a tennis ball. About half the children reported that they had perceived the ball rise towards the ceiling and then vanish. This Vanishing Ball Illusion has been adapted by Kuhn and Land (2006), who demonstrated that 63% of adult observers reported an illusory ball. They also argued that eye-tracking recordings suggested that social cues from the magician contributed to the illusion, that is, spectators who experienced the Vanishing Ball Illusion (the misperception of an illusory ball) looked to the magician's eyes and were misdirected by his gaze as he looked upwards during the false throw. Subsequent studies have demonstrated that this magical effect remains relatively robust even without deceptive social cues (Thomas and Didierjean, 2016a; for a broader discussion of the role of social cues in magic see Cui et al., 2011; Tachibana and Kawabata, 2014; Kuhn et al., 2016). More recent research has demonstrated that the illusion can also be induced even in the absence of the initial "real" throws (Kuhn and Rensink, 2016).

Other studies involving sleight-of-hand magic tricks have used the false transfer method to examine the degree of "magicalness" of performances. Beth and Ekroll (2015) showed participants a series of videos of a magician performing magic tricks that included several "vanishes." The effect was that a poker chip seemed to disappear inexplicably, and this was accomplished with a method known as a false transfer – the magician pretended to pass a poker chip from one hand to his other, while secretly retaining it in his first hand. By manipulating the timing between the moment of the false transfer and the revelation that the poker chip was not in the magician's hand, they found that participants would rate the quicker revelations of the empty hand as being relatively more magical. The authors suggested that such vanishing effects could be linked with the ideas of modal and amodal completion – perceptual experiences that are not directly drawn from any sensory modality (see also Nanay, 2009; Barnhart, 2010; Ekroll et al., 2013).

While many studies of sleight-of-hand magic tricks have focused on the role of spectators' perceptions, an additional small body of literature focuses specifically on the physical actions of the magician's hands. For example, one study (Cavina-Pratesi et al., 2011) has demonstrated that practicing magicians are significantly more skillful at pantomiming actions compared to control participants (non-magicians). When asked to pantomime the action of picking up an object, control participants made hand motions that were notably different from genuine grasping gestures. In contrast, the fake grasping gestures of the magicians were more kinematically similar to their genuine grasping actions. Such expertise contributes to the deceptiveness of sleight-of-hand performances (Phillips et al., 2015), and surveys of professional magicians indicate that they place a particularly high value on pantomimic expertise (e.g., Rissanen et al., 2014).

The present study extends previous research on the false transfer method and the Vanishing Ball Illusion by introducing a novel magic trick, adapted by the first author. The Phantom Vanish Trick was created to investigate the idea that participants can form vivid illusory impressions of objects in response to magic performances. The method is inspired by a sleight-of-hand technique historically referred to as a "bluff vanish" (e.g., Shephard, 1946; Bobo, 1952). In the original method, the magician begins by clearly and openly showing the spectators that he is holding a handful of mixed coins. Then, with his other empty hand, he reaches into the handful of coins and pantomimes the action of taking away a single coin. The magician does not actually take anything from the handful of coins, but he does (falsely) verbally indicate to the spectators that he has taken one of the coins. Next, the magician disposes of the "remaining" coins into his pocket (really *all* of the coins go into the pocket, since he did not actually take any coin away from the original handful). Finally, the magician goes through the pantomime of making the single coin disappear. This trick is effectively a false transfer that depends both on the convincingness of the pantomime and also on the spectator not being able to count the original handful of coins. The Phantom Vanish Trick streamlines this idea by eliminating the handful of coins altogether. The magician simply pantomimes the actions of presenting an object and making it disappear. A real object is never presented at any point during the trick. Additionally, in the current experiment, the Phantom Vanish Trick was presented in the context of a silent video, meaning that the magician was not able to use false verbal information to mislead the spectators.

The Phantom Vanish Trick represents a novel contribution to the perception literature in that it has the potential to demonstrate that a spectator's top-down expectations can lead them to perceive illusory objects where none have been presented. This is an extension of previous experiments that have shown that people may falsely infer the illusory motion of an object. For example, in the Vanishing Ball Illusion, spectators reported seeing an illusory ball leave the magician's hand. Similarly, Cui et al. (2011) reported that participants falsely perceived a coin being tossed by a magician from one hand to the other, despite the fact that the coin was actually retained in the initial hand that was making the toss.

Proponents of ecological theories of perception have made strong predictions about the potential for healthy adults to misperceive objects. Gibson (1982) asserted that it is impossible to induce the false visual perception of an object where none exists (barring optical illusions or pharmacological or psychiatric considerations). He states:

> "Do we ever really "see" a non-existent object or place as if it existed? I do not mean the *virtual* object in a mirror, or a *pictured* object behind the picture, or a *mirage* in the desert air, but a *hallucinated* object, a thing for which no invariants are present in the ambient light even when the presumably drugged or diseased observer walks around it. If it is true that the absence of all structure in the light specifies air, i.e., "nothing" in the sense of *no thing*, the answer must be that we do not and cannot (p. 223, original emphasis)."

While ecological theorists assert that human phenomenological experience is derived directly from bottom-up sensory information, inferential theorists (e.g., Helmholtz, 1867; Gregory, 1997, 2009) propose that phenomenological experiences are derived from top-down interpretations of bottom-up sensory information. Thus, if participants do report the presence of objects after viewing the Phantom Vanish Trick, this would support an inferential theory of human visual perception. Such reports would imply that top-down information, in this case, the strong expectation that the object is present, is subjectively indistinguishable from veridical sensory information. In other words, participants will have the experience of seeing an object even though it is not presented because they think that it ought to be there.

Based on informal observations of professional magic trick performances, as well as previous studies of sleight-of-hand magic tricks and pantomimes (e.g., Kuhn and Land, 2006; Phillips et al., 2015), we predicted that some participants who watched the video of the Phantom Vanish Trick would report the presence of a non-existent object, and that there were three possible outcomes. Of the participants who did experience the Phantom Vanish Illusion (PVI), some would indicate that they saw the magician make "something" disappear while others would indicate that they saw the magician make a specific object disappear (e.g., a "silver coin" or "red ball"). The third possible outcome was that some participants would fail to experience the PVI, and they would simply provide a veridical report of the events shown in the video.

MATERIALS AND METHODS

Participants

Participants were recruited to take part in the study online (see Woods et al., 2015 for a review of online behavioral research methods) through Amazon's Mechanical Turk.[1] There were 420 participants who completed the study (mean age = 33.5 years; age range = 19–73 years; male = 237), and an additional 23 participants who were excluded from the analysis because they did not complete the experiment. All participants self-reported as having normal or corrected-to-normal vision and no history of neurological illness or injury. Participants were tested following a protocol approved by the University of Oxford Research Ethics Committee, and in accordance with the ethical standards laid down in the 2008 Declaration of Helsinki. Each participant completed the experiment individually online and was given US $1.50 as compensation for their time.

[1]A consideration here is that data collection was done online as opposed to in a more traditional laboratory setting. A popular argument for not conducting research online is that the data collected is for some reason unreliable; for example, because it is unknown if participants are properly paying attention. One way of assessing this is to ask participants a "catch" question at the end of the study (e.g., "do not click continue, rather click the small circle at the bottom of the screen"; Oppenheimer et al., 2009). Hauser and Schwarz (2016) tested this issue and found that, while Mechanical Turk participants failed such a task 5% of the time, a staggering 61% of laboratory-based participants also failed the task. We did not include such a catch question for this reason. In terms of the overall data reliability issue, almost all attempts of replicating laboratory-based psychology studies online have been successful (e.g., Germine et al., 2012; Crump et al., 2013; Klein et al., 2014), with the few exceptions being attributable to inconsistencies in the hardware used by the participants. Hardware discrepancies can make it difficult to present very short duration stimuli onscreen accurately, such as is important in the masked-priming study, which failed to be completely replicated (Crump et al., 2013). Our stimuli were videos, all of which were over 10 seconds long, and so would not thus be affected. Of course, we also benefited from our online participants being less WEIRD (Western, Educated, Industrialized, Rich, and Democratic; Henrich et al., 2010; Berinsky et al., 2012) than laboratory-based participants. (Although some would argue that online participants are weird in their own right, for example, by being much more computer literate than individuals recruited off the street; for a discussion on this and a more in depth overview of the above issues, the reader is directed to Woods et al., 2015.)

Stimuli and Procedure

The study was conducted online using Adobe Flash-based Xperiment software.[2] Participants completed the experiment using their own computers, and at the start of the study, participants had the option of viewing the stimuli in a discrete browser window or in "full-screen" mode.

Stimuli consisted of a total of 22 videos. All videos were recorded in 1080 HD, at 30 FPS, using an iPhone 5S, and edited for length in iMovie. All of the videos were silent, to control for the fact that participants would be watching on their personal devices with varying audio capabilities. The stimuli set included one "practice" video, and one "critical" video – the Phantom Vanish Trick. There was only one version of each of these two videos, and they were shown to every participant. The other 20 videos included 15 "magic trick" videos and five "non-magic control" videos. There were three types of magic trick videos: Video 1, Miscellaneous Trick; Video 2, Vanish Trick; Video 4, Appearance Trick, and one type of control video: Video 3, Non-Magic Control. There were 20 videos because each of these four types of videos (Miscellaneous, Vanish, Appearance, and Non-Magic Control) was performed with five different objects: Condition 1, Silver Coin; Condition 2, Red Ball; Condition 3, Poker Chip; Condition 4, Silk Handkerchief; Condition 5, Crayon. See **Table 1** for the number of participants in each of the five object conditions, and **Figure 2** for an illustration of the five different object conditions.

Participants watched a five-video sequence that was presented in an order designed to approximate a routine that might be performed within the context of a magic show. See **Figure 3** for a breakdown of the five-video sequences that were possible with each of the five different object conditions. In all of the videos, a brass cup was visible on the table to the left of the magician. The cup was a receptacle for the objects. The first four videos in the sequence (which always showed an object) were intended to establish an expectation that the magician would take an object out of the cup, while the fifth video (which did not show an object) served as the critical video. See **Figure 4** for an illustration of a five-video sequence. The complete set of videos can be viewed online[3].

[2]www.xperiment.mobi

[3]https://www.youtube.com/playlist?list=PLnfidBe0mwswzhAjRLRLMDrEO0zGJYi23

TABLE 1 | Number of participants in each of five different object conditions.

Condition	Object	Participants
1	Silver coin	81
2	Red ball	80
3	Poker chip	100
4	Silk handkerchief	79
5	Crayon	80

FIGURE 2 | Five different object conditions were used in the experiment. In the first four videos of the five-video sequence, participants only ever saw one of the five objects – silver coin, red ball, poker chip, silk handkerchief, or crayon. In Video 5 there was no object presented.

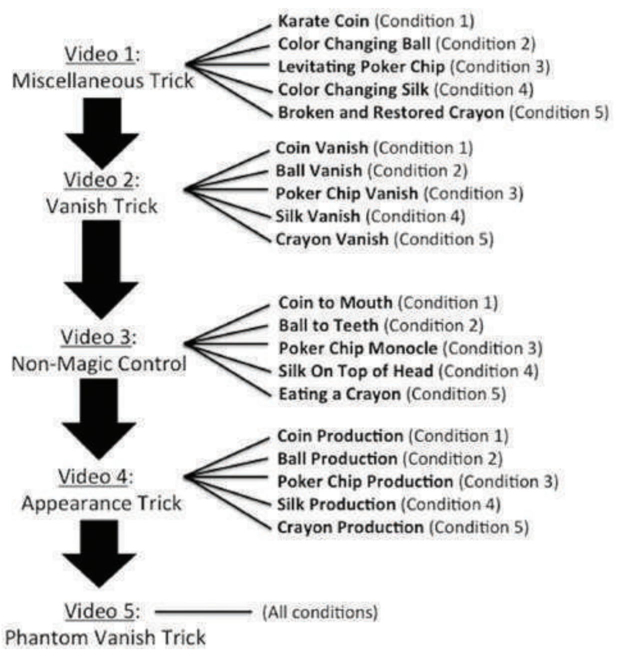

FIGURE 3 | Participants were presented with a five-video sequence – Video 1: Miscellaneous Trick; Video 2: Vanish Trick; Video 3: Non-Magic Control; Video 4: Appearance Trick; Video 5: Phantom Vanish Trick. The first four videos depicted a magician performing with a single object – either a silver coin (Condition 1), a red ball (Condition 2), a poker chip (Condition 3), a silk handkerchief (Condition 4), or a crayon (Condition 5). The object varied for participants, so that one group of participants watched a five-video sequence involving a silver coin (Condition 1) while another watched a five-video sequence involving a red ball (Condition 2), etc. The order of the tricks in the five videos that constituted a video sequence was intended to approximate a routine from a magic show.

Videos 1, 2, and 4 were presented as magic tricks. They were designed to establish that the magician was performing magical actions with the object. The tricks were presented so that the methods could not be easily inferred from the video, assuming that the participant did not have prior knowledge of the methods behind magic tricks. Video 1, the Miscellaneous Trick, showed the magician doing something magical with the object (e.g., breaking it and magically restoring it, or magically changing its color). Video 2, the Vanish Trick, showed the magician making the object seemingly disappear. Video 4, the Appearance Trick, showed the magician apparently producing the object from thin air.

Video 3, the Non-Magic Control, served as a manipulation check for demand characteristics. Participants had been informed that they would be watching a series of magic tricks, which might have led them to describe magic tricks even when the video did not depict a magic trick. Video 3 did not depict any apparent magical or impossible events (e.g., Video 3, Object Condition 1 depicted the magician placing the silver coin between his teeth). Therefore, if participants did report seeing magical or impossible events after watching this video, we would be unable to rule-out the influence of demand characteristics on participants' responses to Video 5, the Phantom Vanish Trick.

Video 5, the Phantom Vanish Trick, served as the critical video of the experiment. Participants' responses to this video directly addressed our central question: Could a silent pantomime of a magic trick result in reports of objects where none were presented? This video showed the magician pantomiming the action of removing an object from the cup and then going through the motions of making the non-existent object disappear. Unlike the first four videos, no object was shown in the Phantom Vanish Trick.

Participants were asked to write a description of each video (Question 1) and to provide three ratings of how surprising (Question 2), how impossible (Question 3), and how magical (Question 4) they found the video. At the end of the experiment, after watching all of the videos, participants were asked to report how interesting they generally considered magic tricks to be (Question 5). See **Table 2**, the *Spectators' Experience Questionnaire,* for the complete list of questions. The ratings for Questions 2–4 were collected using a series of visual analog scales. Participants were presented with a continuous line anchored at one end with the words "not at all surprising" (or impossible or magical) and at the other end with "very surprising" (or impossible or magical). For each rating (of surprising, impossible or magical), participants were instructed: "Please use your mouse to indicate your response on the slider below" (see Reips and Funke, 2008 for a discussion of using computer-based visual analog scales).

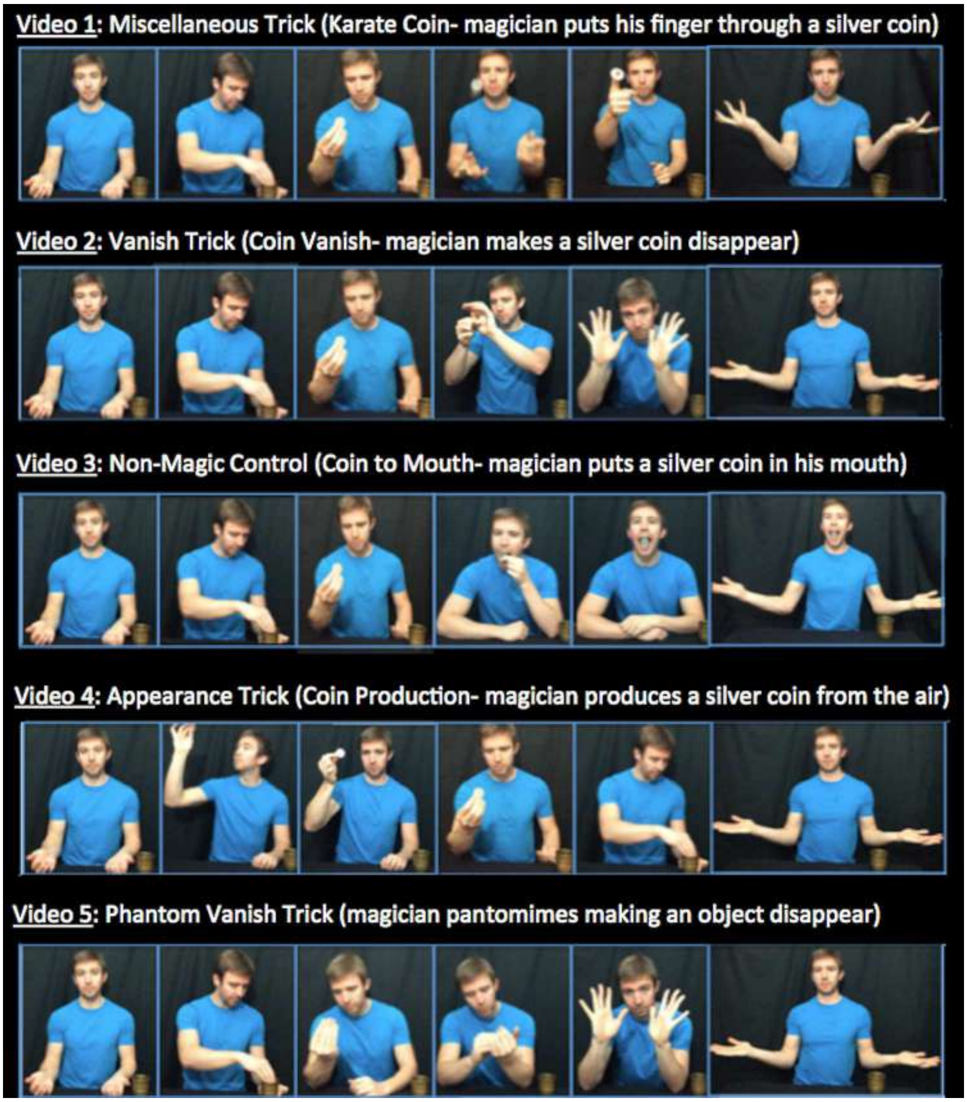

FIGURE 4 | An illustration of a five-video sequence, as viewed by a participant. All participants in Object Condition 1, Silver Coin, watched Videos 1–4 (Miscellaneous Trick, Vanish Trick, Non-Magic Control, Appearance Trick) that depicted a magician performing with a silver coin before they watched Video 5 (Phantom Vanish Trick), which did not include an object. Note that participants in Object Conditions 2–5 also watched similar five-video sequences involving different objects. Regardless of which object condition the participants were in for Videos 1–4, the Phantom Vanish Trick (Video 5) was identical for every participant.

The critical question was Question 1 for Video 5 (Phantom Vanish Trick). The participants' responses to this question allowed us to determine whether they had experienced the PVI. The ratings for Questions 2–4 for Video 5 were intended to corroborate the written reports (i.e., participants who experienced the PVI should consider Video 5 to be more magical and/or impossible than those who did not experience the illusion). Throughout the experiment, the questions served to keep the participants actively engaged with the videos, and by asking the same questions about every video in the sequence, we avoided placing any special emphasis on Video 5 (Phantom Vanish Trick) that might have otherwise influenced the participants' responses.

