.21	0.15	−1.35	0.181
Years of service	−0.08	0.47	−0.17	0.867	0.03	0.46	0.07	0.942
Call priority								
(1) Very urgent	7.00	1.55	4.52	< 0.001	5.61	1.39	4.04	< 0.001
(2) Urgent	1.82	0.87	2.09	0.037	1.32	0.78	1.68	0.093
(3) Routine	–				–			
Weapon(s) reported/accessible								
Yes	3.80	1.60	2.37	0.018	4.11	1.44	2.85	0.005
No	–				–			
Arrest/apprehension								
Arrest	6.48	1.74	3.72	< 0.001	6.49	1.57	4.14	< 0.001
MHA apprehension	3.65	2.02	1.80	0.072	2.80	1.81	1.54	0.123
Present while other officer conducted arrest	3.17	2.19	1.45	0.148	1.47	1.97	0.75	0.454
No	–				–			
Use-of-force								
Firearm	8.30	1.90	4.36	< 0.001	7.64	1.71	4.46	< 0.001
Non-firearm	0.58	1.77	0.33	0.743	−0.17	1.59	−0.11	0.913
No	–				–			
Level of training	−0.22	0.81	−0.28	0.784	−0.19	0.78	−0.24	0.807
Movement	–	–	–	–	2.53	0.11	24.04	< 0.001
Random effects	**Var**	***SD***			**Var**	***SD***		
Officer (intercept)	36.47	6.0			35.69	6.0		

Unstandardized regression coefficient (B), standard error (SE), and t-value (t). Mean resting heart rate was 63 beats per minute. [a]*Repeated measures.*

each officer had a non-significant effect on $HR_{\text{peak above resting}}$ [$F(1,66.555) = 0.076$, $p = 0.784$].

Movement

When speed (km/h) at each phase of the call was included as a covariate to control for movement, it had a significant effect on $HR_{\text{peak above resting}}$ [$F(1,1664.088) = 577.717$, $p < 0.001$]. Results indicate a 2.5 bpm increase in heart rate for every 1 km/h increase in movement. The inclusion of speed (km/h) in the model did not significantly alter the results of the model, except for estimates of HR during the phase of the calls. Specifically, decreases in estimated HR were observed during the phases of the call where one would expect more movement. Thus, controlling for movement, estimates for arrival on scene and the encounter/UoF/arrest decreased by 8.7 and 6.2 bpm, respectively.

DISCUSSION

The current study measured continuous ambulatory cardiovascular reactivity to develop a "profile" of physiological responses associated with various aspects of police encounters. This novel approach expanded on the pilot work of Hickman et al. (2011), to establish the feasibility of using GPS and detailed operational police records to map general duty police officers' autonomic stress responses to the phase of a call and incident factors. Consistent with the findings of Anderson et al. (2002), the current study sample demonstrated that officers had a HRmin of 59 bpm and an HR_{average} of 83 bpm during their shift. The striking similarity between HR measures in our study and those in the only other known study involving on-shift HR tracking of general duty officers, improves the generalizability of our results. The current research also builds on the growing body of evidence (e.g., Anderson et al., 2002; Andersen et al., 2016b) indicating

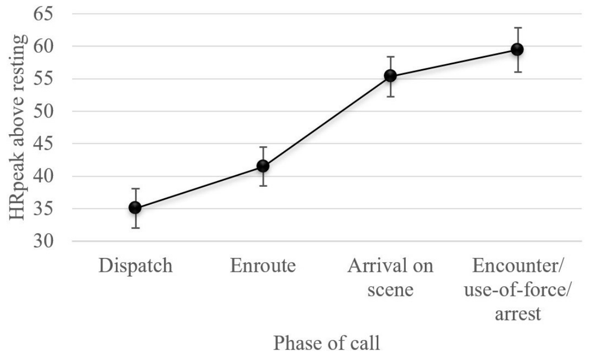


FIGURE 2 | Line chart displaying estimated marginal means for phase of call, without movement as a covariate, from the linear mixed-effects model for repeated measures (of note, results did not significantly change when movement was included as a covariate – see **Table 6**). HR_{rest} was 63 bpm.

that stress arousal is a real consideration in general duty policing. For example, in our study, significant cardiovascular reactivity was observed during shifts with HR_{max} averaging 148 bpm for participants and ranging up to 203 bpm.

Building on the work of Anderson et al. (2002), our use of advanced statistical methods (i.e., LMM for repeated measures) allowed us to examine how officers' cardiovascular reactivity uniquely varied as a function of call priority, the phases of the call, incident factors, demographics, and training. Results indicate that very urgent priority 1 calls, which accounted for 8% of CFS in this study, were associated with a 7 bpm increase in HR compared to routine calls ($p < 0.001$). As we hypothesized, independent of incident factors, average HR at dispatch (98 bpm) was significantly higher than HR_{rest} and steadily elevated while enroute (105 bpm), when arriving on scene (118 bpm), and during the encounter/UoF/arrest phase of the call (123 bpm); demonstrating increasing arousal throughout a CFS (see **Figure 2**). Moreover, in support of our second hypothesis, specific incident factors, such as the report/accessibility of a weapon(s), making arrests, and drawing one's firearm, increased heart rates (by 3.8, 6.5, and 8.3 bpm, respectively) relative to calls where these factors were not present. Unfortunately, it was not possible to consistently determine the phase of a call that an officer became aware of a weapon (or potential weapon). This limits our ability to tease apart whether the influence of weapons on cardiovascular reactivity presented from a perceived (anticipatory) or real threat.