In summary, the experiment began with the participants being informed, through onscreen written instructions, that they would be watching a series of short (less than 30 s) videos. They were told that they would be able to control when the videos started and that, during the experiment, each video could only be played once. Participants then completed the practice trial, and they were given the option to repeat the practice trial or to begin the experiment. The practice trial included a video, depicting the magician magically transforming one playing card into another, followed by Questions 1–4. Once participants confirmed that they wished to begin the trial, they were presented with a written cue: "Press SPACE to start the trial." Pressing the spacebar initiated the trial. The practice trial was in an identical format to the experimental trials; that

TABLE 2 | Spectators' experience questionnaire.

	Response format	Question
Q1	Written Verbal Response	Please write a description of what was shown in the video. Do your best to describe specific actions and events in the order that they occurred.
Q2	Visual Analog Scale (from "not at all surprising" to "very surprising")	How surprising did you find the events shown in this video?
Q3	Visual Analog Scale (from "not at all impossible" to "very impossible")	To what degree did the events shown in this video seem to be physically impossible?
Q4	Visual Analog Scale (from "not at all magical" to "very magical")	How magical did you find the events shown in this video?
Q5*	Visual Analog Scale (from "not at all interesting" to "very interesting")	In general, how interesting do you consider magic tricks to be?

**Participants answered Q1–Q4 a total of five times, that is, once after each video in the five-video sequence, but they answered Q5 only once at the end of the experiment.*

is, after each video ended, participants were presented with Questions 1–4 of the Spectators' Experience Questionnaire (see **Table 2**). For each experimental trial, participants were required to answer each question (by typing text for Question 1 and by clicking on the visual analog scale slider for Questions 2–4) before they watched the next video in the sequence. This process was repeated until participants had watched all five videos in the five-video sequence and responded to the four questions following each video. The *five* five-video sequences differed by the object that was used in Videos 1–4, but Video 5, the Phantom Vanish Trick, was the same for all participants regardless of which object condition they participated in. Finally, every participant answered one additional question (Question 5 of the Spectators' Experience Questionnaire): "In general, how interesting do you consider magic tricks to be? Please use your mouse to indicate your response on the slider below." Participants indicated their responses by clicking with their mouse at a point along a continuous line anchored at one end with the words "not at all interesting" and at the other end with "very interesting."

RESULTS

Participants' Written Reports for Question 1 on the Spectators' Experience Questionnaire

Question 1 (Q1) of the Spectators' Experience Questionnaire was presented immediately after each individual video of the five-video sequence, and the participants were asked:

> *"Please write a description of what was shown in the video. Do your best to describe specific actions and events in the order that they occurred."*

Participants' Written Reports for the Magic Tricks (Videos 1, 2, and 4)

Videos 1, 2, and 4 were designed to be perceived as conventional magic tricks; each video depicted a trick that involved a single effect intended to create an apparent illusion of impossibility. As predicted, participants reported that they found the videos to be both impossible and magical. Overall, the videos were 97.3% effective in successfully conveying the intended magic tricks, and importantly, no participant reported the presence of a non-existent object in Videos 1, 2, or 4. All 420 participants generated one written report for each of the four videos they viewed, for a total 1260 separate verbal reports. Only 34 reports, from 27 separate participants, indicated that the trick was perceived as non-magical:

- Twenty-one reports related to Video 1, the Miscellaneous Trick – four participants reported the correct method behind the Karate Coin Trick, 1 participant reported the correct method behind the Color Changing Silk Trick, and 16 participants erroneously stated that they saw the magician "throw" the chip upwards during the Levitating Poker Chip video (although this was not the genuine method, the trick was nevertheless perceived as non-magical);
- Nine reports related to Video 2, the Vanish Trick – seven participants reported the correct method behind the Chip Vanish Trick, one participant reported the correct method behind the Silk Vanish Trick, and one participant reported the correct method behind the Crayon Vanish Trick;
- Four reports related to Video 4, the Appearance Trick – four participants reported the correct method behind the Crayon Production.

Participants' Written Reports for the Non-Magic Control (Video 3)

Video 3, the Non-Magic Control video, was not a conventional magic trick in that it was not designed to create an illusion of impossibility; instead, the magician performed an action that was intended to appear surprising but not to violate any natural or physical laws. As predicted, none of the participants reported seeing anything impossible or magical in the Non-Magic Control video, and importantly, no participant reported the presence of a non-existent object in Video 3. Some examples of the reports include: "He took a coin out of the cup and put it between his teeth" or "The man took the coin out of the cup and put it into his mouth. Then he waved his hands to the side, and rested his arms on the table afterward. Nothing magical happened." The responses provided by the participants indicated that they were distinguishing between the magic trick videos (Videos 1, 2, and 4) and the Non-Magic Control (Video 3) because, unlike the reports for the magic trick videos, the participants did not report anything impossible or magical in response to Video 3.

Participants' Written Reports for the Phantom Vanish Trick (Video 5)

Video 5, the Phantom Vanish Trick, was the critical video of the experiment. In contrast to the first four videos, no object was visible in this video; the Phantom Vanish Trick was intended to induce the illusory perception of a "phantom" object where no object was presented. Reports of phantom objects were categorized based on the participants' written reports for Q1:

(1) Participants who only described the veridical events of the video were categorized as not having reported experiencing the PVI (e.g., "The magician pretended to take something out of the cup and make it disappear" or "His hands were empty. He reached into the cup. He then waved his hands around and then his hands remained empty");
(2) Participants who reported that the magician took "something" out of the cup but did not provide any details about the object, were categorized as having reported experiencing the PVI but *not* reporting a specific object (e.g., "He took something out of the cup and it disappeared" or "The man takes the object from the cup into his hand. He makes a hand motion and it disappears. He points to his hand to show that it is indeed empty");
(3) Participants who reported that the magician was performing with a specific object were categorized as having not only reported experiencing the PVI, but also having reported a specific object (e.g., "The magician removed a silver coin from the cup and placed it in his hand before making it disappear").

In summary, of the 420 participants who responded to Q1 for Video 5, 284 participants (68%) were categorized as not having reported experiencing the PVI and 136 participants (32%) as having reported experiencing the PVI. Of the 136 participants categorized as having reported experiencing the PVI, 91 participants (21% of the total 420 participants) did not report a specific object and 45 participants (11% of the total 420 participants) reported a specific object. Of the 45 participants who reported specific objects, 39 (87%) reported seeing objects that were congruent with the objects they had been shown in the preceding videos. There were six exceptions, and all six participants reported seeing a coin (one participant in Object Condition 2, Red Ball; five participants in Object Condition 4, Silk Handkerchief).

Participants' Ratings for Surprising (Question 2), Impossible (Question 3), and Magical (Question 4) on the Spectators' Experience Questionnaire

For every written report (Q1) collected for Videos 1–5, we also collected ratings from the participants for Surprising (Q2), Impossible (Q3), and Magical (Q4). See **Table 2** for the questions administered to the participants. These ratings (Q2–4) were included in the experimental design to corroborate the written reports for Q1.

Participants' Ratings (Surprising, Impossible, and Magical) for the Magic Tricks (Videos 1, 2, and 4) Compared to the Non-Magic Control (Video 3)

For Videos 1–4, the written reports (Q1) suggested that participants considered the Non-Magic Control (Video 3) to be less Impossible and Magical than the magic trick videos (Videos 1, 2, and 4). We used a linear mixed-effects model to compare participants' ratings of Surprising (Q2), Impossible (Q3), and Magical (Q4) for the magic trick videos (Videos 1, 2, and 4) compared to the Non-Magic Control (Video 3). To fit the linear mixed-effects model, the error structure of the residuals need to be normal and heteroskadastic; satisfactory normality was achieved by applying a folded logarithmic transformation of the form: $\log((x + 1)/(101 - x))$ to the ratings data. We treated pairings of videos and ratings as fixed effects, such that each of the four videos (Videos 1, 2, 3, and 4) was paired with each of the three ratings (Surprising, Impossible, and Magical) for a total of 12 fixed effects. Participants were treated as random effects. Models were fitted using the nlme package (Pinheiro et al., 2016) in R (R Core Team, 2016). See **Figure 5** for the participants' ratings of Surprising, Impossible, and Magical for Videos 1–4.

Participants' ratings for Surprising (Q2) were significantly lower for the Non-Magic Control Video 3 ($M = 23.41$, 95% CI [19.95, 27.25]) than for each of the magic trick videos: Video 1 ($M = 44.54$, 95% CI [39.65, 49.54], $t(4609) = 8.23$, $P < 0.001$); Video 2 ($M = 52.85$, 95% CI [46.84, 56.81], $t(4609) = 11.09$, $P < 0.001$); Video 4 ($M = 55.53$, 95% CI [50.53, 60.42], $t(4609) = 12.02$, $P < 0.001$).

Participants' ratings for Impossible (Q3) were significantly lower for the Non-Magic Control Video 3 ($M = 1.35$, 95% CI [0.94, 1.85]) than for each of the magic trick videos: Video 1 ($M = 34.66$, 95% CI [30.24, 39.34], $t(4609) = 27.33$, $P < 0.001$); Video 2 ($M = 49.18$, 95% CI [44.18, 54.18], $t(4609) = 32.48$, $P < 0.001$); Video 4 ($M = 48.97$, 95% CI [43.98, 53.98], $t(4609) = 32.41$, $P < 0.001$).

Participants' ratings for Magical (Q4) were significantly lower for the Non-Magic Control Video 3 ($M = 0.99$, 95% CI [0.64, 1.41]) than for each of the magic trick videos: Video 1 ($M = 36.80$, 95% CI [32.25, 41.59], $t(4609) = 29.62$, $P < 0.001$); Video 2 ($M = 54.47$, 95% CI [49.46, 59.39], $t(4609) = 35.79$, $P < 0.001$); Video 4 ($M = 55.10$, 95% CI [50.10, 60.00], $t(4609) = 36.01$, $P < 0.001$).

In summary, the ratings (Q2–4) corroborated the written reports for Q1, indicating that participants considered the Non-Magic Control (Video 3) to be less Surprising, Impossible, and Magical than the magic trick videos (Videos 1, 2, and 4). These findings for ratings Q2–4 further support the earlier findings for Q1, and demonstrate that participants were clearly distinguishing between the magic trick videos (Videos 1, 2, and 4) and the Non-Magic Control (Video 3).

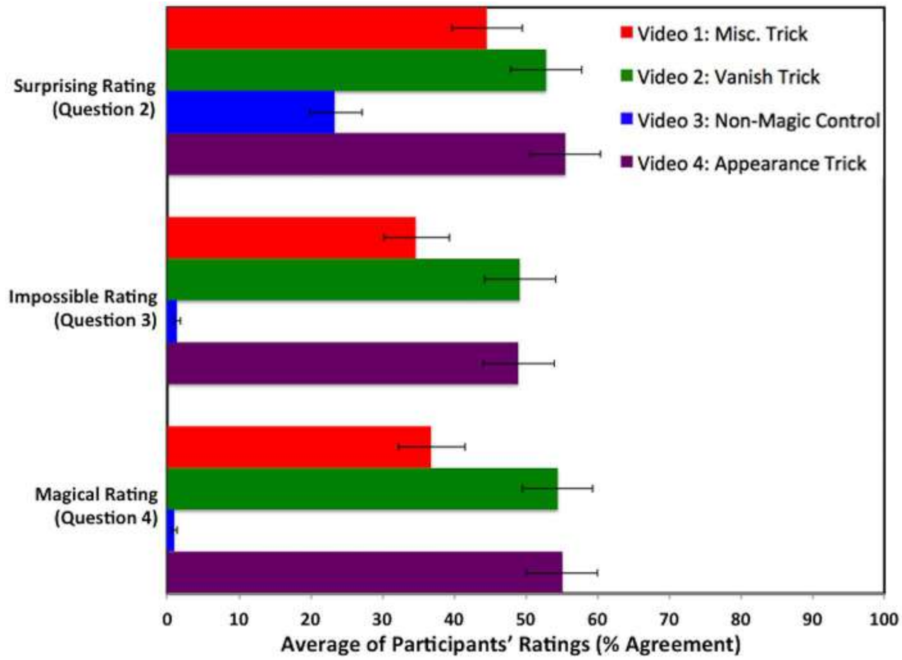

FIGURE 5 | Average of the participants' ratings for Surprising, Impossible, and Magical on Videos 1–4. Error bars represent 95% confidence intervals.

Participants' Ratings (Surprising, Impossible, and Magical) as Predicted by Participants' Written Reports for the Phantom Vanish Trick (Video 5)

Participants' written reports (Q1) for the Phantom Vanish Trick (Video 5) suggested that there were three different ways that participants responded to the PVI. We predicted that the Surprising (Q2), Impossible (Q3), and Magical (Q4) ratings from participants who were categorized as having reported experiencing the PVI (that is, participants who reported that they had seen an object apparently disappear during Video 5) would be higher than the ratings from participants who were categorized as not having reported experiencing the PVI (that is, participants, whose experience could be described simply as watching the magician pantomime an action without an object). We also predicted that the ratings from participants who were categorized as having reported experiencing the PVI and had also reported a specific object (e.g., a silver coin) would be higher than the ratings from participants who were categorized as having reported experiencing the PVI but had *not* reported a specific object (e.g., "the magician took something out of the cup").

We calculated three linear regression models to predict ratings of Surprising, Impossible, and Magical (respectively) from the participants' written reports for Q1 of the Phantom Vanish Trick. To fit the three simple linear regression models, the error structure of the residuals need to be normal and heteroskadastic; satisfactory normality was achieved by applying a folded reciprocal transformation of the form: $\log((x + 1)/(101 - x))$ to the ratings. For each model, our categorization of the participants' reported experience of the PVI in Q1 for the Phantom Vanish Trick was used to predict the participants' ratings of Surprising (Q2), Impossible (Q2), and Magical (Q2) for the Phantom Vanish Trick. Models were fitted using the lm package in R (R Core Team, 2016). See **Figure 6** for participants' ratings for Surprising, Impossible, and Magical on the Phantom Vanish Trick (Video 5).

For each of the three models, we compared the simple regression model to a model that included four additional covariates. There were three categorical covariates: (1) participant gender (male or female); (2) computer screen-view setting (discrete or full-screen); (3) object used (i.e., Silver Coin, Red Ball, Poker Chip, Silk Handkerchief, or Crayon); and one continuous covariate: (4) participants' self-reported interest in magic tricks (this covariate was transformed in the same way as the Surprising, Impossible, and Magical ratings, by applying a folded reciprocal transformation). The covariates were only included in the model reported if the likelihood test indicated that the covariates significantly improved the fit of the model. For example, none of the four covariates provided a significant improvement on the simple regression model for Impossible ratings, $F_{(7,410)} = 1.89$, $P = 0.07$ or for Magical ratings, $F_{(7,410)} = 1.87$, $P = 0.07$, and therefore the simple regression models are presented for these two ratings. In contrast, for Surprising ratings, the likelihood test indicated that the inclusion of two covariates – object used and participants' self-reported interest in magic tricks – significantly improved the fit of the model, $F_{(8,412)} = 0.39$, $P < 0.01$, but that the inclusion of the two other covariates – participant gender and screen-view setting – did not improve the model, $F_{(2,410)} = 0.39$, $P = 0.68$.

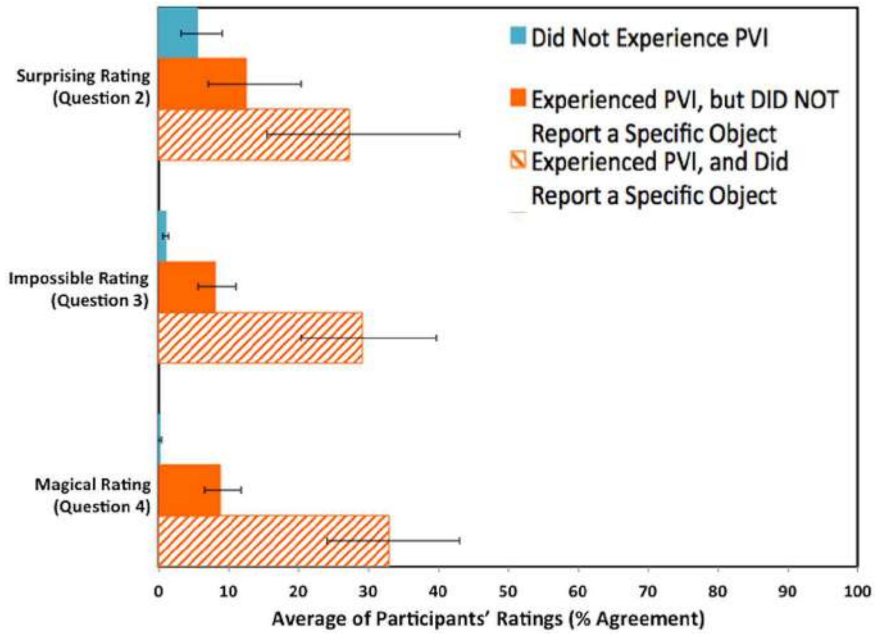

FIGURE 6 | Average of the participants' ratings for Surprising, Impossible, and Magical on the Phantom Vanish Trick (Video 5) – a comparison of participants who did not report experiencing the Phantom Vanish Illusion (PVI) with participants who did report experiencing the PVI, and either did or did not report a specific object. Error bars represent 95% confidence intervals.

Surprising Ratings for Video 5, the Phantom Vanish Trick

In the first of three linear regression models, we found that participants' reported experience of the PVI (as categorized by their written responses to Q1 of Video 5) significantly predicted how Surprising they found the Phantom Vanish Trick (Q2, Video 5) while controlling for object used in the four videos that preceded the Phantom Vanish Trick (i.e., Silver Coin, Red Ball, Poker Chip, Silk Handkerchief, or Crayon) and the participants' self-reported interest in magic tricks, $R^2 = 0.11$, $F_{(7,412)} = 7.59$, $P < 0.001$. There was a significant difference between the Surprising ratings of participants who did not experience the PVI ($M = 5.54$, 95% CI [3.18, 9.09]) and participants who did experience the PVI but did not report a specific object ($M = 12.44$, 95% CI [7.11, 20.45]), $t(412) = 3.29$, $P < 0.01$, as well as between participants who did not experience the PVI and participants who did experience the PVI and did report a specific object ($M = 27.24$, 95% CI [15.50, 43.03]), $t(412) = 5.35$, $P < 0.001$. In addition, for participants who did experience the PVI, there was a significant difference in the Surprising ratings between participants who did and did not report a specific object, $t(412) = 2.54$, $P = 0.02$. This analysis supports our prediction that the participants' written reports (Q1) for the Phantom Vanish Trick would be corroborated by their ratings of how Surprising (Q2) they found the Phantom Vanish Trick. Participants who we categorized (based on their written reports to Q1) as having reported experiencing the PVI rated the Phantom Vanish Trick as being more Surprising than those who we categorized as not having reported experiencing the PVI. Furthermore, participants who we categorized not only as having reported experiencing the PVI but also as having reported a specific object, rated the Phantom Vanish Trick as more Surprising than those who had not reported a specific object.

Impossible Ratings for Video 5, the Phantom Vanish Trick

In the second of three linear regression models, we found that participants' reported experience of the PVI (as categorized by their written responses to Q1 of Video 5) significantly predicted how Impossible they found the Phantom Vanish Trick (Q3, Video 5), $R^2 = 0.31$, $F_{(2,417)} = 93.24$, $P < 0.001$. There was a significant difference between the Impossible ratings of participants who did not experience the PVI ($M = 0.98$, 95% CI [0.65, 1.36]) and participants who did experience the PVI but did not report a specific object ($M = 8.06$, 95% CI [5.73, 11.09]), $t(417) = 8.45$, $P < 0.001$, as well as between participants who did not experience the PVI and participants who did experience the PVI and did report a specific object ($M = 29.17$, 95% CI [20.38, 39.75]), $t(417) = 12.01$, $P < 0.001$. In addition, for participants who did experience the PVI, there was a significant difference in the Impossible ratings between participants who did and did not report a specific object, $t(417) = 5.10$, $P < 0.001$. This analysis supports our prediction that the participants' written reports (Q1) for the Phantom Vanish Trick would be corroborated by their ratings of how Impossible (Q3) they found the Phantom Vanish Trick. Participants who we categorized (based on their written reports to Q1) as having reported experiencing the PVI rated the Phantom Vanish Trick as being more Impossible than those who we categorized as not having reported experiencing the PVI. Furthermore, participants who we categorized not only as having reported experiencing the PVI but also as having reported a specific object, rated the Phantom Vanish Trick as more Impossible than those who had not reported a specific object.

Magical Ratings for Video 5, the Phantom Vanish Trick

In the third of three linear regression models, we found that participants' reported experience of the PVI (as categorized by their written responses to Q1 of Video 5) significantly predicted how Magical they found the Phantom Vanish Trick (Q4, Video 5), $R^2 = 0.37$, $F_{(2,417)} = 127.5$, $P < 0.001$. There was a significant difference between the Magical ratings of participants who did not experience the PVI ($M = 0.89$, 95% CI [0.60, 1.22]) and participants who did experience the PVI but did not report a specific object ($M = 8.91$, 95% CI [6.56, 11.90]), $t(417) = 10.01$, $P < 0.001$, as well as between participants who did not experience the PVI and participants who did experience the PVI and did report a specific object ($M = 32.93$, 95% CI [24.09, 43.11]), $t(417) = 14.07$, $P < 0.001$. In addition, for participants who did experience the PVI, there was a significant difference in the Magical ratings between participants who did and did not report a specific object, $t(417) = 5.81$, $P < 0.001$. This analysis supports our prediction that the participants' written reports (Q1) for the Phantom Vanish Trick would be corroborated by their ratings of how Magical (Q4) they found the Phantom Vanish Trick. Participants who we categorized (based on their written reports to Q1) as having reported experiencing the PVI rated the Phantom Vanish Trick as being more Magical than those who we categorized as not having reported experiencing the PVI. Furthermore, participants who we categorized not only as having reported experiencing the PVI but also as having reported a specific object, rated the Phantom Vanish Trick as more Magical than those who did not report a specific object.

DISCUSSION

Our experiment investigated the illusory presence of objects in scenes where no object was presented. The PVI demonstrates that spectators' expectations, in response to magic tricks, can lead them to imagine the existence of an object that "ought to be there." In some cases, this imagined representation was vivid enough to be mistaken for a veridical visual perception. Thus, this experiment extends previous research demonstrating that magicians' misdirection techniques can induce misperceptions of visual experiences.

One-third of our participants reported having been shown an object after watching a video where no object was presented. Our PVI paradigm is the first investigation of sleight-of-hand magic tricks that has involved participants spontaneously reporting their illusory experiences. After watching each video, participants provided written reports describing what they had been shown. In addition to collecting written reports, we asked the participants to rate how surprising, impossible, and magical they considered the videos. These ratings served to corroborate the written reports: participants who reported phantom objects rated the Phantom Vanish Trick video to be more surprising, impossible, and magical than those who did not experience the illusion. Past research, on false transfer tricks (e.g., Cui et al., 2011; Beth and Ekroll, 2015) and on the Vanishing Ball Illusion (e.g., Triplett, 1900; Kuhn and Land, 2006; Thomas and Didierjean, 2016a), has involved misleading participants about the motion and location of an object: the object was shown, and then was apparently passed from one hand to the other while secretly being retained in the first hand; or, the object was shown and then apparently tossed into the air while being secretly retained in the hand (or secretly dropped into the magician's lap). In contrast, the PVI paradigm entirely eliminates the need to present an object during the critical trial. Overall, our paradigm provides strong evidence that participants who were categorized as having experienced the illusion were honestly confusing "phantom" objects for genuine objects. Our results also suggest that the participants' reports of "phantom" objects cannot be attributed to demand characteristics. Participants' responses to the Spectators' Experience Questionnaire for Video 3 (the Non-Magic Control video) indicated that the participants were not simply describing every video they watched as being impossible or magical merely because they had been told that they would be watching magic tricks. No participant reported seeing anything impossible or magical after watching Video 3, which was rated as significantly less impossible and less magical than the magic trick videos (Videos 1, 2, and 4). These results also raise intriguing questions about exactly what makes-up these "phantom" objects, and what these reports reveal about human perception.

One might argue that the participants' reports of illusory objects can be attributed to memory errors rather than perceptual errors. In other words, participants who reported seeing the phantom objects may not have had a phenomenological experience of "seeing" the object during the Phantom Vanish Trick video, instead they may have retrospectively confabulated the object after they had been cued to describe the events in the video. The design of our experiment allows us to exclude two memory-related factors that might otherwise have contributed to the illusion: post-event misinformation (including verbal and non-verbal information) and false verbal suggestions.

There is a rich literature on misinformation and the unreliability of eye-witness testimony. Researchers have repeatedly demonstrated that people are capable of confusing imaginary events with real memories (see Loftus, 2005 for a review). The idea that people can be led to report imaginary events has been established by research on the effects of leading questions. Loftus and Palmer (1974) showed that participants could be induced to remember seeing things that were not presented in response to leading questions. One week after having watched a video of a car accident, participants were explicitly asked: "Did you see any broken glass?" The reported false memories of broken glass could not have been derived directly from the video, because the video did not actually show any broken glass; thus, the false memory was arguably induced by the question itself. Other researchers have demonstrated that false verbal suggestions presented *co-currently* with events can also induce false reports (Wiseman et al., 2003; Wiseman and Greening, 2005; Wilson and French, 2014).

Similar results have been obtained in the absence of verbal misinformation, such as when Gurney et al. (2013) demonstrated that participants who were being questioned about a video recording of a robbery could be induced to report false information in response to non-verbal "leading gestures." For example, when the interviewer stroked his chin, while asking participants if they noticed any distinguishing features on the robber in the video, participants were more likely to report falsely that the robber had a beard compared to participants who were asked the question without the accompanying gesture.

In both our PVI paradigm, and previous research with the Vanishing Ball Illusion paradigm, the silent video clips that serve as stimuli preclude the use of false verbal suggestions during stimulus presentation. The Vanishing Ball Illusion paradigm involves asking participants a series of questions relating to the ball. After watching the video of the trick, the participants were asked to mark the location of the last place they saw the ball on a still picture that depicted the magician. Participants were considered to be sensitive to the illusion if they indicated that they had seen the ball leave the magician's hand on the last throw. They were considered insensitive to the illusion if they (correctly) marked the magician's hand as being the last place where they had seen the ball. Participants were then asked to describe what they saw, asked how the illusion was created, and given a yes/no forced choice question: "Did you see the ball move up on the final throw?" (Kuhn and Land, 2006). In contrast, in our PVI paradigm, the participants freely reported seeing the phantom object in response to a question that asked them to recall "actions" and "events" but made no specific reference to an object. In the PVI paradigm, given that there was no object presented during the Phantom Vanish Trick video, care was taken to ask participants non-leading questions, so as to rule-out the potential for post-event information to generate introspective errors during the participants' recollection of the events. The omission of a direct question about the object in the PVI paradigm may partially account for the fact that 68% of our 420 participants did not report experiencing the PVI.

With regards to ecological versus inferential theories of perception, our results do not support Gibson's (1982) specific ecological prediction that healthy sober people can never "see" a non-existent object – 32% of the 420 participants who completed our experiment reported that they had been shown objects when none had been presented. These results support a more inferential model of human perception. This concept, that conscious phenomenological experience is actively constructed by combining top-down cognitive processes with bottom-up sensory information, may offer insight into how participants came to experience the PVI.

Gregory's (2009) framework for classifying illusory phenomenon includes both paradoxical illusions and fictional illusions. Paradoxical illusions refer to perceptions that seem to be logically impossible (e.g., Kulpa, 1987), while fictional illusions refer to perceptual experiences that fail to directly correspond with sensory information (e.g., modal and amodal completions). Fictional illusions do not necessarily need to be based on false assumptions. For example, the amodal completion of objects is often based on accurate inferences: if one were to see a person standing behind a picket fence, and this caused the image of the person to be partially occluded, it would normally be correct to assume that the person's body really extends to areas occluded by the fence, rather than them being neatly sliced into separate sections.

We propose that sleight-of-hand illusions be classified as "paradoxical fictions." Magic tricks are designed to exploit spectators' inferences, along with their intuitions about their own perceptual systems, to create the "illusion of impossibility" (e.g., Nelms, 1969; Ortiz, 2006). Magic tricks are paradoxical in that an effective magic trick will appear to violate the laws of nature. For example, in a "vanishing" trick, an object appears to pass from existence into non-existence. Magic tricks are fictional in that the spectators' perceptual experiences can often differ dramatically from bottom-up sensory information, as in the case with our PVI or with the Vanishing Ball Illusion. These magical experiences can be considered "failures of visual metacognition" (Beth and Ekroll, 2015, p. 520). That is to say, we tend to believe what we see, and we are generally unaware of the discrepancy between how our perceptual system actually works and how we think it ought to work. Magic effects result from "hacking" otherwise adaptive perceptual processes to create false fictional experiences that lead to paradoxical experiences. In the case of the PVI, people would generally not believe that they could "see" an object where one does not exist. The "illusion of impossibility" occurs when the magician reveals the conflict between reality and the spectators' perceptual experience. At the "climax" of the Phantom Vanish Trick, the magician clearly shows that both of his hands are empty. Because the spectator does not believe that they could have misperceived an object that was never really there, they are unable to intuit that the true method is even possible.

One explanation for why participants reported phantom objects during the Phantom Vanish Trick is that the participants' top-down expectations about the object outweighed the bottom-up sensory counter-evidence (the absence of the object; Kuhn and Rensink, 2016). Various top-down expectations may have contributed to the creation of an amodal spatiotemporal representation of the object (Beth and Ekroll, 2015; Thomas and Didierjean, 2016b). Among the 136 participants who were categorized as having experienced the PVI, those who reported a specific object (e.g., a coin) might have based their reports on the perceptual experience of modal completion (they had the impression that an object had been openly displayed), while those who reported an object but did not specify which object, might have based their reports on an amodal completion (they had the impression that an object was presented, but that it was occluded by the magician's hand). However, one limitation of our written response format for Question 1, in which participants freely reported their experiences, is that we cannot determine whether the participants who did not report a specific object might have been capable of naming a specific object, if asked. In any case, all participants who reported having seen a phantom object apparently committed a metacognitive error of failing to distinguish the representation from a real object.

Participants' top-down expectations may have been influenced by multiple factors. Because there is no object presented during the critical video, the PVI paradigm can potentially be used to isolate a variety of variables that may contribute to sleight-of-hand illusions, including perceptual priming (i.e., the expectations established by the preceding videos[4]), social cues (i.e., the gaze and head direction of the magician), and the convincingness of the magician's pantomime (i.e., the grasp of the non-existent object). In future studies, each of these factors could be manipulated to isolate their respective roles in creating the PVI. The preceding four videos in the five-video sequence did include real objects. These videos may have served as perceptual primes, analogous to the real tosses that precede the false throw in the Vanishing Ball Illusion. One experiment (Kuhn and Rensink, 2016) has shown that manipulating the perceptual priming aspect of a magic trick (the real tosses that precede the false throw in the Vanishing Ball Illusion paradigm) affects the probability that participants will experience the illusion, and that the illusion can still be effective when the perceptual primes are eliminated entirely from the trick (i.e., the magician simply showed the ball and then immediately performed the false throw without making any real tosses). This suggests that our PVI might still be effective for some participants, even if the experiment were modified to reduce or even eliminate the preceding videos. For example, one could manipulate which objects are shown in the preceding videos, or manipulate the number of videos that precede the Phantom Vanish Trick. Additionally, the social cues of the magician could be manipulated by occluding the magician's face, or by including a condition where the magician maintains a fixed, unmoving gaze (see Thomas and Didierjean, 2016a).

In summary, the PVI represents a new contribution to the rapidly growing field of the "Science of Magic" – the use of methodologies inspired by performance magic to experimentally investigate human psychology. Just as optical illusions and visual arts represent a resource for visual scientists, the more elaborate illusions created by magic performances can be used to examine more complex elements of human visual cognition. We hope that the PVI paradigm represents not only a novel contribution to the Science of Magic, but more generally, a new tool for perception researchers looking to untangle the complex influences of top-down factors on the way people process dynamic visual scenes.

[4] Of interest here is the fact that six participants in our experiment did *not* actually report seeing a phantom object that was congruent with the object they had been shown in previous videos. This might be attributable to the fact that the magician depicted in the videos predominately practices and performs slight-of-hand magic with coins, meaning that his pantomimed grasp shown during Video 5 (Phantom Vanish Trick) may have been most closely related to the grasp that would be used to hold a coin. Alternatively, participants might have had a prior expectation established outside of the experiment, that magic performances often involve disappearing coins.

AUTHOR CONTRIBUTIONS

MT designed the experiment, collected and analyzed the data, drafted and revised the manuscript. AA designed the experiment, analyzed the data, drafted and revised the manuscript. AW assisted with the experimental design, collected the data, and revised the manuscript.

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It's a kind of magic—what self-reports can reveal about the phenomenology of insight problem solving

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Magic tricks usually remain a mystery to the observer. For the sake of science, we offered participants the opportunity to discover the magician's secret method by repeatedly presenting the same trick and asking them to find out how the trick worked. In the context of insightful problem solving, the present work investigated the emotions that participants experience upon solving a magic trick. We assumed that these emotions form the typical "Aha! experience" that accompanies insightful solutions to difficult problems. We aimed to show that Aha! experiences can be triggered by magic tricks and to systematically explore the phenomenology of the Aha! experience by breaking it down into five previously postulated dimensions. 34 video clips of different magic tricks were presented up to three times to 50 participants who had to find out how the trick was accomplished, and to indicate whether they had experienced an Aha! during the solving process. Participants then performed a comprehensive quantitative and qualitative assessment of their Aha! experiences which was repeated after 14 days to control for its reliability. 41% of all suggested solutions were accompanied by an Aha! experience. The quantitative assessment remained stable across time in all five dimensions. Happiness was rated as the most important dimension. This primacy of positive emotions was also reflected in participants' qualitative self-reports which contained more emotional than cognitive aspects. Implementing magic tricks as problem solving task, we could show that strong Aha! experiences can be triggered if a trick is solved. We could at least partially capture the phenomenology of Aha! by identifying one prevailing aspect (positive emotions), a new aspect (release of tension upon gaining insight into a magic trick) and one less important aspect (impasse).

Keywords: insight, problem solving, magic, Aha! experience, impasse

INTRODUCTION

Sometimes, the solution to a difficult problem pops into mind suddenly (Davidson, 1995) and unexpectedly (Metcalfe, 1986). Ever since the Gestalt psychologists (Köhler, 1921; Duncker, 1945; Wertheimer, 1959) began to investigate problem solving, the phenomenon of insight has been of great interest to psychologists (Sternberg and Davidson, 1995). Insight is often reported to be accompanied by an affective response, the "Aha! experience" (e.g., Gick and Lockhart, 1995). This is taken as the discriminative criterion to set it apart from analytic and gradual problem solving (Metcalfe, 1986; Evans, 2008).

Bühler provided the first reports about Aha! experiences, describing a moment "in which suddenly, the lights come on" (translated from Bühler, 1907, p. 341). Traditionally, the Aha! has been regarded as an interesting epiphenomenon of insight (e.g., Ormerod et al., 2002) or even the defining feature of insight (Kaplan and Simon, 1990; Gick and Lockhart, 1995) that defies closer empirical inquiry due to its subjective nature. But the recent interest in possible neural correlates of insight has led to a surge in studies that presuppose the subjective Aha! experience to be the clearest observable aspect of insight (Jung-Beeman et al., 2004), at least until a better behavioral or even neural marker of the occurrence of insight is found. Consequently, many of these studies rely on problem solvers' subjective reports about the occurrence of an Aha! experience to classify a solution as insightful and to distinguish it from solutions without insight (Bowden et al., 2005; Aziz-Zadeh et al., 2009). However, unsolved questions remain, especially with regard to methodology.

The methodological difficulties inherent to insight research have been recognized and discussed in the field (Davidson, 1995, 2003; Chronicle et al., 2004; Ash et al., 2009; Öllinger and Knoblich, 2009). The debate has revolved around the question of whether there are specific insight problems and if so, what defines them. In our opinion, insight problems "*per se*" don't exist (see Öllinger et al., 2013). Any problem can be solved with or without insight, depending on the problem solver's prior knowledge. Of course, some problems are more likely to be solved with insight, like the famous nine-dot problem (Scheerer, 1963).

When prior knowledge leads to a biased initial problem representation (Ohlsson, 1992), a representational change is necessary to overcome self-imposed constraints resulting in an enhanced problem representation that might be appropriate to solve the problem. Unfortunately, the underlying processes of representational changes are opaque. To deal with this problem, a common approach is to ask solvers whether they experienced any changes before a solution occurred. A related unsolved problem is how to assess the occurrence of insight. A well-known observation reported by a vast number of participants is the feeling of Aha! that accompanies the moment of insight. Consequently, each solution can be classified by asking participants whether they had or had not experienced an Aha! moment. Bowden and colleagues advocate the use of such self-reports (Bowden et al., 2005) instead of defining a priori what an insight problem is or not. This means, participants are asked after each solution to report on their subjective experience of insight, indicated by the Aha! experience. The problem solver, not the experimenter, decides whether insight has occurred or not.

We aim at elaborating and differentiating the phenomenological experience before an insight solution occurs—the precondition to identifying reliable markers that demarcate insight from non-insight problem solving and for properly understanding the cognitive and neural processes underlying insight problem solving.