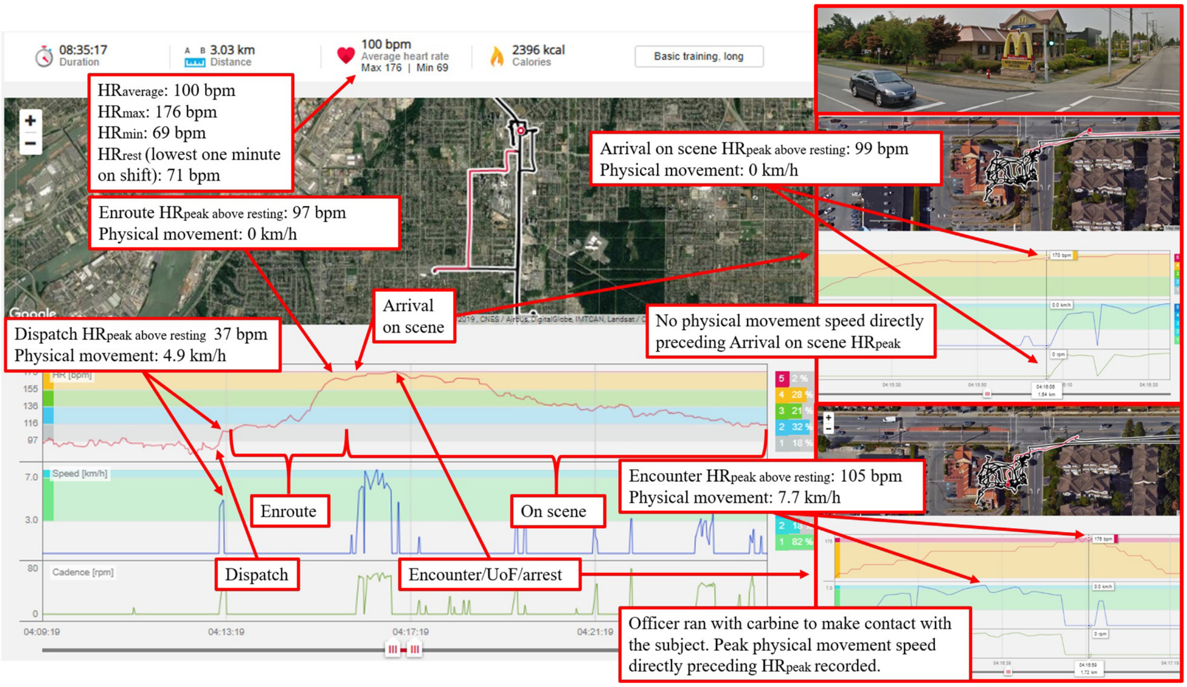
In the current study, individual variables including an officer's age, gender, years of service, and training profiles, were examined to conduct a preliminary exploration of whether demographic variables, experience, or relevant operational skills training impacted cardiovascular reactivity. None of these variables showed a significant effect, indicating that physiological arousal may not be a function of officer characteristics, nor the level of experience (i.e., years of service) or the type of training that was examined in this study, as we hypothesized. Instead, as discussed above, stress reactivity was primarily associated with higher risk incident factors. The findings related to experience and training align with studies of tactical officers, who generally respond to high risk encounters (Andersen et al., 2016a,b). Specifically, Andersen et al. (2016a,b) found that tactical officers, despite their many years of service and elite training, typically operate at a higher level of arousal (e.g., 146 bpm), ranging from 160 to 180 bpm during UoF encounters. In both types of research (general duty and tactical officers) we see that typical police training alone does not seem to reduce physiological arousal to high risk calls. Thus, it seems likely that call risk, or perceived call risk, rather than training itself, may be determining an officer's level of physiological arousal. That being said, it is worth reiterating that although the training results of the current study align with previous research, the basic training measure used in the current study was limited. Specifically, the composite training variable did not consider the recency or frequency of training experience, nor weight types of training differently. Future research should use a more sophisticated measure of training that considers these additional factors.

Notably, this was the first known on-shift policing study to objectively measure physical movement (i.e., location and inertia) to assist in differentiating whether cardiovascular reactivity was due to physical or psychological stress. We know from medical science that movement of the body increases oxygen demands to the muscles and thus could be responsible for the increase in heart rate (via increases in respiration to meet oxygen demands). In this study we were not able to collect respiration rate. Thus, we used movement as a covariate (a proxy of increased oxygen demands) to examine if the increases in heart rate could be explained by purely physical reasons (i.e., oxygen demands to the muscles); if not, then increases in heart rate potentially stem from psychological stress. Interestingly, increases in HR resulting from physical movement appeared to be largely independent of increases in HR related to incident factors (e.g., arrest, use of a firearm). Therefore, significant increases in HR, which were observed when officers were presented with a real or perceived threatening stimulus (i.e., priority 1, reported/accessible weapon[s], arrest/apprehension, and the UoF), appear to be attributable to psychological stress and the initiation of the fight-or-flight response. The inclusion of movement as a covariate in research examining on-shift stress in general duty police encounters is a novel contribution to the field and these results support that psychological stress is a consistent and central component of operational police responses. A real-world example from the study (see **Figure 3**), demonstrates a case of psychological stress during a high risk CFS.

Overall, the general findings reported above form a foundational step for future research investigating the impact of (psychologically related) physiological arousal. This research is likely to have implications for three important components associated with policing: performance, training, and long-term health.

Relationship Between Stress, Experience, and Performance

The relationship between arousal, experience, and performance in police encounters is complex and not fully understood.



HRaverage: 100 bpm
HRmax: 176 bpm
HRmin: 69 bpm
HRrest (lowest one minute on shift): 71 bpm

Enroute HRpeak above resting: 97 bpm
Physical movement: 0 km/h

Dispatch HRpeak above resting 37 bpm
Physical movement: 4.9 km/h

Arrival on scene HRpeak above resting: 99 bpm
Physical movement: 0 km/h

No physical movement speed directly preceding Arrival on scene HRpeak

Encounter HRpeak above resting: 105 bpm
Physical movement: 7.7 km/h

Officer ran with carbine to make contact with the subject. Peak physical movement speed directly preceding HRpeak recorded.

FIGURE 3 | The officer was responding to an assault in progress at a McDonald's restaurant. While enroute, dispatch advised that the subject was possibly armed with a firearm. When arriving on scene, before leaving the police vehicle, the officer's HR had reached 170 bpm (absent of movement). The officer, equipped with his carbine, made contact with the subject through the drive-thru window. The subject had a screw driver in one hand and a spatula in the other. The subject complied with commands to drop the weapons and exited from the drive-thru window. The subject was laid face-down on the ground, but then stood up and took an assaultive stance with clenched fists. The officer transitioned from his carbine and deployed his conducted energy weapon in probe mode. The subject was then taken into custody by multiple officers. Imagery 2019, CNES/Airbus, DigitalGlobe, IMTCAN, Landsat/Copernicus, McElhanney.

Fortunately, several policing studies have demonstrated that realistic scenarios can be developed that elicit average HR that replicate stressful real-world encounters (i.e., ~140 bpm or more). These scenarios provide researchers with the opportunity to carefully study the relationship between these various factors. Within these scenarios, stress reactivity can result in perceptual distortions (e.g., tunnel vision, auditory exclusion) as well as increased performance errors and deficits in verbal communication, of the sort that are often witnessed in the field (Meyerhoff et al., 2004; Lewinski, 2008; McCraty and Atkinson, 2012; Brisinda et al., 2015; Andersen and Gustafsberg, 2016; Andersen et al., 2016b; Arble et al., 2019). However, while stress can deteriorate police performance, officer experience and training has been shown to improve performance in UoF scenarios in some studies. Specifically, studies have shown that, compared to novices, experienced and elite officers often demonstrate improved decision-making processes, attentional control, shot accuracy, and cue recognition, as well as fewer decisions errors (Vickers and Lewinski, 2012; Renden et al., 2015; Boulton and Cole, 2016; Landman et al., 2016b).

Given these findings, the interaction between stress, training, and performance requires further examination. For example, it would be important to determine if there is an optimal range of physiological arousal for best performance, whether this optimal range varies as a function of experience and training, and whether this optimal range varies by call type, call priority, and/or call phase. Once these issues have been examined in scenario-based studies, confirming that the results can be replicated in field studies is important. This seems particularly important given the results of the current study, where experience factors (as measured in the current study and discussed above) were not related to stress reactivity. While performance was not examined in our study, we believe that with slight modifications the methods we used could provide the foundation for future research on the relationship between stress, experience, and performance. For example, a ride-along component could be added to assess performance as other researchers have recently done (e.g., Todak and James, 2018).