We believe that the self-report approach could help to advance insight research, if it is possible to show that such reports are reliable measures, e.g. that they can be repeated over time. We therefore asked whether participants would be able to remember their self-reports after a long delay (2 weeks). Of course, the Aha! experience itself cannot be repeated, only the reports on it. If the Aha! experience is indeed such a strong affective experience, we expect people to remember it clearly. This should be reflected in similar ratings across time, when asked to think back to their Aha! experiences. Another reason to expect a high reliability is the fact that self-reports have already been successfully adopted in other studies as a tool to differentiate insight from non-insight (Sandkühler and Bhattacharya, 2008; Sheth et al., 2009; Subramaniam et al., 2009). It was even possible to reveal different neural activity underlying insight and non-insight solutions, for example, Kounios et al. (2006) analyzed a time interval of 2 s prior to problem presentation and found differences in neural activity (both in the EEG and in the fMRI signal) predicting whether the following problem would be solved with insight (Aha! reported) or without insight (Aha! not reported). Investigating the memorial advantage of insight, we have also used participants' self-reports and found that solutions that had been classified as insightful were remembered better in comparison to non-insight solutions (Danek et al., 2013). In the present work, we adopted Bowden's approach (2005) to determine the occurrence of insight and combined this approach with an a priori selection of a task (magic tricks) that is likely to trigger misleading initial problem representations.

Despite its successful use as a solution type classification criterion and its importance for the interpretation of almost all neuroscientific studies on insight problem solving, the phenomenology of the Aha! experience, as far as we know, has not been investigated in more detail. One hindrance is the methodological difficulty of its assessment (introspective judgments about the occurrence of Aha!), another one might be conceptual problems (what defines an Aha! experience?). So far, there is no general and explicit agreement on a definition of this concept. The common denominator is that an Aha! occurs if a solution suddenly pops into mind. Other aspects like a feeling of surprise, certainty that the solution is correct or a gestalt-like quality of the solution are stressed or disregarded to various degrees across studies (Ohlsson, 1992; Bowden et al., 2005; Sandkühler and Bhattacharya, 2008). The theoretical assumption that prior impasse is a necessary precondition for Aha! experiences to occur (Ohlsson, 1992; Knoblich et al., 2001; Jones, 2003; Öllinger et al., 2006) is taken up by some (e.g., Schooler et al., 1993; Sandkühler and Bhattacharya, 2008) and questioned by others (e.g., Bowden et al., 2005). The conceptual vagueness makes it very difficult to compare findings across studies, and thus it seems critical to further elucidate the phenomenology of this special experience (compare Gick's call for further research on the affective aspects of problem solving, Gick and Lockhart, 1995).

The aim of our study was to provide a detailed analysis of the Aha! experience during sudden moments of insight into magic tricks. We assumed a multidimensional model where the interplay of different dimensions establishes the Aha! experience and assessed the relative importance of the involved components quantitatively as well as qualitatively. As a basis for this assessment, we identified five dimensions of the Aha! experience that have been postulated previously:

(1) Suddenness: That insightful solutions are experienced as very sudden was demonstrated by Metcalfe (Metcalfe, 1986; Metcalfe and Wiebe, 1987) who showed that although problem solvers are able to accurately judge their progress toward the solution (recorded as feeling-of-warmth ratings) for non-insight problems, they are unable to do so for insight problems. This finding was further confirmed by Davidson (1995).
(2) Surprise: Based on introspection and informal observation, Gick and Lockhart (1995) suggested a division of the Aha! experience in two components: Surprise and suddenness. In their account, the surprise aspect can vary by strength and it can be accompanied by either positive (delight) or negative (chagrin) emotions. In order to disentangle surprise from these accompanying emotions, we decided to assess the emotional component separately, adding "happiness" as a new dimension.
(3) Happiness: Because Gick and Lockhart (1995) proposed the emotional response to vary between the positive and negative pole, we used a scale with "unpleasant" and "pleasant" as two extremes. There is also anecdotical evidence for this dimension of the Aha! experience, for example Gruber (1995) who analyzed Darwin's notes from the time of his great discovery on 28th September, 1838 and from them, inferred "a state of elevated happiness" (1995, p. 425).
(4) Impasse: Ohlsson postulated that prior impasse is a necessary precondition for Aha! experiences to occur (1992). An impasse is defined as a state of mind where problem

solving behavior ceases (Ohlsson, 1992; Öllinger et al., 2008; Sandkühler and Bhattacharya, 2008). In an eye-movement study, Knoblich et al. (2001) demonstrated that for successful solvers of insight problems, the number of long fixation times (i.e., periods with few eye movements) increases throughout the problem solving process, with longest fixation times occurring in the last time interval before the solution. That is, before insight occurred, there was a phase without systematic eye-movement patterns. Their interpretation of such an "idling" phase was that more appropriate representations can be established that yield a new insight.

(5) Certainty: Obviousness of solution, i.e., the certainty that an insightful solution is correct, was stressed as an additional aspect by Bowden and Jung-Beeman (2007). This "intuitive sense of success" related to insightful solutions is also often described in the context of scientific discoveries (Gick and Lockhart, 1995, p. 215).

Furthermore, we wanted to test Bowden's claim (2005) of the usefulness of subjective judgments. The differential assessment of the five dimensions was therefore repeated after 2 weeks to test their reliability. The present study addressed the following two hypotheses:

(1) Multidimensionality: We assumed that the Aha! experience is a syndrome of well-defined characteristics and hypothesized that all five dimensions are equally important.
(2) Reliability: We tested whether participants' assessment of their Aha! experiences would be stable across time and predicted that they would remember it well, resulting in similar ratings across time.

The present work focuses on the phenomenology of the Aha! experience. With the aim of triggering strong Aha! experiences, we used magic tricks as a problem solving task, assuming that gaining insight into a magic trick would lead to a strong affective response since the secret of a magic trick is typically extremely hard to find out. Further, we have shown previously that magic tricks are ideally suited to investigate insight because in order to discover the magicians' secret method, observers must overcome implicit constraints by restructuring their problem representation (Danek et al., 2014). This is a crucial aspect common to other insight problems, too (Ohlsson, 1992; Knoblich et al., 2001). We also claim that, in contrast to most classical insight problems, magic tricks are less artificially construed and are more "ecologically valid" stimuli in the sense that efforts to solve the tricks are naturally set in motion. When observing a magic trick, people are astonished and surprised and usually want to find out "how it was done," i.e., how the magic effect was achieved. The magician deeply affects prior knowledge representations, by seemingly overturning them (e.g., a levitation effect that seems to defy gravity). Consequently, we assume that discovering the secret of a magic trick results also in an intense Aha! experience, comparable with finding the solution to classical paper-and-pencil tasks by insight. Most important, and this makes magic tricks superior to classical insight problems, it is possible to present a large number of consecutive problems that usually have a high attraction for the observer, so that we get much more data points than in classical studies that use only 1–5 insight problems (e.g., Fleck and Weisberg, 2004).

Previous research implementing magic tricks as stimuli supports our view: Parris and colleagues investigated the neural correlates of disbelief by contrasting video clips of magic tricks with other surprising video clips and found specific activity in the left dorsolateral prefrontal cortex (Parris et al., 2009). This shows that there is something special to magic tricks that goes beyond mere surprise—Parris et al. interpreted this activity as a detection mechanism for violations of causality which are the essence of most magic tricks. In another fMRI study to be published in the same Frontiers research topic (Danek et al., Submitted), we focused on these violations of causality with a new and larger set of magic tricks and could replicate some of Parris' findings. In addition, we found that the brain activity of the magician who had performed the tricks clearly differed from the brain activity of naïve observers. In contrast to lay participants, the trick apparently did not involve any causality violations for the magician himself (this can be compared to the scenario of a magician practicing his gestures in front of a mirror—and no magic effect takes place). In sum, observing a magic trick seemingly invalidates the spectator's implicit assumptions about what is possible in the world, and therefore leads to the strong desire to discover the secret behind the trick. If this is achieved, we assume that the typical Aha! experience will be triggered.

MATERIALS AND METHODS

PARTICIPANTS

Fifty students (mean age 24.4; 16 male) participated for 32€ in the study and were tested individually after giving informed consent. Two participants were excluded because they did not solve any of the presented tasks, resulting in a final sample size of 48. The experiment was approved by the Institutional Review Board (Ethics Committee) of the Department of Psychology, LMU Munich.

TESTING MATERIAL

The testing material consisted of 37 (3 of them used for practice) video clips of magic tricks that had been performed by a professional magician (TF) and recorded in a standardized setting. The video clips that ranged from 6 to 80 s were presented on a 17" computer screen displayed by the Presentation® software version 12.1. The tricks covered a wide range of different magic effects (e.g., transposition, restoration, vanish) and methods (e.g., misdirection, gimmicks, optical illusions). The magic tricks were presented to participants as a problem solving task. See http://www.youtube.com/watch?v=3B6ZxNROuNw for a sample trick clip from our study. Stimulus development, a complete list of the tricks and the experimental rationale are described in further detail in another paper (Danek et al., 2014).

PROCEDURE

There were two separate testing sessions with exactly 14 days delay. In session 1, participants' task was to watch magic tricks and to find the secret method used by the magician to produce the magic effect. If a trick was solved, they had to indicate on a trial-by-trial basis whether they had experienced an Aha! during the solution. After completing all tricks, participants were asked to evaluate their Aha! experiences. 14 days later, participants were invited again for a second evaluation of their Aha! experiences, this time from memory. In addition, a recall of participants' solutions was conducted in session 2. The results of this recall do not contribute to the present research question and are thus reported elsewhere (Danek et al., 2013). Both sessions lasted about 2 h.

Session 1: magic tricks

Participants were seated in a distance of 80 cm in front of a computer screen. After filling in an informed consent, they were orally instructed by the experimenter to watch the video clips of magic tricks and think of a solution how the trick could work. If participants failed to solve the trick, the video clip was repeated up to two more times while solving attempts continued.

As soon as they had found a potential solution, participants were required to press a button which stopped the video clip and ended the trial. A dialog with the following question appeared (all questions in German): Did you experience an Aha! moment? Participants indicated Yes or No with a mouse click. Subsequently, they were prompted to type in the solution on the keyboard and gave a certainty rating of how confident they felt about the correctness of their solution on a scale from 0 to 100%. **Figure 1** shows the procedure of one trial.

Following Bowden and Jung-Beeman's approach (2007), participants categorized their solution experiences into insight (with Aha!) and non-insight (without Aha!) solutions. We used the following instruction for these judgments (adapted from Jung-Beeman et al., 2004): "We would like to know whether you experienced a feeling of insight when you solved a magic trick. A feeling of insight is a kind of "Aha!" characterized by suddenness and obviousness. Like an enlightenment. You are relatively confident that your solution is correct without having to check it. In contrast, you experienced no Aha! if the solution occurs to you slowly and stepwise, and if you need to check it by watching the clip once more. As an example, imagine a light bulb that is switched on all at once in contrast to slowly dimming it up. We ask for your subjective rating whether it felt like an Aha! experience or not, there is no right or wrong answer. Just follow your intuition."

After three practice trials, the experiment started and for each participant, a randomized sequence of 34 magic tricks was presented.

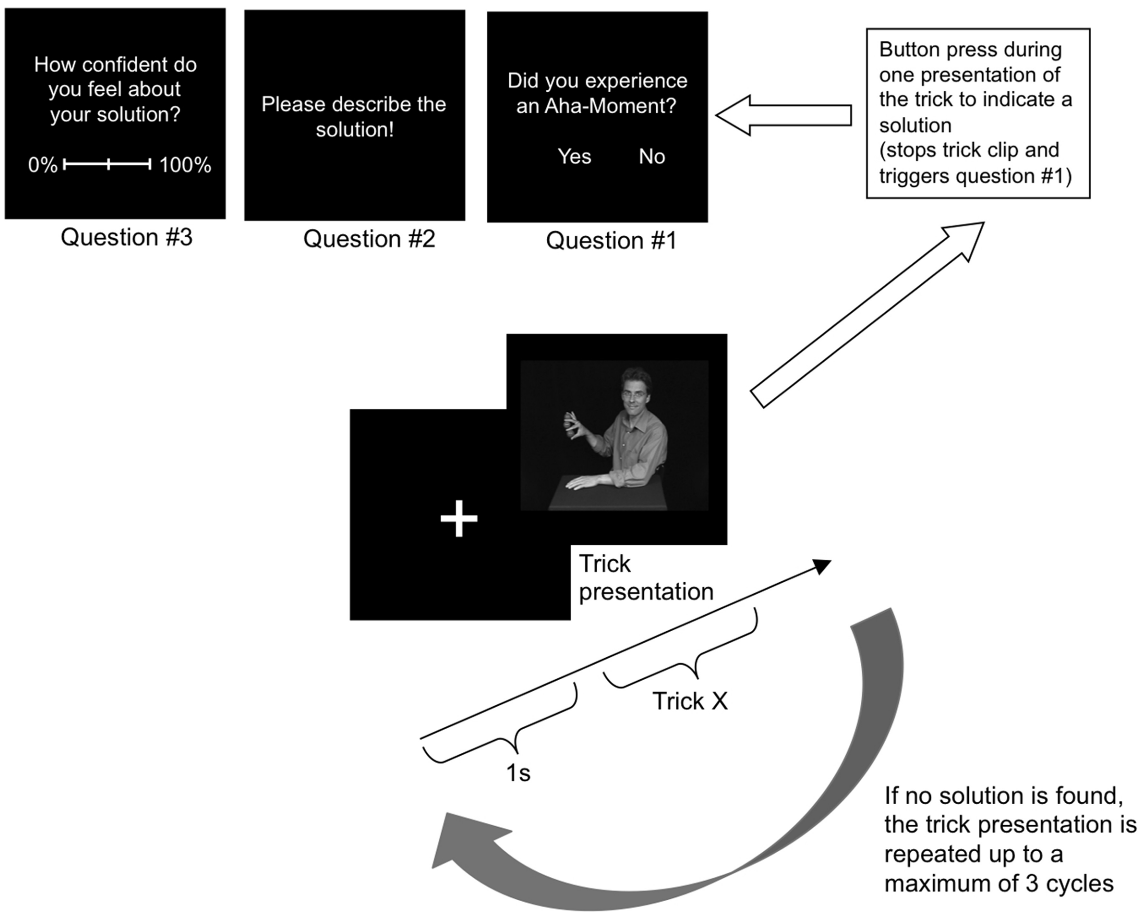

FIGURE 1 | Procedure of one trial. Different phases and timing are displayed. Note that individual tricks vary in length.

Session 1: assessment of Aha! experience

Adopting a similar procedure from MacGregor and Cunningham (2008) who collected a global self-rating of insight after participants had worked on several different insight problems, we decided to conduct the comprehensive assessment after all tasks were completed. This procedure of asking participants to report their overall feeling of Aha! allowed us to collect the most basic, overarching characteristics of the insight experience, independent from individual fluctuations caused by differences between single problems (e.g., a very difficult trick in contrast to a less difficult one that might lead to less strong Aha! experiences). We used a two-fold approach:

- Self-report (qualitative): participants were given the opportunity to describe the thoughts and emotions that occurred while they gained insight into the working of a magic trick. This self-report was performed prior to the rating of importance to avoid possible transfer effects—so that participants could freely describe their actual Aha! experience without being influenced by the given dimensions.
- Rating of importance (quantitative): five previously postulated dimensions were subjected to a rating of importance by participants (compare Sandkühler and Bhattacharya, 2008).

Session 1: self-report. After completing all 34 magic tricks, participants were asked to give introspective self-reports ("Think back to the Aha! moments that you had during the experiment. For you, how does an Aha! moment feel like? Please describe it in your own words!"). It was stressed that the self-reports should refer to Aha! solutions only, not to the other solutions which participants had classified as non-insightful. Participants used the keyboard to type in their descriptions. There was no time limit for this task.

Session 1: rating of importance. Subsequently, participants rated their Aha! experiences on each dimension separately, using a visual analog scale. For each dimension, a new scale was displayed on the screen (see **Figure 2**), with specific text on top of the scale and specific end point denominations (translated from the German original for the purpose of this paper).

- Please rate your Aha! experiences! unpleasant—pleasant
- Please rate your Aha! experiences! not surprising—surprising
- The solution came to me. . . slowly—quickly
- I felt about the solution. . . uncertain—certain
- Before the Aha! moment I felt. . . in no impasse—in an impasse

These descriptions refer to the dimensions happiness, surprise, suddenness, certainty, and impasse. As default, the cursor was set in the middle of the scale and participants moved it along the scale using the mouse to select a position. The left end of the scale corresponded to a value of 0 and the right end to a value of 100, but participants did not see any numbers. Participants were instructed as follows: "Think back to the Aha! moments that you had during the experiment. Now we ask you to rate them with regard to different aspects. Please indicate on the scale how much each aspect applies to your Aha! moments."

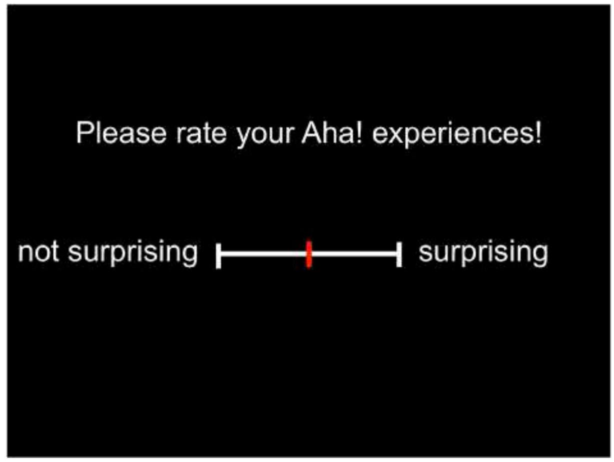

FIGURE 2 | Visual analog scale for the dimension surprise.

To control for familiarity, at the end of session 1 participants received a questionnaire with a screenshot from each trick and were asked to indicate whether the solution of a trick had previously been known to them. These tricks were excluded on an individual level and handled as missing values (5.2% of all trials).

Session 2: re-assessment of Aha! experience

To control for its stability across time, the same assessment (self-report and rating of importance) was conducted 14 days later. The procedure was identical to session 1. Again, participants were explicitly asked to refer to the Aha! experiences they had had during the experiment (now 2 weeks ago) and to describe them from memory.

RESULTS

RESPONSE CODING AND CATEGORIZATION OF SELF-REPORTS

Participants' solutions were coded off-line as true or false by two independent raters, Cronbach's alpha as a measure of inter-rater reliability was 0.99. True solutions were identical with the procedure that the magician had actually used. False solutions consisted of methods that were impossible with respect to the conditions seen in the video clip. If no solution at all had been suggested, the tricks were coded as unsolved.

Each participant produced a free report of their subjective Aha! experiences that was repeated after a 14 day delay. For six participants, the second rating was missing. The full statements are provided as Supplementary Material (translated from German). The reports were sorted into five main categories (see below). To avoid any a priori assumptions about the nature of Aha! experiences, the categories were compiled by a rater who was blind to the experimental rationale, and who based the compilation only on data from session 1. The rater read all statements from session 1 and collapsed them into meaningful, self-created categories. This rating scheme was subsequently used by three independent raters who re-categorized all reports (both session 1 and 2). A categorization was valid if at least two of the three raters assigned the same category. Critical ones were discussed until an agreement was reached. Each report could be assigned to more than one category, because participants often mentioned several different aspects that belonged to different categories. These were the categories:

(1) Cognitive aspects
   (a) Elaboration (compare representational change theory, Ohlsson, 1992): A solution is found because a crucial detail is detected. This means, the initial problem representation is enriched with additional, previously overlooked details that eventually lead to a solution.
   (b) Restructuring (compare Ohlsson, 1992): A new way of looking at the problem, separate parts suddenly fit together, everything falls into place.
(2) Emotional aspects
   (a) Happiness: feelings of joy, contentment, pleasure, positive arousal.
   (b) Tension release: strain is released, feelings of relaxation and relief.
   (c) Performance-related emotions: pride, drive, increased motivation, competitiveness, satisfaction.
(3) Somatic reactions: physiological arousal or other reactions related to the body.
(4) Reproduction of instruction: if participants simply repeated or paraphrased parts of the instruction that described the "standard" Aha! experience, this category was assigned, including the following aspects: Suddenness, rapidness, clarity of solution, certainty about correctness of solution, light bulb metaphor and common conceptions of Aha! experiences (e.g., "struck by lightning, the penny has dropped").
(5) Other: rest category

MAGIC TRICKS

Table 1 provides an overview of the problem solving data obtained in session 1. See Danek et al. (2014) for a detailed analysis of solution rates, solution accuracy, certainty and influence of demographic variables.