Evidence-Based Training

While the body's default response to successfully cope with a threat is to stimulate fight-or-flight physiology (LeDoux and Pine, 2016), research indicates that this threat response is malleable, with certain types of training being shown to improve performance and increase resilience to stress reactions (Driskell et al., 2001; Arnetz et al., 2009; Nieuwenhuys and Oudejans, 2011b; Andersen et al., 2018). Research suggests that initial learning (e.g., skills acquisition) occurs best under low levels of stress (Driskell and Johnston, 1998; Driskell et al., 2008). However, skilled performance is typically learned through practice in settings that mimic the environment in which the skills will be performed operationally (Schmidt and Lee, 2013).

For example, traditional firearms qualification scores have high congruency with other marksmanship assessments, but low congruency with the dynamic and rapidly unfolding nature of real-world OISs (Morrison and Vila, 1998; Wollert et al., 2011).

A well-established method for developing stress resilient skills and performance is stress exposure training (SET; Johnston and Cannon-Bowers, 1996; Driskell and Johnston, 1998; Driskell et al., 2008). SET is comprised of three carefully scaffolded phases: (1) information provision, (2) skills acquisition, and (3) application and practice, which encompass various techniques and components (Johnston and Cannon-Bowers, 1996; Driskell and Johnston, 1998; Driskell et al., 2008). The application and practice phase is typically achieved through scenario-based training (SBT), which provides officers a realistic, yet safe environment to make errors that, if made on-duty, could have severe consequences. SBT also allows officers to receive corrective feedback on their performance (Armstrong et al., 2014). The purpose of this phased approach is to increase knowledge of stress effects, reduce individuals' anxiety and reactivity to stressors, and increase resources (e.g., skills schemas), confidence, and ability (e.g., coping) to perform under stress.

There is also growing evidence that decision-making accuracy and performance is not only related to increased sympathetic activity, but also the suppression of the stress modulating parasympathetic influence (Saus et al., 2006; Andersen et al., 2018). As such, police training that targets officers' capacity to recognize and self-regulate their responses to stressors are demonstrating promise (McCraty and Atkinson, 2012). For example, Andersen et al. (2018) demonstrated that a physiologically focused intervention that taught police officers how to modulate SNS and PNS activation during SBT with real-time cardiovascular biofeedback led to significant reductions in lethal force decision-making errors and quicker physiological recovery from stress; improvements which were maintained over the 18 month study period.

While these training methodologies provide evidence of improved performance and increased resilience to the sorts of stress reactions observed in the current study, their adoption in policing is rare; in fact, stress-based training of any type appears to be used infrequently and training is seldom evidence-based or evaluated for intended outcomes (Sherman, 2015). For example, the authors are not aware of any studies that evaluate standard in-service police training for the alignment with the principles of SET. Furthermore, we could locate only one study that objectively measured levels of stress in training (Armstrong et al., 2014).

Armstrong et al.'s (2014) study examined four scenarios that were part of an agency's mandatory UoF SBT. The results showed that, on average, HRs rose from 97 bpm pre-scenario to 116 bpm during physical contact. In contrast, the results of the current study found average HR between 116 and 142 bpm during the encounter/UoF/arrest phase (dependent on the incident factors present). This discrepancy highlights the value of research, like the sort presented in this paper. Our study indicates that the SBT training evaluated by Armstrong and colleagues may not be achieving its intended level of realism (i.e., training or testing skills under realistic conditions). The results of studies like ours can help inform the development and delivery of realistic and effective operational skills training that approximates real-world stress exposure. This evidence-based training approach is likely to be particularly important for improving performance in UoF encounters, which while low frequency (Hall and Votova, 2013; Baldwin et al., 2018), can result in tragic consequences and present substantial liability for officers and agencies (Braidwood, 2010; MacNeil, 2015; Dubé, 2016). It is also important to point out that studies like ours can also inform the development of SBT content, by informing agencies as to what sort of CFS and incident factors are occurring within their jurisdiction (e.g., if weapons are often accessible in CFS, that should be an element that is built into SBT scenarios).

Arousal and Health

How occupational stress arousal impacts long-term health is also an area of avid interest and requires further investigation. Longitudinal research studies conducted with frontline officers have demonstrated elevated risks of chronic disease such as cancer, diabetes, and heart disease compared to populations of similar age (Violanti, 1983; Violanti et al., 2006b; Charles et al., 2007). Results described in this paper highlight the sorts of risks that officers are routinely exposed to in the course of their duties, while also revealing the nature of the stress reactions (and the frequency of these reactions) that may be at the root of some of these health concerns.

That being said, it is important to note that physiological arousal associated with high risk encounters (including those that involve UoF) may not necessarily be detrimental. In fact, it may be the case that higher levels of physiological arousal are appropriate (even preferred) in some encounters in order to meet the demands of the situation. What will be critical from a health risk standpoint, is not necessarily the level of arousal one experiences during the event, but *quick recovery* from the arousal (e.g., recovery within or shortly after the event). The frequency of high risk encounters in an officer's shift, which was routinely observed in our study, may be problematic if it means that officers do not have time to recover fully during their active duty days. If this occurs, officers may experience accumulated stress that results in allostatic load, or "wear and tear" on the cardiovascular system, that is associated with long-term health outcomes (McEwen, 1998; Violanti et al., 2006b). Longitudinal research with police officers indicates that occupational stress is associated with chronic health outcomes such as cardiovascular and metabolic disease (Violanti et al., 2006b), but the study design does not allow for the distinction between the contribution of acute versus chronic stress to disease. Unfortunately, in the current study, we were unable to examine recovery rates and levels due to the varying and confounding nature of post-CFS activities (e.g., sitting, standing, reporting writing, immediately responding to another CFS) and inconsistent documentation of activities between calls (e.g., breaks, meals, interactions with officers/public). Thus, we cannot speak to health outcomes directly. Future research should certainly prioritize this so we can understand the long-term health implications of the "physiological profiles" that were generated from our study.

Limitations

While we are optimistic about the use of these research findings to improve police training and health research, we caution future researchers and lay persons to interpret and use the findings with consideration given to study limitations. For example, there is significant public interest in understanding (and being able to explain) all police actions, particularly lethal encounters. Thus, there may be a temptation to use physiological arousal, as measured in research studies such as this, to find an individual officer culpable for their actions (e.g., "that officer was likely so stressed that their performance must have been compromised"). However, it is not appropriate to do this using research of the sort reported on here. For example, it is incredibly important to remember that *group level analyses* of stress, training, and performance can only be used to understand general relationships between these variables. While this understanding may be useful to improve police training, real-world performance, or overall health, in a general way, at no time are group level research findings on physiological arousal able to be used to explain why *one particular officer* acted in the way he/she did in the field.

While HR is the most easily monitored physiological measure of stress, we must stress that this is not an absolute measure of an individual's stress, nor does it unequivocally predict individual performance under stressful conditions (Meyerhoff et al., 2004; Brisinda et al., 2015; Arble et al., 2019). Research equipment used to measure ambulatory physiological arousal in police research is not as accurate as tests used for diagnostic medical purposes (i.e., hospital grade ECG testing for cardiovascular disease), and therefore this measure must be interpreted with caution. Furthermore, the collection of additional biological indicators of the stress response (e.g., HPA activity, blood markers) was not possible in this real-world study as it may have interfered with the officer's ability to meet the challenges of the emergency situation at hand. As heart rate reactivity is only one aspect of the stress response system, future research should include as much bio sampling as is logistically and ethically possible.

Above all else, research of this type (regardless of which recording device or bio-physiological measure one uses) cannot account for all the factors that likely go into an individual officer's continuous risk assessment of a situation (which will likely include an assessment of subject behavior, environmental features, tactical considerations, etc.) and in the moment decision-making during a real-world encounter. Therefore, the appropriateness of an individual officer's behavior in any particular encounter must be judged based on the *reasonableness* and *necessity* of their actions, given the totality of the circumstances.

CONCLUSION

Very limited research exists that objectively measures stress reactivity experienced by police officers during active duty. This study provides several contributions to the field and adds to the dearth of research in this area. Of note, this study establishes the feasibility of using GPS and detailed operational police records to map general duty police officers' autonomic stress responses to the phase of a call and incident factors. The use of this innovative approach, advanced statistical methods (i.e., LMM for repeated measures), and the ability to differentiate between physical and psychological stress (by controlling for movement), provides robust estimates of (psychologically related) physiological arousal to CFS factors (e.g., call priority, use-of-force). The research findings provide evidence of the extent and frequency of stress arousal in police operations, which has important implications for general duty policing, police training, and health research.

DATA AVAILABILITY STATEMENT

The datasets for this manuscript are not publicly available because of privacy and ethical restrictions. Requests to access the datasets should be directed to SB (simonbaldwin@cmail.carleton.ca).

ETHICS STATEMENT

All procedures were approved by the Carleton University's Research Ethics Board (REB #17-106853) and the agency's Research Review Board (RRB).

AUTHOR CONTRIBUTIONS

SB and CB conceptualized the study. SB, TS, and BJ conducted the data collection. SB performed the data analysis and interpretation with guidance from JA and under the supervision of CB, and drafted the manuscript. CB, JA, TS, and BJ provided critical revisions. All authors approved the final version of the manuscript for submission.

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REVIEW
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The Impact of Acute Stress Physiology on Skilled Motor Performance: Implications for Policing

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Investigations of police performance during acutely stressful situations have primarily focused on higher-order cognitive processes like attention, affect or emotion and decision-making, and the behavioral outcomes of these processes, such as errors in lethal force. However, behavioral outcomes in policing must be understood as a combination of both higher-order processes and the physical execution of motor skills. What is missing from extant police literature is an understanding of how physiological responses to acute stress contribute to observed decrements in skilled motor performance at the neuromuscular level. The purpose of the current paper is to fill this knowledge gap in the following ways: (1) review scientific evidence for the physiological (i.e., autonomic, endocrine, and musculoskeletal) responses to acutely stressful exposures and their influence on skilled motor performance in both human and animal models, (2) review applied evidence on occupationally relevant stress physiology and observed motor decrements in performance among police, and (3) discuss the implications of stress physiology for police training and identify future directions for applied researchers. Evidence is compelling that skill decay is inevitable under high levels of acute stress; however, robust evidence-informed training practices can help mitigate this decay and contribute to officer safety.

Keywords: police, stress response, cortisol, hypothalamic-pituitary-adrenal axis, motor control, movement, muscle tension

INTRODUCTION

High level motor performance skills, including the use of physical control techniques and weapons, are expected of law enforcement officers who routinely operate under acutely stressful work conditions. Mistakes in the application of physical skills can have devastating effects on the individuals involved in such incidents, with serious implications for long-term physical and mental health. Yet, much of the applied research on police performance under stress does not speak to the effects of acute stress physiology on the physical (i.e., neuromuscular) aspects of skilled motor performance, which is necessary to optimize training and best practices. The goal of this paper is to synthesize information from peer-reviewed indexed journal articles in the basic and applied sciences, which address the impact of stress physiology on skilled motor performance among police as a novel contribution to the literature. Following a brief discussion on the definition of "stress," this paper reviews various physiological responses to stress. Using both animal and human evidence, we outline the impact of stress physiology on motor unit recruitment and the skilled performance of motoric workplace tasks. Converging lines of evidence provide a theoretical framework for understanding stress-induced decrements in skilled occupational performance, including a limited body of applied research on stress physiology among police. We conclude with a review of the efficacy for scenario-based training in improving performance decrements among police by way of adaptively inducing skill-appropriate stress and provide future directions for applied research.

PHYSIOLOGICAL RESPONSES TO ACUTE STRESS EXPOSURES AND THEIR INFLUENCE ON SKILLED MOTOR PERFORMANCE

Defining Stress

The term "stress," as originally introduced by Selye (1956), refers to a challenge (i.e., stimulus), psychological or physical in nature, that threatens (or that is perceived to threaten) the internal balance or homeostasis of physiologic systems. However, stress has been used interchangeably to describe the physiologic stress response itself, the stimulus-response interaction, or even the whole spectrum of interacting factors (e.g., stimulus, cognitive appraisal, perception, and coping style) (Violanti and Aron, 1995; Anshel et al., 1997; Anderson et al., 2002; McEwen, 2008). For clarity, in the current review, stress is defined according to the definition provided by Selye (1956), as a challenge or stimulus and is separate from the physiological reactivity that follows in response to the stress or challenge. Thus, a stressor is anything that leads to physiological stress reactivity. As such, stressors can be "real" externally perceived objects such as a weapon, or internally perceived appraisals of an uncertain or potentially threatening situation. The intensity of the physiological reaction to a stressor is therefore highly individual and situationally dependent (Dewe, 1993; Peters et al., 1998). Many variables, including personal attributes, implicit or explicit neurocognitive appraisals, coping strategies, social support, and past experiences may modify the physiological stress response in any given situation and can account for the different response of two individuals exposed to the same stressor (Anshel et al., 1997; Anderson et al., 2002; Babenko et al., 2015; Ambeskovic et al., 2017).

Independent of the type of stressor, a physiological stress response is initiated by the brain and can be understood as a nonselective response (i.e., fight-or-flight response) that acts to reorient the individual's cognitive and physiologic capacities to deal with the challenge and return to the original state of homeostasis (Chrousos and Gold, 1992). Situations or stimuli that are novel, unexpected, or unpredictable are generally perceived as more stressful and associated with a stronger physiological response (Thayer and Sternberg, 2006). The following sections will review key physiological systems that respond to acute stressors in order to provide a theoretical context for understanding how occupationally relevant stress can result in decrements to skilled motor performance.

Physiological Responses to Acute Stress Exposure

The Autonomic Nervous System Response to Stress

The physiological response to a stressor occurs largely outside conscious awareness, arising from neural circuits that are also responsible for imbuing meaning and personal relevance to external stimuli (LeDoux and Pine, 2016; Ginty et al., 2017). In response to a stressor, a complex cascade of internal processes is stimulated and coordinated by the brain, beginning with autonomic nervous system (ANS) activation, thermogenesis, elevated blood glucose levels, and other responses in the service of returning the body to homeostasis (e.g., see Rivolta et al., 2014). The ANS regulates the function of internal organs, such as respiratory and cardiovascular activation (DeRijk and de Kloet, 2005; Agorastos et al., 2018). The ANS is divided into sympathetic (SNS) and parasympathetic (PNS) branches (Thayer and Sternberg, 2006). Although the relationship between SNS and PNS activity is complex and should not be thought of as an "either/or" system, it is generally accepted that during a physiological stress response, the SNS is activated and PNS, responsible for calming and stabilizing the body, is withdrawn (Thayer and Sternberg, 2006). The degree of a SNS response is thought to be determined by one's perception of how threatening the stimulus is, even if the perception is not within conscious awareness (Kalisch et al., 2015; LeDoux and Pine, 2016). Further, the physiological responses during stress can be enhanced or diminished by psychological factors, such as perceived control over the situation (McEwen, 2008).