For 41% of all solved magic tricks, participants indicated that they had experienced an Aha! during the solving process. Of course, the subsequent Aha! assessment referred only to those events. Participants had been instructed to think back to their insight experiences, and to rate only those (compare methods).

ASSESSMENT OF Aha! EXPERIENCE

Reliability of Aha! ratings across time (ratings of importance)

There was a delay of 14 days between the first and the second rating time point. We addressed the reliability of those ratings by statistically comparing the two time points. For six participants, the second rating was missing.

Figure 3 shows that the 2nd rating of importance (conducted in session 2) did not differ substantially from the 1st rating (session 1). This observation was confirmed by a repeated measures ANOVA with the factors Session (two levels: session 1 and session 2) and Dimension (five levels: suddenness, surprise, happiness, impasse and certainty) that revealed no significant main effect for the factor Session [$F_{(1,\ 41)} = 1.1, p = 0.3$]. Thus, participants' ratings of their Aha! solution experiences remained stable across time.

There was a significant main effect for the factor Dimension, $F_{(4,\ 164)} = 16.43, p < 0.01$, indicating that there were differences between dimensions. We will focus on the two dimensions that significantly differed from all others, the one with the highest (happiness) and the lowest (impasse) rating, respectively. Pairwise post hoc comparisons revealed that happiness (mean 88.5%) was rated significantly higher than all other dimensions (all $p < 0.05$). This means, happiness was the most important aspect of

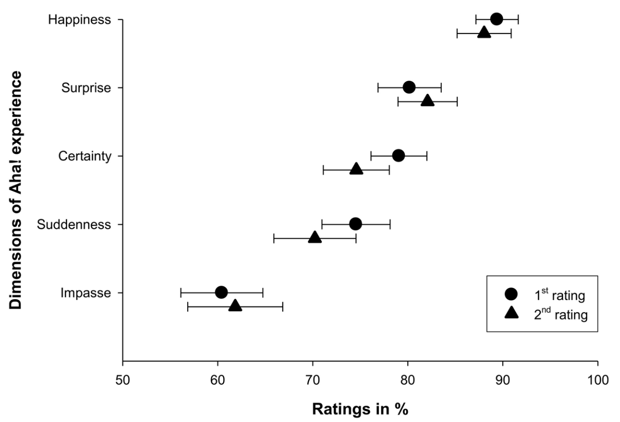

FIGURE 3 | Comparison of the averaged 1st (circle) and 2nd (triangle) importance rating for each dimension. For each time point, the mean rating across participants is depicted. Horizontal bars denote standard errors of the mean.

Table 1 | Solution rates collapsed into different categories.

Outcome	Frequency(Σ = 1632)	Percentage of all trials (*n* = 1632)	Percentage of solved trials (*n* = 800)
Not solved	747	45.8%	–
Discarded trials	85	5.2%	–
True insight solution (with Aha!)	254	15.6%	31.7% } 41.1% insight
False insight solution (with Aha!)	75	4.6%	9.4%
True non-insight solution (without Aha!)	263	16.1%	32.9% } 58.9% non-insight
False non-insight solution (without Aha!)	208	12.7%	26.0%

Thirty-four tricks × Forty-eight participants yielded a total of 1632 trials. Fifty-one % of them were either not solved or discarded due to familiarity of the trick (see first two rows) and 49% of all trials were solved (see four last rows). False solutions refer to implausible or even physically impossible solution suggestions.

the Aha! experience. The feeling of being stuck in an impasse was in comparison less often reported: Impasse ratings were in general lower (mean 60.9%), and differed significantly from all other dimensions (all $p < 0.05$).

Analysis of self-reports

Table 2 shows how often the aspects had been described and provides one prototypical example each.

For the 1st assessment (from session 1), comparing the cognitive and the emotional categories (1a + 1b vs. 2a + 2b + 2c) with a cross tab, we found that 24 participants mentioned emotional aspects (but no cognitive ones) whereas only 5 participants mentioned cognitive aspects (but no emotional ones). This difference was significant (McNemar test, $p < 0.01$).

After 2 weeks, this difference was even more pronounced: In session 2, 30 participants mentioned emotional, but no cognitive aspects (in contrast to only two participants with the reverse pattern), and the McNemar test was significant with $p < 0.01$.

Regarding the emotional categories, clearly the most relevant aspect was happiness (mentioned 43 times). Performance-related emotions (24 times) and the feeling of tension release (19 times) were mentioned less often.

Apart from reproductions of the instruction, which dealt mainly with the solution strategy used (Aha! vs. more analytic solving styles), only few cognitive aspects were mentioned.

Somatic reactions were only mentioned by three participants at each time point. Two statements were from the same participants, i.e., in session 2, two participants described the same physiological reactions as they had during the first session. In the first case, this was "a slight pull in my chest and tummy," and the second participant expressed the feeling "like a shot through my body."

Category 4 was used as a manipulation check. Obviously, participants remembered the instruction well or used the same characteristics, with 51 total instances of naming one of these aspects.

DISCUSSION

The new task domain of magic tricks proved to be well suited to trigger Aha! experiences with 41% of all solutions classified as such. This finding provides further evidence for our conception of magic tricks as an insight task (see Danek et al., 2014). The comprehensive assessment of solution experiences revealed participants' strong emotional involvement upon gaining insight into the working of a magic trick. To our knowledge, this emotional component of insight has not been specifically documented yet for any other problem solving task. We therefore advocate magic tricks as useful tools to investigate insight problem solving.

With regard to phenomenology, the present results support our conception of the Aha! experience as multi-dimensional. However, the hypothesis that all five dimensions of the Aha! experience would be rated as equally important was not confirmed. Instead, we found "happiness" as prevailing aspect. This primacy of positive emotions is also reflected in participants' self-reports although two different methods were used (qualitative self-reports and quantitative ratings on a visual analog scale with fixed dimensions).

The dimension "impasse" appears to be less important than previously thought (Ohlsson, 1992), casting doubt on the theoretical assumption that being in a state of impasse is a prerequisite for experiencing insight later. This finding is in accordance with results from a study on the Candle Problem (Duncker, 1945) by Fleck et al. (Fleck and Weisberg, 2004) who found only few instances of impasse in verbal protocols obtained during the solution process. However, this finding might perhaps also be attributed to characteristics of our new stimulus domain. We argue that watching a magic trick directly puts the observer in a state of impasse—namely in the first moment of astonishment and wonder about the magic effect. At first, the observer is left

Table 2 | Categorization of participants' self-reports with prototypical examples (translated from German).

#	Category	Example	Frequency in session 1	Frequency in session 2	Total frequency
1a	Cognitive (elaboration)	I detected a small detail and suddenly, the things that I had observed previously make sense.	8	1	9
1b	Cognitive (restructuring)	What in the beginning didn't fit together suddenly makes sense.	6	2	8
2a	Emotional (happiness)	I am happy and get into a good mood.	20	23	43
2b	Emotional (tension release)	I feel relieved and relaxed.	8	11	19
2c	Emotional (performance-related emotions)	- I was much more motivated to continue working on the task. - Like a competition between me and the magician, and in Aha! moments, I felt like the winner. - I feel so much more intelligent.	12	12	24
3	Somatic reactions	Like a shot through my body.	3	3	6
4	Reproduction of instruction	I suddenly feel an enlightenment.	29	22	51
5	Other		6	4	10
			Σ 92	Σ 78	Σ 170

Their corresponding frequencies are listed separately for the two time points, as well as summed up (last column).

completely baffled, without any solution prospect. But later, after the problem solving process has been initiated, participants don't necessarily experience an impasse.

The importance ratings remained stable across time in all five dimensions (see **Figure 2**). To evaluate such a fleeting moment by pinpointing its dimensions on five different scales is arguably quite a difficult task. It seems impressive that participants were able to recall their Aha! experience so vividly after 14 days that they rated it identically. This finding provides empirical support for Bowden's claim (2005) for the usefulness and reliability of self-reports in insight research.

A weakness of the visual analog scale used here is the lack of negatively poled questions, reflected in the answers' general trend toward the positive pole. The temporal stability of the importance ratings might thus partly be explained by reduced variability caused by this positive bias. An alternative explanation for the ratings' stability must also be considered: It is conceivable that participants did not actually remember their Aha! experiences, but instead reported what they remembered reporting in session 1. However, this seems unlikely for two reasons: First, participants had not been informed about what would happen in the second experimental session—they were completely unaware that the rating would have to be repeated. Second, to make it difficult to remember the previous rating, we had deliberately implemented a visual analog scale without any numbers. There was only a line on which the cursor had to be positioned. In this way, participants could never know the value to which the selected position corresponded and could therefore not retain any numbers, only a visual image of the scale. It seems unlikely that participants were able to incidentally retain this visual impression for 2 weeks for five dimensions, especially when considering the complex wording of the different rating scales (see Section Session 1: rating of importance).

The free self-reports helped to obtain further information about problem solvers' actual experience. A qualitative analysis of this data revealed positive emotions as the prevailing aspect of Aha! experiences. These quotes from two of our participants may serve as an illustration: "A moment of bliss. I am happy and get into a good mood." and "Explosively, the bad feeling of frustration and confusion turns into a feeling of happiness and I feel a swell of pride." (see Supplementary Material). This is in accordance with results from the importance ratings in which happiness received the highest value. We thus demonstrated the occurrence of strong positive emotions during sudden moments of insight.

We found two new aspects in participants' self-reports. The comparably high frequency of performance-related aspects (e.g., "I feel really clever now" or "With Aha! experiences, I am much more motivated to continue working on the task or problem") has not been reported before. However, it can be assumed that this aspect is relevant for many problem solving tasks since participants' cognitive abilities are put to the test. Finding a solution can be experienced either positively or negatively (chagrin about prior "stupidity," compare Gick and Lockhart, 1995). The present data suggests that the majority of participants felt happy about being able to solve the magic trick, see above. That some participants felt a heightened motivation to continue with the task after an Aha! experience offers many possibilities for interesting follow-up studies. For example, Aha! experiences could be used to motivate students in classroom settings.

Although we subsumed them both under the category "performance-related aspects," the comments about motivation and cognitive abilities must be differentiated from comments about a competition with the magician (e.g., "The magician can't fool me anymore because by now, I could do the trick by myself"). This was not expected, and at first glance, might be attributed to the special task situation with our participants being confronted with the magician as a kind of rival, thus engaging in a competition with him. However, even if no direct opponent is presented, a certain flavor of competitiveness is a shared characteristic of all problem solving experiments. Typically, participants are worried that their level of intelligence will be assessed or that the experimenter will find out that they perform worse compared to other participants. Thus, they either compete against the experimenter (who typically knows all the solutions) or against other participants. Consequently, if our comprehensive assessment of Aha! experiences would be conducted with traditional problem solving tasks, we would expect similar results. Of course, this remains to be shown in future studies.

Tension release was the other new aspect of the Aha! experience (e.g., "I feel relieved and relaxed now" or "feeling of relief after a phase of strain caused by failure"). It seems plausible to assume that tension arises if there exists no obvious solution for a problem. During unsuccessful problem solving attempts, the tension builds up further. If at last, unexpectedly, a solution is found, the tension will rapidly decline. Apparently, this is an important aspect still missing from current definitions of the Aha! experience.

These empirical findings relate to theoretical assumptions about the phenomenology of the Aha! experience. Ohlsson (1984) summarized the Gestalt psychologists' main ideas in a set of principles. Some of them overlap with the self-report data: In the category "performance-related emotions," participants repeatedly describe heightened motivation ("I am much more motivated to continue working on the task"). This closely resembles proposition N (Ohlsson, 1984, p. 70) in which an "energizing effect on problem solving behavior" is described. Other aspects also match: "Recentering as a displacement of attention from one part of the situation to another [. . .] reveals what the central part of the situation really is" (Ohlsson, 1984, p. 70). This corresponds to the "elaboration" category and matches the idea of selective encoding (Davidson, 1995), i.e., that a problem solver suddenly detects certain features which were not obvious before (and not encoded) as relevant for a solution. For example, one of our participants noted that "Through a small detail, the entire action sequence becomes clear."

We conclude that there is a wealth of information to be gained through subjective self-reports. Most participants took several minutes to diligently describe their thoughts, using vivid and expressive language as documented in the Supplementary Material. We recommend the use of such direct, qualitative self-reports as a promising tool to learn more about the phenomenological aspects of insight problem solving.

Of course, there are obvious limitations to the introspective method: It is highly subjective, and general conclusions can only be drawn with caution. Moreover, it is difficult to clearly determine what participants actually used as the basis for their report, especially if several defining aspects of the experience in question are mentioned in the instruction, as done in the present study. Durso even suggested that because participants were shown to be unable to correctly judge their progress toward a solution (Metcalfe, 1986), "... self-reports following insight are equally unreliable." (Durso et al., 1994, p. 94). Yet we argue that for the elusive phenomenon of insight, subjective Aha! reports might provide information that would not be accessible through more rigorous experimental methods. Other researchers have successfully used verbal protocols to elucidate the processes during insight problem solving (Kaplan and Simon, 1990; Dominowski and Buyer, 2000; Fleck and Weisberg, 2004; see also Fox et al., 2011, for a recent meta-analysis on verbalization procedures in general) and others even argue that the rejection of introspective methods hinders the advancement of the field (Jäkel and Schreiber, 2013). We suggest that the traditional approach of using pre-defined "insight problems" and assuming the occurrence of insight in the case of a solved problem, without taking into account participants' individual problem solving experiences, should always be complemented by subjective measures (e.g., Aha! self-reports or thinking-out-loud protocols) directly obtained from participants.

Another limitation of the present study is that we did not collect any ratings on non-insight solutions. On a trial-by-trial basis, additional ratings would have increased task demands too much (considering the large number of difficult problems that participants had to solve). But a second global rating at the end for non-insight solutions, too, would have been feasible. This would have offered the possibility of directly comparing the two types of solutions and thus would have allowed answering questions regarding the difference in participants' subjective experiences while solving problems with or without insight. Future studies should incorporate this improved design. However, since the focus of the present study was on the phenomenology of the Aha! experience, aiming to disentangle its several components, we decided not to introduce any ratings on non-insight solutions. Instead, participants concentrated on insight solutions in all ratings, with the aim of grasping the Aha! experience as fully as possible.

Critical appraisal of magic tricks as problem solving tasks: We claimed that magic tricks represent a more authentic task domain than previous insight tasks because participants start working on the problem quite naturally, eager to find out the magician's secret. During the testing, participants were highly motivated to solve the presented tricks, even after many trials. In addition, magic tricks are less artificially construed than classical insight problems in which participants must solve verbal riddles, logical brainteasers, mathematical problems or connect dots according to arbitrary rules. They are authentic because they take place in familiar situations with ordinary objects like coins or cigarettes. The present work indicates that such authentic stimuli can be as valuable as strictly controlled paper-and-pencil tasks. A systematic comparison of magic tricks with traditional types of stimuli (e.g., with regard to motivational aspects) is needed to further substantiate this claim.

Another open question is how much the findings from the present study about insight in a magic context will generalize to other tasks. It is actually a weakness of most problem solving studies, ours included, that only one type of task is used (but there are exceptions, e.g., Metcalfe and Wiebe, 1987). Attempts at setting up taxonomies of "insight problems" show the large range and heterogeneity of tasks used (Weisberg, 1995). Future studies should include different types of problems to allow a direct comparison of the results across tasks. However, we are confident to assume that the present findings will generalize to other insight problems, because, applying the framework of the representational change theory (Ohlsson, 1992), it seems obvious that classical insight problems and magic tricks rely on fairly similar processes. Both activate self-imposed and over-constrained problem representations that have to be relaxed in order to come up with a solution. Our rationale for using magic tricks as an insight task is explained in detail in Danek et al. (2014). Moreover, we could already show (Danek et al., 2013) that magic tricks that are solved by insight had a higher recall rate after 2 weeks, a similar effect as found with classical insight problems.

Inducing positive mood could be another important advantage of using magic tricks in insight research, because it has been shown previously that positive affect facilitates insight (Isen et al., 1987; Bolte et al., 2003; Subramaniam et al., 2009; Sakaki and Niki, 2011). For example, Isen et al. (1987) induced positive mood by presenting a comedy film (Gag reel) to participants shortly before they began working on Duncker's Candle Problem (1935). A control group who had watched a neutral film (a math film, Area under a curve) produced significantly less solutions than the positive mood group. It seems plausible that in the present study, participants' emotional state was positively influenced by watching the magic tricks, similar to watching a comedy film. The self-reports showed the high emotional impact of solving a magic trick. Although we did not directly assess mood, it was obvious that participants liked to watch the tricks and were highly motivated to do the task. Perhaps the drop-out rate of zero (for the second visit to the lab) can also be accounted to that. In pilot studies, participants scored very high on the question "How much did you like the trick?" with a mean of 2.94 (on a rating scale from 1 = not at all to 4 = very much). We speculate that the positive mood induced by watching magic tricks also facilitated insight in the present study. In future experiments using magic tricks, we recommend to systematically control for mood.

In sum, this study demonstrates that the Aha! experience should not only be regarded as an interesting epiphenomenon or trial-sorting criterion, but that the phenomenon itself can be investigated systematically and fruitfully. Implementing magic tricks as problem solving task, we could show that strong Aha! experiences can be triggered if a trick is solved. We could at least partially capture the phenomenology of Aha! by identifying one prevailing aspect (positive emotions), a new aspect (release of tension upon gaining insight into a magic trick) and one less important aspect (impasse). We hope to have contributed to a deeper understanding of the nature of this complex phenomenon by introducing magic tricks as a useful research tool for insight problem solving.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/Journal/10.3389/fpsyg.2014.01408/abstract

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Explanations of a magic trick across the life span

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Studying how children and adults explain magic tricks can reveal developmental differences in cognition. We showed 167 children (aged 4–13 years) a video of a magician making a pen vanish and asked them to explain the trick. Although most tried to explain the secret, none of them correctly identified it. The younger children provided more supernatural interpretations and more often took the magician's actions at face value. Combined with a similar study of adults ($N = 1008$), we found that both young children and older adults were particularly overconfident in their explanations of the trick. Our methodology demonstrates the feasibility of using magic to study cognitive development across the life span.