Adaptive SNS arousal is beneficial for performing optimally during critical incidents. The benefits of adaptive arousal include alertness, focused attention, and improved cognitive performance (Jamieson et al., 2010). During adaptive SNS arousal, sensory perception including visual, auditory, and olfactory senses are enhanced (McNish and Davis, 1997). Improved sensory awareness increases an individual's ability to successfully address a stressor (Kalisch et al., 2015). However, during more extreme stress, the SNS response may dominate or become maladaptive and performance starts to deteriorate. The mechanism by which the autonomic stress response influences skilled motor performance is poorly understood in humans, and animal models have been used to help explain the underlying mechanisms. Evidence for skilled motor performance decay in animal models and various occupations are reviewed below, with emphasis on police.

Neuroendocrine Stress Model: The Brain's Hormonal Response to Threat

If a stressor does not dissipate immediately, the brain will initiate an endocrine response following the activation of the ANS. The endocrine response begins *via* the activation of the hypothalamic-pituitary-adrenal (HPA) axis. The HPA axis prompts the release of hormones, including corticotropin releasing factor (CRF) from the hypothalamus (DeRijk and de Kloet, 2005; Frasch et al., 2018). CRF in turn triggers the release of adrenocorticotropic hormone (ACTH) from the anterior pituitary, which then reaches the cortex of the adrenal glands to stimulate secretion of adrenal glucocorticoids (GCs). The increase of adrenal GCs in blood, such as cortisol in humans and corticosterone in rodents (in the following both referred to as CORT), is considered the main physiological correlate of stress (de Kloet et al., 1998). GCs can travel with the blood to reach any organ in the body, including crossing the blood-brain barrier to exert their most prominent actions on the brain (Chrousos, 2009). The action of GCs has been explained by the concept of the "inverted U-shape" (Sapolsky, 1997; Salehi et al., 2010; see also Di Nota and Huhta, 2019). Depending on the duration and severity of the stress, the response to GCs can promote or impede brain function and adaptive behaviors. Thus, optimal GC levels ensure best performance in day-to-day work situations, including acutely stressful policing situations (Regehr et al., 2008).

Repeated Exposure to Acute Stress: Causes and Effects

While this paper addresses acute exposures to stress, the repeated and prolonged exposure to occupational stress in police officers can manifest as chronic stress, and this in turn impacts skilled performance under acutely stressful events. In the brain and other organs, CORT binds to two types of receptors – the high-affinity mineralocorticoid receptor (MR) and the low-affinity glucocorticoid receptor (GR; de Kloet et al., 1998). Once bound, CORT and GR build a complex that binds to DNA to activate gene expression and generate lasting changes in cellular functions. Furthermore, GRs within the HPA axis serve an important negative feedback function, like a thermostat, to downregulate GC production once the stressful event subsides. The negative feedback regulation is critical to end the stress response when dealing with an acute, short-term stress. The enduring activation of the stress response, however, when faced by lasting, chronic stress, may eventually be associated with down-regulation of GRs (Mizoguchi et al., 2003) or the development of GR resistance (Cohen et al., 2012) at the feedback sites of the brain. This change will diminish the negative feedback regulation by the HPA axis and result in prolonged maintenance of the stress response and prolonged exposure of the brain to higher levels of GCs. Extended periods of stress and elevated levels of GCs can alter brain function and increase vulnerability to neurological disease (McEwen, 2000; Madrigal et al., 2003; Cottrell and Seckl, 2009), including those conditions that affect motor function. Recent evidence shows consistently elevated levels of diurnal (i.e., daily fluctuating) CORT among police officers relative to the general population, with specialized tactical officers demonstrating even higher levels of resting CORT than frontline officers (Planche et al., 2019). These findings provide a physiological basis for long-term risk of physical and mental disorders among law enforcement personnel (Franke et al., 2002; Ramey et al., 2009; Joseph et al., 2010; Violanti et al., 2018), which may be further compounded by the level of risk exposure in policing subspecialties (Planche et al., 2019).

Manifestation of Chronic Stress in the Musculoskeletal System

It has long been hypothesized that increased muscle tension occurs during stressful situations (Malmo et al., 1951), although the data are mixed and depend on the population tested. Westgaard and Bjørklund (1987) demonstrated a consistent pattern of increased muscle tension over and above that required to maintain postural stability during psychophysiological testing. In a series of studies, Lundberg et al. (1994) reported increased muscle tension above that required to overcome the physical load of cashier work when psychological stress was induced and also demonstrated a link between trapezius myalgia and increased stress (both self-report and increased blood pressure) in cashiers (Lundberg et al., 1999). Lundberg (2002) concluded that both physical (such as repetitive movement) and psychosocial (such as increased mental stress) work may be related to the development of upper extremity disorders. In a prospective study, Veiersted (1994) showed higher "resting tension" in the trapezius muscles of chocolate packers who became symptomatic with shoulder pain when compared to healthy controls. Lundberg et al. (1994) suggest psychological stress, with or without physical load, may play a role in musculoskeletal disorders by increasing muscle tension through activation of low threshold motor units creating overload with subsequent degenerative processes.

While Anderson et al. (2002) have demonstrated anticipatory and reactive stress responses in police officers across entire shifts, it can be expected that increased muscle tension may play a role in the physical response patterns and efficiency of police officer movement. As skilled performance activates muscle fibers in a pattern from low to high threshold motor units, it can be hypothesized that chronic stress could shift both the recruitment pattern (requiring more higher threshold motor units to be active) and efficiency of movement (requiring more force to overcome the resting tension) in both stressed and non-stressed environments. However, direct measurement of neuromuscular activation in police officers has yet to be conducted during acutely stressful situations (i.e., real-world or simulated critical incidents), or following prolonged exposure to stress. In a study on combat soldiers, Tornero-Aguilera et al. (2017) found greater lower body muscle strength (measured by various vertical jumps) and higher lactate concentrations in elite relative to novice soldiers following stressful combat scenarios, suggesting that experience (and training) contributes to greater efficiency of movement. In a study by Lewinski et al. (2015b), officers performed several sprinting maneuvers with and without their heavy tactical and safety equipment (approximately 9 kg, or 11% of the participants' body mass). Officer velocity and acceleration was significantly reduced by the additional weight of the equipment, which is required for all officers. These results demonstrate a significant physical burden on officers' ability to operate and further underscore the need to investigate neuromuscular aspects of police performance.

Skilled Motor Impairments in Response to Acute Stress

Even popular culture recognizes the impact of acute stress on motor performance; as illustrated by a classic movie situation in which someone is stalked by an aggressor, gross motor behavior like running away is not problematic. But once at the door, they frantically try to unlock it and experience difficulty inserting the key into the lock. This example best exemplifies the considerable impact of stress on motor skills that require finer control over developed muscle tension, and muscle fiber firing patterns that allow for smooth and accurate movement.