Keywords: magic, magical beliefs, magical thinking, appearance–reality distinction, conjuring

1. INTRODUCTION

Magic tricks depend on assumptions about the world. Magicians skillfully violate these assumptions to create mysteries (Rensink and Kuhn, 2014). Since assumptions change with age, magicians perform differently for children and adults. Children, for example, may prefer watching physical magic such as vanishing objects, while adults can understand psychological magic such as mind-reading. To keep performances suitable, magicians have developed intuitions about which tricks work best for which ages (e.g., Ginn, 2004; Kaye, 2005). Examining these intuitions could lead to new insights or methods in the study of cognitive development.

Scientists have leveraged magic to explore other areas in psychology (Kuhn et al., 2008) including attention, perception, decision-making, and problem solving. Some have used both children and adults in their samples to compare cognitive development (e.g., Subbotsky, 2001). Few, however, have explored developmental differences with a large sample over a wide age span. Combined with previous research on adults (Demacheva et al., 2012), we present a feasibility study of 1175 participants aged 4–90 years.

Due to their level of maturation, children have different expectations and assumptions than adults; magicians thus cater to them with a specific set of effects (Sharpe, 1988; Rissanen et al., 2014). Around 4 years of age, children begin to understand that other people have distinct beliefs and intentions—that is, they begin to form a Theory of Mind (Apperly et al., 2009). Around the same time, the distinction between appearance and reality becomes clearer (Flavell, 2000). When executive attention develops around 3–7 years of age, logical thinking and sustained attention improve (Posner and Rothbart, 2007). With these developments, children are better able to make assumptions about what is going to happen and thus become more receptive to magic tricks.

Magical beliefs—such as beliefs about the existence of events which violate physical laws—also change with age (Subbotsky, 2014). Young children tend to believe in fantasy figures (such as fairies; Phelps and Woolley, 1994; Woolley, 1997) and many preschool children believe magicians have supernatural powers (Evans et al., 2002). During school age, children start to develop a more scientific perspective which can override magical beliefs (Subbotsky, 2010). Even so, these beliefs can persist into adulthood. In one study, more than half of college students ascribed psychic abilities to someone performing tricks resembling clairvoyance and psychokinesis, even if he was introduced as an amateur conjurer (Benassi et al., 1980). In another study, adults who claimed not to believe in supernatural abilities were reluctant to let the experimenter cast a spell on their identification cards (Subbotsky, 2001). Though some magical beliefs decrease with age, they continue to play an important role throughout the life span (Subbotsky, 2014).

In this paper we present a preliminary study of magical beliefs in children and adults. Participants watched a magician make a pen vanish then they tried to explain the trick. This "non-permanence magic" (Subbotsky, 2001) surprises most people over 4 years old (Rosengren and Rosengren, 2007). We had three hypotheses:

1. Confidence in one's explanation of the secret will decrease with age. This is consistent with magicians' observations and with studies showing that young children feel overconfident in their cognitive abilities (Shin et al., 2007; Lipko et al., 2009).
2. Younger children (aged 4–8 years), compared to older ones, will show more magical beliefs when explaining the trick (see Phelps and Woolley, 1994).
3. Younger children (aged 4–5 years) will more often take observed events at face value, since the appearance–reality

distinction is still developing (Flavell, 2000). Specifically, they will more often believe that the pen broke or dissolved in the magician's hands.

2. METHODS

The experimenter led participants to a testing room with individual computers. The participants watched a recorded magic trick, tried to explain it, then rated their confidence in the explanation. Next, the experimenter prodded for alternative explanations using a questionnaire. Finally, participants explained the trick again and re-rated their confidence level. The entire procedure took under 30 min for each participant.

2.1. PARTICIPANTS

We recruited 167 children from a summer camp in Montreal, Canada. They were 8.8 ± 2.3 years old (mean ± SD, range 4–13) and around half (54%) were male. Each age group had at least ten participants (**Table 1**). The procedure conformed to the guidelines of the Jewish General Hospital Research Ethics Committee and we obtained parental consent.

Previously we recruited a sample of 1008 participants 22.3 ± 6.6 years old (14–90, 31% male; see **Table 1**) which we used as a comparison group (Demacheva et al., 2012). They completed an analogous questionnaire online.

2.2. MATERIALS

2.2.1. Magic trick

The experimenter explained that we were studying how people think about magic tricks. On a computer, a 15-s silent video clip showed a magician making a pen vanish. In the video, the magician begins by showing a pen then appears to break it. When his hands open, the pen has vanished (**Figure 1**; see Supplementary Material for a video). We chose this minimal magic trick because it can fool both children and adults without needing patter, interaction, or explicit social cues (Demacheva et al., 2012; cf. Joosten et al., 2014). Participants could watch the video as many times as they wanted. Throughout the study, the experimenter referred to the magic trick in the video as a trick and avoided mentioning "real magic."

There are several methods of performing this trick. Here, the secret involved the pen quickly moving inside the magician's jacket. A small cue in the video of an object hitting the magician's shirt hinted at this method. For a full description of the mechanism behind the trick, see Wilson (1988, p. 279, "The Vanish of the Handkerchief").

2.2.2. Questionnaire

The experimenter then led the children through a questionnaire (Appendix A in Supplementary Material); we used the same one as Demacheva et al. (2012) after a developmental psychologist adapted the wording for children. Most children tried to explain the secret of the trick. A magician who was unaware of our hypotheses later rated these explanations on a scale from 1 (i.e., completely wrong) to 5 (i.e., complete grasp of the method). Children rated their confidence in the explanations on a similar 5-point scale (1: not at all, 2: a bit, 3: some, 4: a lot, 5: a whole lot). The questionnaire then probed for alternative explanations by asking about required materials and possible methods to perform the trick. Some materials and methods were accurate (e.g., rubber bands, the pen moves quickly to a different location) and others were not (e.g., mirrors, the magician still holds the pen but it cannot be seen). Finally, children revised their initial explanations and re-rated their confidence.

3. RESULTS AND DISCUSSION

Consistent with our hypotheses, younger children gave more supernatural interpretations, more often took the magicians' actions at face value, and felt more confident in their explanations. Inconsistent with our hypotheses, confidence also increased with age among adults.

3.1. SECRET

Although most children (62%, CI [54, 69%][1]) tried to explain the secret, none correctly identified it. The magician gave 96% [92, 99%] of the initial explanations the lowest accuracy rating: completely inaccurate. (We considered the explanation correct if the magician rated it 3 or more out of 5). Even after being probed for alternative explanations, participants performed only marginally better: 2% [0, 6%] guessed it correctly. Adults similarly had little success in guessing the secret (5% were correct in their first explanation and 9% in the second; Demacheva et al., 2012). The trick was thus effective in that few people figured it out. We excluded these few from the rest of the analyses.

3.2. EXPLANATIONS

Attempts to explain the trick were broad. The 4–6-year-olds usually remarked the pen "just disappears" or the magician "just breaks it." Indeed, the younger children more often took the magician's actions at face value. Specifically, they more often believed that the pen broke or dissolved in the magician's hands (**Figure 2**). Thus, age related to reports that the pen broke ($\chi^2_{(8)} = 22.459, p = 0.004$) or dissolved ($\chi^2_{(8)} = 25.54, p = 0.001$)[2]. These reports largely flattened out after the teenage years (**Figure 2**).

[1]Square brackets denote 95% confidence intervals (see Cumming, 2014).
[2]Statistical tests used data from participants 4–13 years old. Four and five-year-olds were combined due to their small sample sizes (see **Table 1**).

Table 1 | Sample sizes and gender proportions for each age group.

Age	4–5	6	7	8	9	10	11	12	13	14–17	18–19	20–29	30–39	40+
N	10	20	31	22	17	23	16	18	10	37	225	655	62	29
% Male	10	35	55	86	35	65	56	72	40	46	25	30	55	52

Participants aged 13 and under completed the child version of the questionnaire; the rest did the adult version (Demacheva et al., 2012).

FIGURE 1 | Participants watched a silent video of a magician making a pen vanish. For the video, see Supplementary Material.

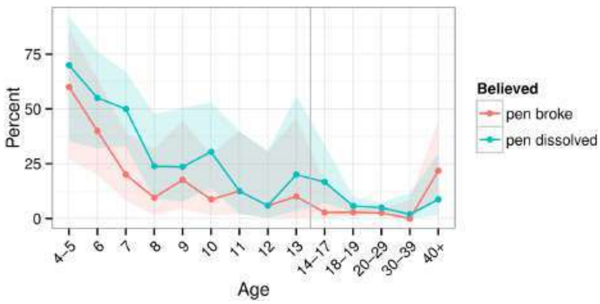

FIGURE 2 | Percent of participants believing that the pen broke or dissolved. The vertical line separates those who took the child vs. adult version of the questionnaire. Shaded areas show bootstrapped 95% confidence intervals.

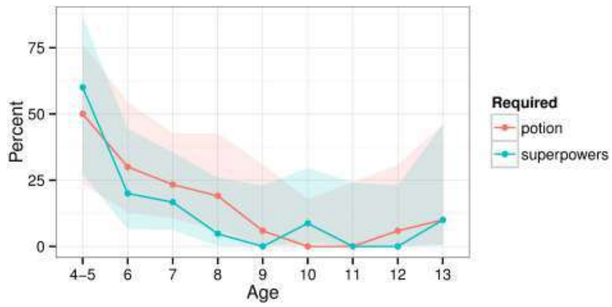

FIGURE 3 | Percent of participants believing that the magic trick required a magic potion or superpowers. Shaded areas show bootstrapped 95% confidence intervals.

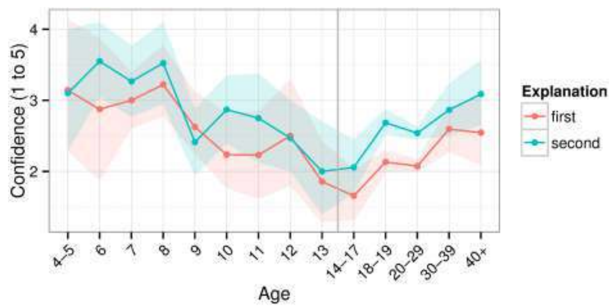

FIGURE 4 | Confidence in one's inaccurate explanation of the magic trick. Shaded areas show bootstrapped 95% confidence intervals.

The 7–9-year-olds began to develop possible yet implausible explanations. Some suggested the magician hid the pen in his sleeves (which were rolled up in the video) or hid it in his skin. Others suggested the pen crumbled into smaller and smaller pieces until nothing remained. One suggested that the torso in the video was actually a mannequin and the magician hid the pen in the empty torso. The 10-year-olds and older children started to develop plausible explanations, such as a trick pen, camera tricks, or a hidden pocket. These progressive changes in the explanations presumably reflect both increased verbal ability and cognitive development.

Consistent with previous studies (e.g., Evans et al., 2002), many of the younger children showed magical beliefs. Some suggested that the pen vanished simply because "the pen is magic." When asked in the questionnaire, younger children more often believed the secret involved superpowers or a magic potion (e.g., "there is secret invisible stuff on his hands that makes [the pen] disappear"; **Figure 3**). There were thus relationships between age and the frequency of beliefs that the trick used a potion ($\chi^2_{(8)} = 24.008, p = 0.002$) or superpowers ($\chi^2_{(8)} = 32.74, p < 0.001$). The adult version of the questionnaire used different wording ("chemical reaction" rather than "magic potion") which prevented a comparison to the children.

3.3. CONFIDENCE

Despite their lack of accuracy, children felt confident in their explanations: 84% reported at or above the midpoint of confidence. The majority (73%) reported "some" or "a lot" of confidence in their explanation. Adults reported roughly similar levels of confidence (57%).

Among children, confidence seemed to decrease with age (**Figure 4**); there was a relationship between age and confidence in the explanation of the trick (first explanation: Kruskal-Wallis $H_{(8)} = 15.509, p = 0.05$; second: $H_{(8)} = 19.176, p = 0.014$). This general pattern is consistent with the finding that younger children are particularly overconfident (Lipko et al., 2009). Indeed, when presenting a deck of cards to young children, magicians (e.g., co-authors JO and AR) often hear, "Oh! I know that trick!."

Among adults, confidence seemed to *increase* with age (**Figure 4**). This seems inconsistent with findings that younger

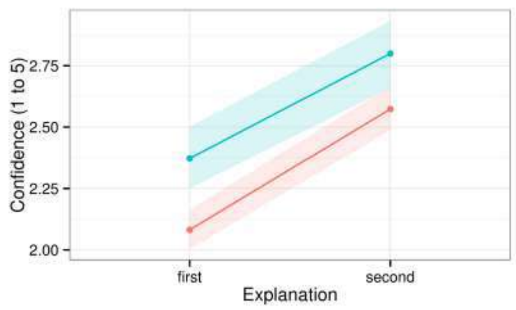

FIGURE 5 | Confidence in one's inaccurate explanation of the magic trick by gender. Shaded areas show 95% bootstrapped confidence intervals.

adults are generally more overconfident than older ones (Pliske and Mutter, 1996; Zell and Alicke, 2011). In our sample, gender differences may have contributed to this effect. Some studies have found that men are more overconfident in their abilities than women (Barber and Odean, 2001; Bengtsson et al., 2005). Our sample included more men as age increased above 18 (see **Table 1**) and overall males were more overconfident than females (**Figure 5**). The increase in males among older adults could have likewise increased confidence at older ages. Still, this could only explain part of the effect. Zell and Alicke (2011) found an interaction between age and overconfidence depending on which dimension was measured. For example, older adults were more confident about their sociability but less so about their athleticism. Perhaps, then, explaining magic tricks is a dimension showing more overconfidence with age. It remains unknown whether similar results apply to other magic tricks or cognitive tasks among adults.

3.4. LIMITATIONS

This study had three potential limitations. First, the questionnaires for children and adults differed slightly in wording (compare Appendix A in Supplementary Material here with Demacheva et al., 2012). Although we consulted a developmental psychologist to help ensure analogous wording, different results between children and adults could be partly due to inconsistencies in wording. To account for this, we minimized comparisons between those who took the child vs. adult version of the questionnaire. Second, the magic trick was recorded rather than performed live, which complicated the explanations of the trick. When young children claimed that the pen dissolved or vanished, they could have either intended that the pen actually vanished (in reality) or simply that it appeared to vanish (in the video); we could not differentiate these with certainty. Third, our methodology was insensitive to different interpretations of other questionnaire items. For example, when asked whether the trick needed "superpowers," perhaps some children thought of supernatural abilities while others thought of specialized skills. One potential solution would be to perform the trick live each time followed by a more in-depth interview; in our case, this would have prevented such a large sample.

3.5. IMPLICATIONS

Using magic tricks may have several advantages for studying cognitive development across the life span. Traditional illusions in developmental psychology often require props such as boxes, screens, or backdrops (e.g., Baillargeon, 2002). These illusions can make the prop itself seem magical, such as when transforming objects inside a special box (e.g., Subbotsky, 2004). Using magic, as in the current study, the experimenter can make a person look magical rather than a prop. Shifting the locus of magic from props to people could help clarify differences in the development of magical beliefs regarding people vs. objects.

Further, unlike many of the illusions used to test phenomena like object permanence, magic tricks are robust across age: they amaze a large majority of people (here, 95%) over a wide age span. Many tricks work in diverse environments (e.g., Kuhn and Tatler, 2005) and can be translated for use in controlled experiments (Danek et al., 2014; Olson et al., 2015). Children and adults can thus view the same stimuli, which allows researchers to make more direct comparisons across different age groups. Such comparisons may be particularly useful to examine phenomena like magical beliefs or overconfidence which change their presentation across the life span (Benassi et al., 1980; Woolley, 1997; Zell and Alicke, 2011; Subbotsky, 2014). Similarly, magic tricks work across different cultures (Kiev and Frank, 1964) and thus could shed light on intercultural differences in magical beliefs.

In sum, our feasibility study demonstrated a method to test developmental hypotheses with large and diverse samples. Such a method combining video stimuli and online surveys is particularly useful to explore age-based changes in magical beliefs and overconfidence in children and adults. Magic may thus offer a useful tool to gain new insights in developmental psychology across the life span.

AUTHOR CONTRIBUTIONS

JO wrote the manuscript and analyzed the data; ID designed the experiment, collected the data, and helped with the writing; AR helped with the design and manuscript revisions.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2015.00219/abstract

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An fMRI investigation of expectation violation in magic tricks

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Magic tricks violate the expected causal relationships that form an implicit belief system about what is possible in the world around us. Observing a magic effect seemingly invalidates our implicit assumptions about what action causes which outcome. We aimed at identifying the neural correlates of such expectation violations by contrasting 24 video clips of magic tricks with 24 control clips in which the expected action-outcome relationship is upheld. Using fMRI, we measured the brain activity of 25 normal volunteers while they watched the clips in the scanner. Additionally, we measured the professional magician who had performed the magic tricks under the assumption that, in contrast to naïve observers, the magician himself would not perceive his own magic tricks as an expectation violation. As the main effect of magic – control clips in the normal sample, we found higher activity for magic in the head of the caudate nucleus (CN) bilaterally, the left inferior frontal gyrus and the left anterior insula. As expected, the magician's brain activity substantially differed from these results, with mainly parietal areas (supramarginal gyrus bilaterally) activated, supporting our hypothesis that he did not experience any expectation violation. These findings are in accordance with previous research that has implicated the head of the CN in processing changes in the contingency between action and outcome, even in the absence of reward or feedback.

Keywords: expectation violation, magic, fMRI, caudate nucleus, perceptual prediction error, movement observation, action

INTRODUCTION

A deep need of humans is to predict future events. This ability, technically speaking causal reasoning, helps us to navigate in a complex world. Although it is questioned whether our conscious will actually controls our actions (Wegner, 2002), it is clear that the perception of causality exists. Evidence from developmental psychology tells us that infants can discriminate causal from non-causal events (Michotte, 1963). In so-called violation-of-expectation tasks, even young infants try to predict the outcome of observed events as evidenced by their looking longer at trials which violate their expectations (e.g., Wang et al., 2004). Over time, humans acquire a broad knowledge base that is constantly enlarged, modified, and updated. Relying on prior knowledge is helpful for learning, for problem solving, for decision making and for more effective action selection (e.g., Ericsson et al., 1993; Ericsson and Lehmann, 1996; Bilalić et al., 2012). To a large extent, this knowledge base consists of the knowledge of causal relations between action and outcome. Long-established causal relations like this one are typically no longer questioned, and not even explicitly represented. This makes the case of magic so interesting: predictions about the outcome of observed actions and violations of these predictions are key ingredients in magic. Magic tricks provide counterfactual evidence to our prior knowledge about objects, how they can be handled and about the set of possible outcomes. Let us consider the following magic trick: sitting at a table, the magician takes an egg from an egg box. He throws it on the floor – and it jumps back into his hands, undamaged. To prove that it is a real egg, he then breaks it and empties the content into a glass. This is astonishing. We have learnt, probably from our own experience, that if we throw an egg to the floor, it will break and not jump. The observed event strongly violates the expected relationship between action (throwing egg to the floor) and outcome (broken egg).

Before we discuss the possible neural basis of the violation-of-expectation that is present in magic tricks, a short clarification of terms is needed. The term "expectation violation" is used in different contexts from developmental psychology (e.g., Wang et al., 2004) and neuroeconomics (e.g., Chang and Sanfey, 2009) to motor control (e.g., Grush, 2004), and thus refers to very different types of expectations. For the purposes of this paper, we define "expectation violation" as the violation of the expected action outcome in a magic trick. This means, the observer watches an entire action sequence and expects a certain outcome – but another outcome is presented.

The brain areas recruited for expectation violation reflect the nature of the task at hand (Bubic et al., 2009). Thus, an anatomical hypothesis can be derived from the very first (and only) study that investigated hemodynamic activity during magic tricks.

Contrasting magic tricks with situations in which the expected relationship between action sequence and effect was upheld, Parris et al. (2009) reported activity in the dorsolateral prefrontal cortex (DLPFC) and the anterior cingulate cortex (ACC). The ACC is a key area known to mediate cognitive conflict (e.g., Kerns et al., 2004). This fits with results from another fMRI study that found ACC activated when inconsistent information was presented (Fugelsang and Dunbar, 2005). This is supported by several electrophysiological studies (e.g., Holroyd, 2004), for example Huster et al. (2010) reported the cingulate cortex to be the neural generator of the N200, the event-related potential reliably triggered by Go/Nogo tasks (e.g., Johnstone et al., 2007). However, we believe that Parris et al.'s (2009) study cannot fully answer the question of what brain regions support magic trick expectation violations because their analysis was restricted to only one time point (the discrete time point of the moment of surprise). We argue that although the moment of expectation violation is traceable to a specific time point, expectations related to the magic trick are built up over the entire clip. In order to have expected motor outcomes violated, the entire sequence of preceding events is also taken into account. Otherwise magicians would only have to present one specific movement as a "trick" and not the sequence of movements leading up to the single event that violates the already built-up expectancy. For example, in the magic trick described above, the action of breaking the egg and emptying its content into a glass would not violate any expectations, if the egg had not previously been tossed to the floor and jumped up again. It is possible that different but overlapping cognitive processes are active throughout the entire magic trick and at the specific moment of surprise. For this reason, we decided to also look at the complete time window of each clip, besides analyzing the specific time point of surprise.

Another possible candidate region that could subserve the function of signaling expectation violation is the caudate nucleus (CN). Tricomi et al. (2004) conducted a series of fMRI experiments to disentangle reward-related caudate activity and found that the CN was only active in tasks with a perceived contingency between action and outcome. If the outcome was thought to be unrelated to the previous action, CN was not active. A comprehensive review (including anatomical, behavioral, and imaging studies on healthy controls and patients as well as on animals; Grahn et al., 2008) focusing on the head of the CN sketches its cognitive functions as follows: in contrast to the putamen that is thought to be responsible for more rigid habit learning, the CN is responsible for flexible action-outcome learning, in particular when task contingencies change. It subserves a goal-directed response system that monitors the outcome of an action and responds to changes in the contingency between action and outcome. As discussed, magic tricks overturn the learnt contingencies between initial action and expected effect. We expect that this mismatch will activate the CN.

The aim of the present study is to replicate parts of a previous study using a similar paradigm (Parris et al., 2009) with a larger set of magic tricks (24 instead of 13) and a stronger magnet (3 Tesla instead of 1.5). In contrast to the previous study (Parris et al., 2009), we were additionally interested in ongoing activity throughout the entire magic trick, which should correlate with the build-up of an expectation about the contingency between action and outcome. To further investigate the expectation violation in magic tricks, we measured the professional magician (Thomas Fraps) that had performed the magic tricks, as a single case baseline. In order to be able to flawlessly present magic effects, magicians invest in many years of training. The "choreography," i.e., the secret as well as the official action sequence of each specific trick must be learnt through many repetitions. Depending on the difficulty of the trick and the experience of the magician, a conservative estimate by Thomas Fraps is that 150–200 repetitions are required. The individual gestures are also practiced separately. We therefore assumed that, in contrast to the naïve observer, the magician himself should not show any expectation violation due to his familiarity with the entire action sequence of each trick. We hypothesize that the magician's brain activity will differ from that of the experimental group. Contrasting events that violate action-outcome expectations with control events without expectation violation, we hypothesize to find higher activity in the CN, the DLPFC, and the ACC.

MATERIALS AND METHODS

PARTICIPANTS

Twenty five healthy right-handed adults (mean age: 26 years, range 21–35 years; 10 male) participated in this experiment. In addition, the right-handed magician that created the magic tricks (male, age 46) also participated in the study. Before beginning the experiment, participants were given a detailed informed consent form describing the study, as well as discomforts and potential risks of functional MRI. After agreeing to participate in the study, participants were additionally orally instructed about the details of their task. Participants were monetarily compensated for their time. Participants had no history of neurological disease, and were not taking medication at the time. All participants understood the instructions without difficulty. Participants had no knowledge of the solutions to the magic tricks at the time of the experiment and had no expertise as magicians. The study was performed in accordance with the Declaration of Helsinki and approved by the ethics committee of the medical faculty of the Ludwig-Maximilians-Universität Munich. None of the participants were excluded from the analysis.

TESTING MATERIAL AND TASK

Magic tricks

We used 24 short video clips of magic tricks, two more clips were shown in the practice trials. They had been performed by a professional magician (Thomas Fraps) and recorded in a standardized theater setting. The magician whose appearance (e.g., shirt) was kept identical during the recording sessions was shown on stage, either seated behind or standing behind a table, see **Figure 1**. The background was a black curtain. The set of tricks included different magic effects (e.g., appearance, levitation, restoration, vanish) and methods (e.g., sleight of hand, gimmicks, optical illusions) and are described in detail in the Supplementary Material. See http://www.youtube.com/watch?v=3B6ZxNROuNw for a sample trick clip. We used short tricks, with only one effect and one key method. Clip duration ranged from 6.3 to 42.5 s. This set of tricks had previously been tested to ensure that all tricks

FIGURE 1 | Standardized setting shortly before the magic trick (here: Rubik's Cube) is performed.

were understandable, i.e., that participants perceived the intended magic effect. This is an important prerequisite for actually experiencing expectation violations. Further, the tricks consisted only of visual effects that could be performed in absolute silence, with no other interactive elements necessary (e.g., assistant, interaction with the audience). Thus, the fMRI signal was only measured during visual, not auditory processing. Further details about the development of these stimuli can be found in a previous paper (Danek et al., 2014).

Control clips

For each magic trick, we provided a corresponding control clip (see full list in the Supplementary Material). We made sure that the same general action sequence was shown, but with no magic effect and thus without expectation violation. For example, in the vanishing coin trick (see list), the magician presents three coins in his hand. He closes the hand, shakes it and opens it to reveal that only two coins are left. In the control clip, the magician presents three coins in his hand. He closes the hand, shakes it and opens it to reveal all three coins. Thus, in the control clip, the expectation that all three coins should be still there is not violated.

Piloting the testing material

A pilot study was conducted to ensure that the observed events in the magic clips triggered a feeling of surprise and expectation violation. Fifteen independent observers (that did not take part in the subsequent fMRI study, mean age: 24 years, range 20–27 years; 5 male) watched all clips (the 24 trick clips as well as the 24 control clips, in randomized order) and rated them on a scale from 1 (not at all) to 4 (very much) for how surprising the clip was, how much it involved illusion, how much it violated the law of cause and effect and whether the magician's actions led to an unexpected outcome. On average, the magic clips were rated as follows: surprise 2.94 (SD = 0.3), illusion 3.15 (SD = 0.3), violation of law of cause and effect 3.16 (SD = 0.3), and unexpected outcome 2.86 (SD = 0.3). In contrast, the control clips were rated much lower: surprise 1.19 (SD = 0.2), illusion 1.03 (SD = 0.1), violation of law of cause and effect 1.03 (SD = 0.1), and unexpected outcome 1.17 (SD = 0.1). These differences between magic and control clips with regard to the ratings were all statistically significant (t-tests for repeated measures, all $p < 0.01$). Another sample of 15 participants (one of them had to be excluded as an outlier) was presented with both the magic and the control clips (see below) in randomized order and indicated after each clip whether they had seen a magic trick or not. Collapsed across all clips from the same condition (magic or control), 89.7% of all participants identified the magic clips correctly as magic clips and 98.3% of them correctly identified the control clips as such. Thus, compared to the control clips, participants found the magic tricks more surprising, involving more illusion and unexpected outcomes, more strongly violating the law of cause and effect, and they could distinguish them from the control clips.

Color task

We also introduced a cognitive task that had nothing to do with magic tricks, in order to allow activity to return to baseline between blocks, but keep attentional demands at a constant level. A color decision task was presented at the end of each block. Different colored squares (red, orange, yellow, green, blue, and violet) appeared on the screen and participants indicated whether the square was a primary color (red, yellow, blue) or not (primary color = left, other color = right). Directly after their response, the next square appeared. Feedback was provided during training, but not during the experiment.

PROCEDURE

Stimuli were presented in 24 randomized blocks. Each block consisted of one magic trick and the corresponding control clip, in randomized order. In other words, if the control clip were presented first, then the specific magic trick corresponding to that control clip would follow. This was done to reduce the time between consecutive presentations of the same condition, and to minimize the likelihood that subjects would associate films between blocks. After watching the first clip, participants were already aware of the nature of the second clip, so the order of the clips was taken into account during analysis (see Data Analysis). With this design, the expectation violation related to the magic trick is separable from the expectation of the type of clip presented, since the nature of the magic trick (e.g., vanishing, transposition, physical impossibility etc. – see Supplementary Material) is unknown regardless of whether participants know that a magic trick will be shown.

Figure 2 shows the procedure of one block plus subsequent color task. The block started with the outline of a white rectangle (the same size and shape as the video clips) on a black background, which was presented for 1000 ms (±300 ms). Then the magic and the control clip followed in randomized order. The outline was also presented after each clip. Afterward the color task was presented for 16 s between blocks. Subject responses were only required during the color task. For the magic and the control clip, participants were instructed to passively watch the videos. Two practice blocks with feedback were performed outside the scanner. The entire experimental session lasted about 90 min, with 60 min spent in the scanner.

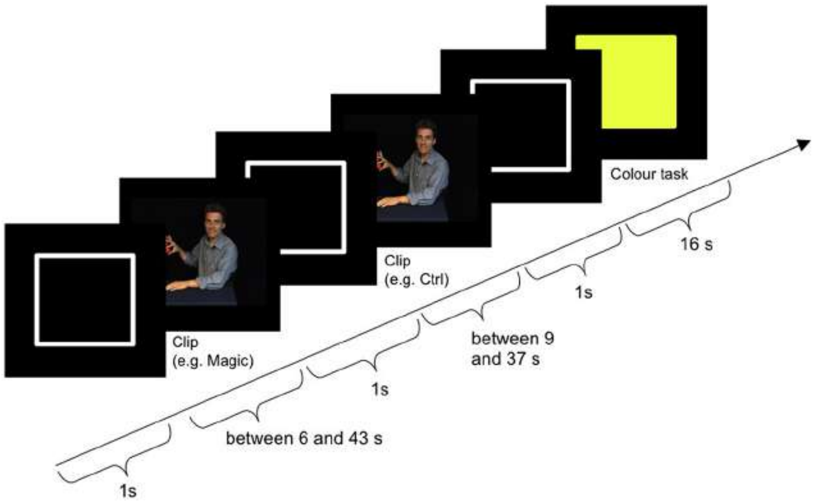

FIGURE 2 | Procedure of one block including color task.

MATERIAL

Visual stimuli were projected with a LCD projector (Christie LX40, Christie Digital Systems, USA) with a True XGA 1024 × 768 system onto a back-projection screen placed behind participants in the MR-scanner. Participants viewed the projection through a mirror placed 14 cm above them at 45°. The distance from the mirror to the screen was 26 cm for a horizontal visual field of view of 25°. The experiment was run in Matlab 7.5.0 (R2007b, The Mathworks, Inc.) with Cogent Graphics developed by John Romaya at the LON at the Wellcome Department of Imaging Neuroscience. The experiment was controlled from a 64 bit Windows 7 personal computer (Dell Precision M4500) with an NVIDIA Quadro FX 1800M Graphics card.

fMRI DATA ACQUISITION

Images were acquired with a 3T MRI Scanner (Signa HDx, GE Healthcare, Milwaukee, WI, USA) using a standard 8-channel head coil. Thirty-seven contiguous transverse slices (slice thickness 3.5 mm, no gap) were acquired using a gradient echo echo-planar-imaging (EPI) sequence (TR 2.0 s, TE 40 ms, flip angle 80°. Matrix 64 × 64 voxel, FOV 200 mm). 736 volumes were acquired. After functional imaging, a 3D T1-weighted high-resolution structural image of the entire brain (0.8 × 0.8 × 0.8 isotropic voxel size) was acquired using a fast spoiled gradient recalled sequence.

DATA ANALYSIS

Functional imaging data were analyzed using Statistical Parametric Mapping (SPM8, Wellcome Department of Imaging Neuroscience, University College London) on Matlab 8.2.0.701 (R2013b). To improve coregistration performance, all images were first manually reoriented so that the origin was set to the anterior commissure. Then the functional volumes were slice time corrected, realigned to the first volume of the first run and then to the mean across all runs. They were then coregistered to the anatomical image from that subject. The anatomical image was segmented into tissue probability maps based on standard stereotaxic space [Montreal Neurological Institute (MNI)], and the transformation parameters used to normalize the functional volumes. Noise was then reduced by smoothing the functional data using a 8-mm full-width at half-maximum Gaussian kernel.

To compare with the previous study (Parris et al., 2009), we determined the discrete time point of the moment of violation of expectancy in the magic trick. These time points were extracted in pilot studies for each trick separately by asking a sample of 15 participants to watch the clips and to quickly press a button in the moment of expectation violation (i.e., the moment where "the magic happens"). Their button press was acknowledged by a short beep. Their reaction times were averaged and used as the time points for the events for the magic clips. For the control clips we took the time points that corresponded to the same relative time than in the magic clip by using the following equation: (surprise moment time divided by entire length of magic clip) multiplied by the length of the control clip. This means that if the expectation violation moment was at 80% of the length of the magic clip, then the event for the control clip was also set to 80% of the control clip.

Functional data were analyzed in each single subject using two univariate multiple regression models. Both models included separate predictors for magic and control clips, separated by the order of appearance within a block (first or last). In the first model, the events were time-locked to the moment of expectation violation and the duration of the event was set to 0 as in the Parris et al. (2009) study. In the second model, we used regressors that were time-locked to the start of the video presentation, with a variable duration depending on the length of the video clip. Each single-subject model therefore included four events of interest corresponding to a 2 × 2 factorial design with factors film type (magic/control) and order (first/last). These events were convolved with the canonical hemodynamic response function (HRF). The six motion correction parameters from the realignment step were modeled separately as events of no interest. The data were high-pass filtered (cutoff frequency = 0.0078 Hz) to minimize slow scanner related drifts and global changes were removed by proportional scaling. For each subject, we computed four contrasts that averaged the parameter estimates across the two fMRI-runs, as a function of condition.

The contrast estimates for each subject and condition were then entered into two whole-brain group-level within-subject 2 × 2 ANOVAs, with the same factors and levels as above, plus participant effects. One ANOVA analyzed the time point of the expectation violation, the other ANOVA modeled the entire clip. All normal subjects were used in both models ($N = 25$). This allowed us to test for main effects of order and film type as well as any interactions. Corrections for non-sphericity accounted for non-independent error terms for the repeated measures as well as differences in error variance. We then tested for differences between the magic tricks and the control clips, both as main effects and as interactions.

We compared the results of the normal healthy group to the single subject results from the magician by calculating the percent of overlapping supra-threshold voxels for the contrast magic-control. In addition, we created a group-level model to test for differences between the magician and the normal participants for the main effect of magic tricks vs. control clips, although the informative value of this analysis is limited due to the group size of one for the magician. Nonetheless, we tested for similarities between the two groups using a conjunction analysis with the conjunction null (Nichols et al., 2005). For comparison with the previous study and to enable meta-analyses, both the images and the tables are presented at a threshold of $p < 0.001$ uncorrected for multiple comparisons and a voxel extent threshold of 30 voxels. However, we consider only voxels that survive a voxelwise statistical threshold of $p = 0.05$ family wise error (FWE) corrected for multiple comparisons across the entire brain volume for further discussion. The $p < 0.05$ FWE corrected p-values are presented in the tables.

Anatomical regions were identified by manual inspection using the Juelich Histological Atlas and the Harvard Oxford Structural Atlas (in FSLView 3.1.8).

RESULTS

The results are organized as follows: first, the main effect of expectation violation at the time point of the violation is presented in our experimental sample ($N = 25$) and compared to the findings of a previous study (Parris et al., 2009). Second, the main effect of expectation that exists throughout the entire trick is presented. Third, the individual activity of the magician who performed the tricks will be presented, using the same contrast. Fourth, the findings from the magician will be contrasted with those from the naïve lay sample.

EXPECTATION VIOLATION (MAGIC – CONTROL): MOMENT OF VIOLATION

To examine the effect of expectation violation, independent of when the film was presented, we examined the main effect of magic tricks vs. control clips, at the moment of magic, determined by independent ratings of each clip (see Materials and Methods). We did not find any supra-threshold voxels for the interactions between film type and order, so we continued to look only at the main effect of film type (magic vs. control). The main difference between the magic tricks and the control clips is the lack of expectation violation in the latter. The same objects are used in a very similar action sequence, but without any unexpected outcome. For example, the magician closes his fist around a silver coin, and when he opens the fist again, the coin is still there, as expected. The standard action-outcome sequence is thus preserved in the control clips.

In this analysis, we saw a left dominant activity that partially overlapped with those seen in the previous study (Parris et al., 2009). However, unlike Parris et al. (2009), we did not use a region of interest analysis and the regions survive after a more stringent

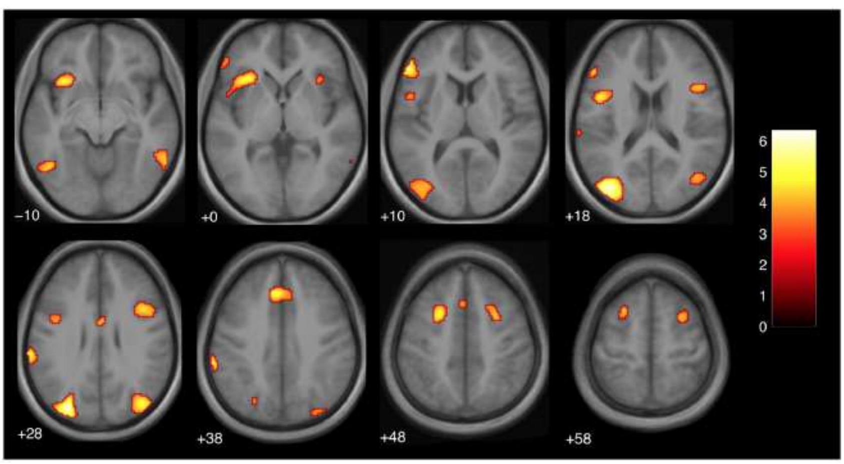

FIGURE 3 | Brain activity at the moment of expectation violation for magic tricks compared to control clips, independent of presentation order (main effect, $p < 0.001$ uncorrected, voxel cluster threshold 30). The discrete time point of magic was determined by an independent group of subjects (see Materials and Methods). The color bar depicts the t-values of the supra-threshold voxels. Activations are overlaid on the normalized average structural image from all subjects tested, values represent z-values in Montreal Neurological Institute (MNI)-coordinates.

statistical threshold. The regions are reported in **Table 1** and **Figure 3**. The clusters in the inferior frontal gyrus are very similar to those found in an action-observation study (Kilner et al., 2009), which suggests that the action-outcome processing is taking place. The activity in the occipital lobe is known to process visual motion (Greenlee, 1999), which would be involved in understanding the violation of the action-outcome in magic.