As opposed to skilled movements requiring finer motor control, general motor patterns, such as navigating through a novel environment, are determined mainly by cognitive, emotional, and motivational aspects, and therefore they do not offer a useful model for studying the mechanisms of how stress interacts with the motor system. Skilled movements, however, are an ideal model to examine discrete motor disturbances in response to stress and stress-induced neuroplasticity. Studies in rats have shown that, through direct interaction of CORT and GRs as well as emotional changes, stress can alter the movement trajectories and accuracy of skilled movements in forelimbs and hindlimbs, and disrupt inter-limb coordination (Metz et al., 2005). Furthermore, stress perturbs postural stability in both human subjects and rodents (Maki and McIlroy, 1995; Metz et al., 2003).

A variety of studies have described the contribution of distinct motor areas to skilled reaching movements in humans and animals, mainly through the study of focal lesions of the underlying neural substrate. These investigations revealed discrete changes in the qualitative movement trajectories of reaching for food produced by areas such as the red nucleus (Morris et al., 2011), corticospinal tract (Metz and Whishaw, 2002), motor cortex (Kirkland et al., 2012), striatum (Faraji and Metz, 2007; Jadavji and Metz, 2008; Faraji et al., 2014), and cerebellum (Azim et al., 2014). In these systems, chronic stress was shown to diminish the ability to perform rotatory limb movements in skilled reaching and reduce movement accuracy in the forelimb subsequently leading to significant reduction in skilled reaching success (Metz et al., 2005; Metz, 2007). Furthermore, this study showed that both stress and CORT affect the temporal aspects of movement in that reaching movements became faster and more frantic. This finding concurs with the notion of the fight-or-flight response, which proposes that an individual mobilizes energy to move faster and escape from a threatening situation. Using detailed frame-by-frame analysis of video recordings, the authors suggested that this gain in function may come at the expense of movement accuracy, which in the animal studies was illustrated by animals needing more attempts to grasp a single pellet in parallel to diminished reaching success (Metz et al., 2005; Kirkland et al., 2012). Such a failure to maintain success rates under stressful conditions might also reflect altered sensory feedback, such as loss of haptic feedback and inability to adjust the paw position to grasp a food pellet. Furthermore, dependent on the task, stress and CORT may also impede the use of compensatory movement strategies, such as the modification of a movement strategy to adjust the paw trajectory in a task-specific manner after brain damage (Kirkland et al., 2012).

Central Mechanisms of Skilled Motor Performance Decay

The physiological mechanisms that predict skilled motor performance decay under high stress primarily involve the brain's ability to initiate the proper motor sequences and less to do with changes at the contractile sites within muscle tissue. In support, there are three lines of evidence rooted in fundamental scientific research in animal and human models that suggest that stress and GCs are likely to affect central motor control.

1. *Brain regions participating in motor control have receptors for GCs*. Brain regions participating in motor control, such as motor cortex, cerebellum, basal ganglia, and spinal cord, have a significant density of GRs (Ahima and Harlan, 1990; Ahima et al., 1991; Marlier et al., 1995) rendering them susceptible to the influence of stress-induced elevations of GCs. Accordingly, stress can change the execution of skilled movements. For example, stress and GC treatment significantly diminish skilled reaching success when reaching for a food pellet and impair limb placement accuracy in skilled walking on a horizontal ladder (Metz et al., 2005; Merrett et al., 2010; Kirkland et al., 2012). Stress hormones including CORT, CRF, and ACTH may interfere with motor function *via* direct interactions with GRs, but may also interact with the brain's catecholaminergic systems (Finlay et al., 1995), in particular dopamine, which critically controls balance and fine motor function (Abercrombie et al., 1989; Smith et al., 2008).
2. *Stress hormones can modify pathological processes of the motor system*. Stress is a primary candidate to interact with pathological processes and recovery after motor system lesion. For instance, work investigating rat models has shown that stress can slow motor recovery after dopamine depletion lesion (Smith et al., 2008; Hao et al., 2017) or motor cortex lesion (Metz and Whishaw, 2002; Faraji et al., 2011; Kirkland et al., 2012). The reduced functional recovery in stress-treated animals seems to parallel with increases in lesion size (Kirkland et al., 2008). Stress might exert these effects in association with altered neurotrophic factor expression (Sun et al., 2014). In human studies, stress has also been recognized as possibly the single most important factor to affect recovery and neuroplasticity after motor system injury (Walker et al., 2014).
3. *Stress can modulate motor patterns by altering the affective state*. In addition to direct effects of stress hormones on nervous system function, stress also alters the emotional state which in turn modulates general motor patterns (e.g., walking) and fine movements (e.g., reaching and grasping: Lepicard et al., 2003; Metz et al., 2005) and balance (Maki and McIlroy, 1995). Thus, stress-induced anxiety can modulate motor behaviors, such as motor activity in open field tests (Treit and Fundytus, 1988; Zhu et al., 2014; Monteiro et al., 2015). The relationship between stress-associated anxiety and decrements in motor performance is further supported by the observation that mouse strains bred for high anxiety traits show greater motor skill impairments than less anxious mouse strains (Lepicard et al., 2000, 2003). These effects can be reversed by treatment with anxiolytic drugs, which

were shown to improve motor skill (Lepicard et al., 2003; Metz et al., 2003).

Patterns of maladaptive motor strategies have been observed in police officers, which interact with perceived stress and impact skilled motor performance. By inhibiting a preferred movement strategy (i.e., step then fire) in experienced police officers, self-reported anxiety increased and shooting accuracy was reduced, even if the preferred movement strategy puts the officer at greater risk (Nieuwenhuys et al., 2017).

POLICE STRESS PHYSIOLOGY AND SKILLED MOTOR PERFORMANCE

While the influences of acute stress on police performance have largely focused on cognitive functions, such as decision-making, learning, and memory (see Morgan III et al., 2006; Taverniers et al., 2013; Hope, 2016), a comparably small number of studies have investigated the influence of stress physiology on skilled motor performance. The following will summarize the comparably small number of applied studies that have focused on the influence of stress physiology on skilled motor performance among police.

Stress Physiology During Active Duty and Training Among Police

Individuals employed in public safety and protection environments are often exposed to a wide variety of stressors, and the response to each type of stressor will vary greatly across the population or different responders. As one would expect, various physiological measurements have revealed increased stress reactivity during physical and psycho-social aspects of police work in active duty settings (Anderson et al., 2002; Andersen et al., 2016b,c). Anderson et al. (2002) found increased cardiovascular stress responses while measuring police officers during periods of heightened physical demand (e.g., escalating use of force activities), situations where there is potential threat (e.g., hand on gun situations) and during periods of anticipation (e.g., pre-deployment or driving to an event with lights and sirens). These data are consistent with those of Anshel et al. (1997) who rated facing unpredictable situations as the most severe acute stressor experienced by this population and which is characteristic of most police deployments.

More recently, work by Baldwin et al. (2019) measured officers' cardiovascular activity (peak heart rate above resting average) and physical movement (speed) to reveal unique and dynamic influences of physical and psychological stressors during various phases of general duty calls (i.e., arriving on scene, encountering a subject). Officers' stress responses increased with the priority of a call (i.e., very urgent > urgent > routine) and with the report of a weapon present. Calls involving use of force had elevated stress responses during all phases of the call, including dispatch, en route, and arrival. Officer age, gender, years of experience, and level of specialized operational skills training in use of force and other physical tactics did not significantly modulate stress reactivity (Baldwin et al., 2019).

A misconception remains among some police trainers and law enforcement agencies that simulation training cannot elicit real world stress responses because the results of the training are not grievous. A growing body of research shows that this is not the case and demonstrates significant increases in police officers' stress physiology during high threat simulations or scenarios relative to rest (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010, 2011; Nieuwenhuys et al., 2012, 2015; Andersen and Gustafsberg, 2016; Andersen et al., 2016a, 2018; Arble et al., 2019; Bertilsson et al., 2019b). Using salivary (Andersen et al., 2016a) and cardiovascular biomarkers of stress reactivity (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010, 2011; Nieuwenhuys et al., 2012, 2015), researchers have demonstrated significant increases in stress reactivity during high-threat relative to non-violent or low-threat scenarios. During virtual lethal use of force training, Groer et al. (2010) demonstrate high levels of stress reactivity through several different endocrine measures, concluding that training scenarios designed and delivered in a virtual modality were capable of producing realistic physiological stress responses (see section "Implications for Motor Skills Training" for discussion of performance gains with virtual training).

Armstrong et al. (2014), Andersen and Gustafsberg (2016), and Andersen et al. (2018) also show ecologically valid increases in heart rate among police officers when accessing weapons and engaging in live-action use of force training scenarios. Recent evidence from Bertilsson et al. (2019b) show that repeated and consecutive performance of stressful training scenarios lead to cumulative physiological effects, such that increases in heart rate are observed even prior to scenario onset (i.e., anticipatory stress) and continue to escalate with subsequent stressful exposures. Additionally, Bertilsson et al. (2019b) demonstrate a complex pattern of pupil dilation that also reflects sympathetic stress responsivity, with greater increases in pupil dilation during early tasks. These findings bear greatly on the immediate and cumulative impact of repeated exposure to stressful encounters on police physiology, but performance results were not reported. Direct comparison of training and general duty stress physiology by Andersen et al. (2016c) confirm that scenario-based training can successfully reproduce the stress reactivity one would expect in real-world environments.

Stress-Induced Decrements in Skilled Motor Performance Among Police

Physiological responses to stressful encounters observed in police officers and described above are typically paired with decrements in skilled motor performance. The investigations by Nieuwenhuys, Oudejans, and colleagues summarized above demonstrate significantly greater physiological arousal as well as shooting skill deterioration under high stress conditions that included a heavily armed person or cannon that could shoot back at the officer, versus low threat conditions with static or unarmed targets. Stress-induced decrements to participants' shooting performance include decreased accuracy, faster reaction times, and more false positives (i.e., shooting unarmed targets) (Oudejans, 2008; Nieuwenhuys and Oudejans, 2010, 2011; Nieuwenhuys et al., 2012, 2015). Together, these results demonstrate significant skill deterioration during stressful shooting situations that feature either physical or psychological stress.

As another variant of gross (versus fine) motor skills, complex motor skills typically used in the line of duty, including non-verbal communication, arrest, and self-defense skills, have also been shown to degrade under high versus low stress conditions (Nieuwenhuys et al., 2009). Arble et al. (2019) show differential effects of cardiovascular stress responses on motor skill decrements such that increased antithrombin – an anti-clotting factor released following increases in heart rate – predicted improved overall performance as evaluated by experienced police trainers, but also predicted a specific deficit in verbal communication. Nieuwenhuys and Oudejans (2010) measured shooting accuracy, movement times, head orientation, and blink behavior in police officers in a low anxiety condition with a non-threatening opponent and in a high anxiety condition against a threatening opponent who could shoot back using colored soap cartridges. Under the high anxiety condition, participants changed their body position, acted faster, and increased blink frequency, hence increasing the amount of time the eyes were closed. As a result of quicker movement, a compressed body position that might not facilitate proper shooting mechanics and an extended period of time without visual contact with the suspect (i.e., more blinking), significant decrements in shooting performance were observed. Similarly, Renden et al. (2014) found police officers were "less able to inhibit stimulus-driven processing (fear of getting hit) and enforce goal-directed processing (perform the skill as well as possible) leading to avoidance behavior (p. 100)" with a decrease in simulated arrest performance (Renden et al., 2014). Officers' reactions to stressful encounters are also bound by their natural (i.e., untrained) startle responses, which induce muscle contractions within milliseconds of perceiving a threatening stimulus. Two investigations by Lewinski et al. (2013, 2015a) systematically evaluated officer reaction times and skilled motor responses from various tactical starting positions. Kinematic analyses of officer movement patterns reveal that officers who successfully completed retreat movements *before* drawing their firearms were faster at reaching a safe zone, and that officer's finger-indexing (e.g., high on the slide) and tactical positions (e.g., low-ready, high-guard) significantly impacted performance time. Therefore, training that promotes skill learning by inducing stress can help override natural, unconditioned startle responses or preferred positioning that could endanger officers during critical incidents.

These investigations provide evidence for decrements in the cognitive (i.e., stimulus versus goal) and visuomotor processes (i.e., attention, perception) underlying motor performance under stressful simulated environments. However, the precise mechanisms by which occupationally relevant stress physiology impairs neuromuscular aspects of skilled motor performance among law enforcement remain unknown. Inferences from fundamental scientific literature using animal and human models described above can be drawn, but future investigations accounting for the unique and highly dynamic nature of police work can begin to fill this gap in the applied literature while also contributing to the development of evidence-based training practices.

IMPLICATIONS FOR MOTOR SKILLS TRAINING

Prior to skill mastery, novice learners need to learn fundamental motor skills in the absence of high stress conditions. Component "chunks" of behavior should be learned in a progressive manner, with increasing skill complexity once movement patterns are engrained, efficient, and accurate. Once primary skills can be demonstrated at a high level of performance, training should progress to the application of these skills in a wider variety of complex situations that also increase the stress response (*cf*, Di Nota and Huhta, 2019). While the underlying mechanisms remain unknown, Vickers and Lewinski (2012) provide evidence for experience- and (possibly) training-related differences between novice and elite police officers in visuomotor (gaze control) and motor performance during stressful live training scenarios. Officers with more experience made fewer decision-making errors, shot more accurately, had faster motor onsets (i.e., draw/aim/fire) and greater visual fixation on targets (referred to as "quiet eye") prior to firing, contributing to greater accuracy and fewer errors. Highlighting specific motor decrements in novice versus experienced officers can help inform the skills that need to be targeted in firearm and tactical training, especially for recruits.

A growing body of research reveals the effectiveness of live simulation or scenario-based training for improving stress-induced decrements to skilled motor performance among first responders. Scenario-based training is founded on adult learning principles that adaptively expose officers to realistic and occupationally relevant stressors in a safe, controlled environment. With constructive feedback from experienced trainers, correct motor strategies are encoded either through correct performance or feedback on errors that can be made without life-threatening consequences. Scenario-based training is effective for teaching both new skills or refreshing essential skills that can be recalled and utilized more successfully under the same stressful conditions with which they were taught (Murray, 2005; Barney and Shea, 2007; McNaughton et al., 2008).

Physiological stress responses are induced during scenario-based training by using realistic actors, environments, props, and subject matter that are challenging for the skill level and experience of the student (Birzer and Tannehill, 2001; Murray, 2006; Bennell et al., 2007; Krameddine and Silverstone, 2015; Andersen and Gustafsberg, 2016; Andersen et al., 2018). Scenario content should be based on situations and events that the trainee will typically face in their day-to-day duties, but may also include preparation for worst-case events. However, worst-case events are rare and research indicates that a sole focus on such events in training may result in an individual overweighting the probability of rare events at the expense of learning how to manage the most common and realistic exposures they will face in their general duties (Birzer and Tannehill, 2001; Harman and Gonzalez, 2015; Harman et al., 2019).

In the previously reported investigations that show stress-induced decrements to skilled police performance, officers that trained with live opponents under high threat, stress-inducing conditions performed better than officers trained using static targets under low threat conditions (Oudejans, 2008; Nieuwenhuys and Oudejans, 2011). Andersen and colleagues have successfully improved police lethal use of force decision-making following an intervention that targets the modulation of the physiological stress response during training (Andersen and Gustafsberg, 2016; Andersen et al., 2018). Further, significant improvements in an occupationally relevant health indicator, specifically, recovery from stress, as measured by heart rate returning from maximum to rest following critical incident scenarios, were maintained up to 18-months of follow-up (Andersen et al., 2018). Similar to the existing evidence for stress-induced decrements to skilled police performance, training-induced improvements to performance mainly pertain to decision-making (i.e., shoot/no-shoot) and visuomotor processes underlying perception and attention (i.e., gaze, blinking). Future investigations that directly measure training-related neuromuscular gains including muscle force, speed, and resulting behavioral accuracy are required to fill gaps in the applied police literature regarding skilled motor performance under stress.

The use of video simulation technologies for police use of force training is increasing in popularity (Davies, 2015). The stated benefits of this approach include controlling for dynamic situational factors such as actor behavior, which may vary in live simulations despite pre-defined scripts and situational outcomes (see Bennell et al., 2007). The uptake in usage is surprising given the lack of research validating the effectiveness of virtual simulation training that has been used for various purposes, including lethal use of force decision-making and shooting accuracy. Nieuwenhuys et al. (2015) failed to show improvements in high-stress performance decrements following training with video scenarios, while their interventions with stressful live scenario training did show significant post-training performance improvements (Nieuwenhuys and Oudejans, 2011). Forthcoming evidence demonstrates significantly higher errors in lethal force decision-making and significantly less autonomic stress arousal during video simulation trials compared to live-actor simulation trials within the same sample of frontline police officers (Di Nota, Boychuk, Andersen, under review). More empirical research is needed on a variety of virtual simulation tools and platforms before considerable investments are made in technologies and training methods that are less effective than live scenario-based training, and in the worst case could reinforce maladaptive (i.e., under-reactive) stress responses and errors in both cognitive decision-making strategies and tactical motor skills.

Future Directions for Applied Research on Motor Performance

While animal models would suggest skilled motor performance decrements are inevitable under high stress, applied police research has shown significant improvements in various aspects of skilled motor performance following training under highly stressful conditions. Nonetheless, the direct influence of occupationally relevant stress physiology on neuromuscular aspects of skilled motor performance among law enforcement remains less clear. Before such investigations can occur, it is important that researchers carefully evaluate and define "performance" on more dimensions than just the behavioral outcome (i.e., shoot or no-shoot), which can be interpreted as reflecting cognitive decision-making processes as much as physical performance capability, quality, or success (see Renden et al., 2017). Haller et al. (2014) evaluated officer performance according to several aspects that together comprised an "ethological profile" (p. 3) at different stages of critical incident scenarios. A recent investigation by Bertilsson et al. (2019a) also evaluated multiple performance categories, including general motor control distinct from motor control of voice, verbal content, as well as spatial and temporal tactical implementation. By scoring verbal, orientation, positional, and movement parameters, training and evaluation become more detailed by providing feedback on specific elements of officer's behaviors that might be maladaptive (e.g., poor positioning) but not contribute to a negative outcome per se (were not injured by the suspect in this scenario, but could put themselves in danger in future situations). This study is a step in the right direction and utilizes objective physiological measures of individual stress responsivity to demonstrate a link between decrements in skilled motor performance (i.e., complex verbal and physical de-escalation) and stressful occupationally relevant exposures among police.

Once skilled motor performance has been operationalized, various non-invasive methodological approaches can be used to pinpoint the contribution of stress physiology on musculoskeletal functioning. Electrical brain signals originating in motor cortex and terminating in targeted muscle groups can be measured using surface-level electrodes *via* electroencephalography (EEG) and electromyography (EMG), respectively. The frequency (time series) and amplitude of neuromuscular signals under high- and low-stress conditions could be compared to identify the influence of stress on the speed and timing of motor skills, including reaching for and utilizing a firearm. Muscle tension as recorded by EMG could also reveal subtle differences between anticipatory (i.e., psychological) and physical stress, clarifying whether these stressors manifest similarly in musculoskeletal architecture.

Training aimed at reducing police performance errors in the use of lethal force have already started to focus on physiological-based interventions, including physiological stress modulation (Andersen and Gustafsberg, 2016; Andersen et al., 2018). In an exploratory pilot study, Johnson et al. (2014) compared performance (i.e., shoot/no-shoot decision-making), heart rate, and EEG activity between experienced military and police officers and civilians during virtual use of force scenarios. As expected, performance errors were significantly higher among civilians, and EEG data showed several experience-dependent differences, including greater task-related changes in alpha power among experts, including when a shot was taken relative to rest. Further, EEG metrics differentiated intermediates (<10 years' experience) from experts (>10 years' experience), consistent with previous evidence for greater alpha suppression (indicative of cognitive load and task engagement) when engaging in a familiar motor task relative to less familiar experts and non-experts (Di Nota et al., 2017). Johnson et al.'s (2014) groundbreaking work suggests that non-invasive neurophysiological recordings could be a useful training tool for optimizing virtual lethal force/decision-making training, and objectively assessing skill learning and expertise. Further validation of existing training paradigms, including virtual technologies, are needed for truly evidence-based training practices.

CONCLUSION

A growing body of literature has demonstrated significant physiological activation following exposure to acutely stressful events among police, both in real-world and simulated settings. However, there are little data that document the direct impact of stress physiology on skilled motor performance at the central (brain and spinal cord) or peripheral (neuromuscular) level. Future investigations in this regard can aid in further optimizing effective interventions that train adaptive physiological stress responses to acutely stressful situations and which reduce errors in lethal use of force and improve physiological recovery from stress. Together, this evidence-based line of research can immediately improve stress-induced decrements to skilled motor performance, preserve occupational and public safety, and reduce the risk for physical and mental health disorders disproportionately observed in first responder populations (Franke et al., 2002; Ramey et al., 2009; Joseph et al., 2010; Carleton et al., 2018; Violanti et al., 2018).

AUTHOR CONTRIBUTIONS

GA and GM completed the first conceptualization and draft of the manuscript. JA conceptualized components and wrote sections of the manuscript. PD contributed to writing significant revisions of the final manuscript.

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