Comparison to previous literature

The regions that were more active during a violation in expectation are similar to those found in a previous study with a similar design (Parris et al., 2009). In particular, the DLPFC (superior frontal gyrus), and parts of the cingulate gyrus were active bilaterally (see **Table 1**; **Figure 3**). In the previous study, similar regions were active but in a left-dominant manner. For comparison, results from Parris et al. (2009) are listed in **Table 2**.

MAGIC – CONTROL: ENTIRE CLIP DURATION

We then examined the main effect of magic tricks vs. control clips, for the entire duration of the magic clip. By examining the entire clip, regions involved in the expectancy throughout the entire action sequence should be revealed. We found higher activity in four distinct clusters for magic tricks compared to control clips. These were the head of the CN bilaterally, the left inferior frontal gyrus and the left anterior insula (see **Table 3**; **Figure 4**). Additional frontal and occipital regions overlapping with those found at the time point of the violation of expectation were also significantly active at a more liberal threshold.

LACK OF EXPECTATION VIOLATION: ACTIVITY IN A MAGICIAN

We assumed that, in contrast to naïve observers, the magician would not perceive the magic effect as an expectation violation since he had performed the magic himself and knew the entire action sequence of each trick and each control clip, (see Introduction). As expected, the activity in the magician's brain substantially differed from the activity of our experimental sample. Calculating the same magic vs. control contrast as before, we found significant activity in the parietal lobe, namely in the supramarginal gyrus (which is part of the inferior parietal lobule) bilaterally, in the right superior parietal lobule as well as in the right postcentral gyrus, see **Table 4**; and **Figure 5**.

There were no overlapping clusters, so it was not possible to calculate a percent overlap between the two groups. By simply looking at the corresponding activity maps (**Figures 4** and **5**), it is clear that the activity observed in the magician differs from the one in the experimental sample. For the magician, we found parietal and sensory-motor activity, whereas the naïve subjects had active clusters in the more anterior parts of the brain and the basal ganglia (CN). To additionally confirm this, we conducted a conjunction analysis (with the conjunction null, Nichols et al., 2005) for the contrast magic – control to identify common areas of activity between both the magician and the normal volunteers. However, no common clusters of activity between the magician and the normal volunteers were found, even at

Table 2 | Significant clusters found in Parris et al. (2009) for comparison magic – control.

Anatomical area from Parris et al. (2009)	*X*	*Y*	*Z*
Left superior frontal gyrus	−24	10	58
Left middle frontal gyrus	−22	36	44
Left middle frontal gyrus	−42	23	26
Left anterior cingulate	−4	38	19

Corresponding areas are marked red. We used the program "tal2mni.m" from http://imaging.mrc-cbu.cam.ac.uk/imaging/MniTalairach to convert their Talairach coordinates to the MNI values reported here.

Table 1 | Activation clusters for comparison magic – control for the discrete time point of the moment of magic (i.e., expectation violation).

Anatomical area	*X*	*Y*	*Z*	*k*	*t*-value	$P_{FWE\text{-}corr}$
Left superior lateral occipital cortex	−30	−80	28	393	6.33	0.000
Left inferior frontal gyrus, pars triangularis	−52	34	10	40	5.67	0.003
Left anterior supramarginal gyrus	−66	−32	32	28	5.47	0.007
Left posterior cingulate gyrus	−4	28	40	26	5.45	0.007
Left anterior insula	−32	20	−4	33	5.18	0.018
Left superior frontal gyrus	−24	10	52	17	5.17	0.019
Right superior lateral occipital gyrus	44	−78	32	12	5.02	0.031
Right middle frontal gyrus	28	8	52	226	4.88	0.049
Right inferior temporal gyrus, temporo-occipital division	62	−56	−8	221	4.79	0.064
Left inferior temporal gyrus, temporo-occipital division	−46	−60	−12	148	4.69	0.088
Anterior cingulate gyrus	0	0	26	34	4.23	0.303
Left amygdala	−22	−8	−20	50	3.78	0.721
Left anterior insula	34	20	−2	53	3.71	0.775

A voxel cluster threshold 30, $p < 0.001$, uncorrected for multiple comparisons was used, but the p-values for a voxel-wise FWE-corrected threshold are shown. Montreal Neurological Institute (MNI) coordinates are used.

Table 3 | Clusters for comparison magic – control throughout the entire clip presentation (voxel cluster threshold 30, $p < 0.001$, uncorrected).

Anatomical area	*X*	*Y*	*Z*	*k*	*t*-value	$P_{FWE-corr}$
Right caudate nucleus (CN; head)	14	8	14	21	5.26	0.011
Left CN (head)	−10	12	6	18	5.24	0.011
Left inferior frontal gyrus	−50	32	6	10	5.09	0.019
Left anterior insula	−32	22	−6	12	4.93	0.031
Left lateral occipital cortex, superior division	−32	−80	26	452	4.87	0.038
Right superior frontal gyrus	28	8	54	244	4.66	0.074
Left superior frontal gyrus	−26	10	54	201	4.52	0.111
Left paracingulate gyrus	−6	30	38	138	4.43	0.144
Right lateral occipital cortex, superior division	38	−78	28	170	4.13	0.307
Right anterior cingulate gyrus	4	0	26	58	4.10	0.330
Left inferior frontal gyrus	−44	4	18	135	4.02	0.395
Right inferior frontal gyrus	44	12	24	183	3.91	0.492

MNI coordinates are used. The p-values for a voxel-wise FWE-corrected threshold are shown.

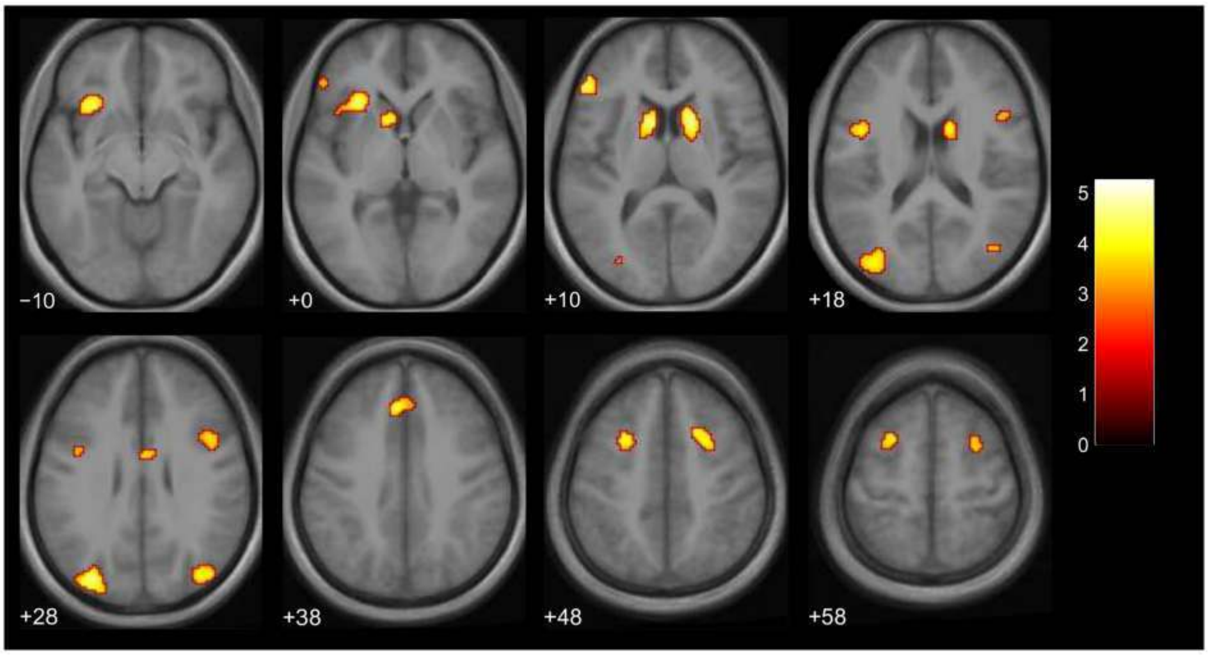

FIGURE 4 | Brain activity for entire clip duration for the contrast magic – control (main effect, $p < 0.001$ uncorrected, voxel cluster threshold 30). The color bar depicts the *t*-values of the supra-threshold voxels. Activations are overlaid on the normalized average structural image from all subjects tested, values represent *z*-values in MNI-coordinates.

the less restrictive threshold of $p < 0.001$ with 30 consecutive voxels.

DISCUSSION

In this study, we examined the violation of expected action-outcome sequences that are pervasive in magic tricks. When comparing magic tricks with a condition in which the action-outcome relationship was expected, we found four specific clusters of activity in the head of the CN bilaterally, the left inferior frontal gyrus and the left anterior insula. This activity was not present in the magician who had performed the tricks, and where we would not expect an expectation violation. The frontal activity was present at the moment the expected action–outcome contingency was violated, as well as throughout the entire magic clip. The CN, on the other hand, was only significantly active throughout the entire clip but not at the time point of the expectation violation.

Table 4 | Activity in the magician (Thomas Fraps).

Anatomical area	X	Y	Z	k	t-value	$P_{FWE-corr}$
Right supramarginal gyrus	60	−26	44	2709	5.65	0.001
Right superior parietal lobule*	26	−56	56		5.21	0.005
Right postcentral gyrus*	52	−34	58		4.95	0.015
Left supramarginal gyrus	−58	−34	34	394	5.58	0.001
Right precentral gyrus	54	12	32	144	4.73	0.037
Right inferior frontal gyrus, pars opercularis	50	10	12	68	4.48	0.097
Left precentral gyrus	−52	6	6	84	4.27	0.201
Right premotor cortex	24	−4	50	177	4.11	0.332
Right middle frontal gyrus	44	30	42	58	4.05	0.395
Right premotor cortex	14	2	68	98	3.97	0.487
Right superior lateral occipital cortex	40	−80	26	78	3.96	0.500
Left inferior temporal gyrus, temporooccipital division	−44	−58	−10	193	3.74	0.750
Left frontal pole	−42	42	24	59	3.74	0.757
Left inferior temporal gyrus, temporooccipital division	56	−56	−12	51	3.73	0.767
Right frontal pole	42	46	8	55	3.63	0.860
Superior parietal lobe	−34	−54	52	33	3.41	0.976

Shown are all clusters for comparison magic – control for the entire clip duration (voxel cluster threshold 30, $p < 0.001$, uncorrected).
Note that MNI coordinates are used. The p-values for a voxel-wise FWE-corrected threshold are shown. Stars delineate sub-clusters that are more than 8 mm from the center coordinate.

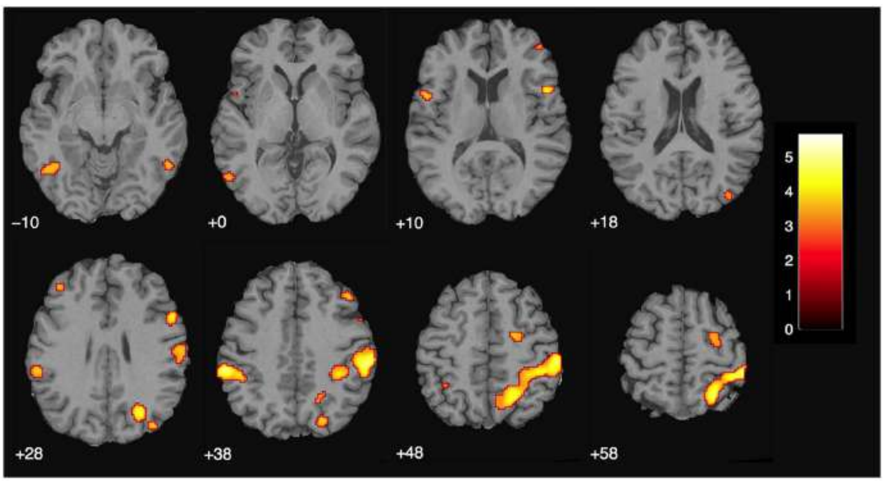

FIGURE 5 | Magician Thomas Fraps: significant activity for magic vs. control condition showing sensory-motor and parietal activity in the magician. The color bar depicts the *t*-values of the supra-threshold voxels. Activations are overlaid on the normalized structural image from the magician tested, values represent *z*-values in MNI-coordinates.

The presence of subcortical activity may seem surprising at first, but it is now widely accepted that, in addition to their traditional role in motor processes, the basal ganglia also subserve higher cognitive functions (Middleton and Strick, 2000). The CN has been implicated in processing changes in the contingency between action and outcome for successful goal-directed action (see Grahn et al., 2008 for a review). Such changes in contingency are common in magic tricks, as illustrated in the following example from our stimulus set (Salt Vanish, see Supplementary Material): pouring salt into the closed fist of one hand and then slowly opening the fingers should let the salt trickle down on the table. The action "opening fingers" starts at once an internal simulation (e.g., Wolpert and Flanagan, 2001; Grush, 2004) that results in an expected outcome, namely the salt trickling down. This outcome expectation is violated when the salt vanished. As discussed in the Section "Materials and Methods," the main difference between the two conditions in the present study (magic and control) is the expectation violation that is present in the magic clips but completely missing in the latter. We argue that in the present study, the head of the CN is bilaterally activated due to the expectation of an incongruency between the observed action and the presented outcome. The CN was not significantly active when only the discrete time point of expectation violation was analyzed; rather it was active throughout the entire magic clip. This suggests that the CN is involved in expectation rather than the incongruency itself. This is reasonable if we assume that in order to experience any violation in an expected action-outcome congruency, this expectation must build up during the preceding action sequence that leads to the unexpected outcome.

The present findings fit to a previous study that reported the CN to signal "breaches of expectation" (Schiffer and Schubotz, 2011). In contrast to the majority of studies (see Diekhof et al., 2012; or Sescousse et al., 2013 for recent reviews), they investigated caudate activity not in the context of conditional learning and reward, but under the assumption that the CN signals violations of expectations in general, independent of feedback. Schiffer and Schubotz (2011) used a movement observation paradigm (watching the movements of a dancer, with unexpected deviations from a previously learnt choreography), which can be compared to observing the magician's unexpected movements.

We believe our results suggest a specific role of the CN during the observation of magic tricks in signaling the expectation of a violation in an action-outcome sequence, together with the prefrontal cortex (PFC). The PFC is thought to subserve the ability to select actions or thoughts to achieve internal goals, based upon a hierarchy of cognitive function along the anterior–posterior axis of the lateral PFC (Koechlin and Summerfield, 2007). In this model of executive function, decisions between multiple prior cues occur at the most anterior part of the PFC, whereas the posterior PFC is responsible for interpreting immediate environmental cues for action selection. A recent study showed that this hierarchy is reflected in the cortico-subcortical loop (Jeon et al., 2014). Branching and episodic control of action activated the ventrolateral PFC (BA45) in a region very similar to the area activated in our study and this region was connected to the anterior region of the head of the CN, where we also see activity. A meta-analysis of 126 PET and fMRI studies uncovered substantial functional connections between the left CN and the left inferior frontal gyrus (Postuma and Dagher, 2006). This means, across a large number of studies and tasks, both regions tended to be simultaneously active. Although there were no explicit task demands in our study, it seems plausible that observing a magic trick involves the conceptualization and expectation of possible action-outcomes, which relies on the information processing in the PFC and CN. This interplay is consistent with the activity in both of these regions throughout the entire magic clip, with an additional increase in PFC activity during the moment of expectation violation.

The inferior frontal gyrus activity that we found may to some degree reflect the processing of surprise. Since our study was designed to increase statistical power with a larger number of clips, we did not implement a condition controlling for surprise and thus cannot exclude this possibility. Notably, Parris et al. (2009) report a similar region (although more ventrally) underlying surprise processing. That we found inferior frontal gyrus activity when exclusively looking at the moment of magic points into that direction, too. But it is difficult without further experiments, or perhaps a future meta-analysis, to know whether the inferior frontal region found by Parris et al. (2009) is the same region found here and whether this corresponds to an overlapping underlying cognitive process. We are just beginning to understand the subdivisions and cognitive functions attributed with these regions.

The anterior insula has been implicated in a wide range of tasks and cognitive processes (e.g., Craig, 2009; Gasquoine, 2014). Craig (2009) pointed out that these heterogeneous findings could be subsumed under the header "awareness" and postulated that the anterior insula is a key area in human awareness and consciousness. Based on their meta-analysis of 1768 fMRI experiments, Kurth et al. (2010) suggested the anterior–dorsal insula as a multimodal integration region, because it was the only region in which nearly all of the 13 investigated functional categories (e.g., emotion, empathy, memory, interoception) overlapped. It is often found to be co-activated with the ACC, one of the regions that was also found in the Parris et al. (2009) study where ACC activity was interpreted as mirroring conflict detection mechanisms.

To a large extent, we were successful in our replication attempt of Parris et al. (2009). We also found activity in the DLPFC (superior frontal gyrus), and in parts of the cingulate cortex, when we used the same time point of the analysis. The remaining differences in activation are likely due to differences in the design, as well as in the additional condition to control for surprise that was present in Parris et al. (2009). Also, our analysis was a whole-brain analysis whereas Parris et al. (2009) analyzed specific anatomical regions of interest. One intriguing consensus between the two studies was the left-dominant activity in the PFC. The left PFC, in particular the DLPFC, is thought to be involved in interpreting complex actions (Gazzaniga, 2000; Roser et al., 2005). A previous study on causality violation also found left-dominant DLPFC activity, which they associated with reasoning and interpreting the observed events (Fugelsang and Dunbar, 2005). Our results agree with the previous findings.

As hypothesized, the magician's brain activity differed clearly from the experimental group. It was mainly parietal activity, whereas the experimental group had active clusters in the more anterior parts of the brain and the basal ganglia. That we did not find any overlapping regions in our conjunction analysis shows that the magician processed the magic tricks and the control clips differently than lay people and supports our hypothesis that he did not experience any expectation violations. The most prominent cluster was centered in the supramarginal gyrus bilaterally. Recently, the right supramarginal gyrus was proposed to subserve self–other distinction in a paradigm investigating the emotional egocentricity bias (Silani et al., 2013). In that study, the right supramarginal gyrus was implicated in overcoming emotional egocentricity. Since the magician watched himself in the videos, but was fully aware that other people would be watching the clips, too, it seems plausible that he was trying to see himself with other people's eyes. However, it is not clear to which extent emotions played a role in the current paradigm, neither for the experimental group nor for the magician, because this was not assessed.

Of course, a comparison between a group and a single subject, as performed in this work, is methodologically dissatisfying. However, for the question we were trying to tackle, namely how the magic tricks would be perceived by someone who knew the action sequences very well and would thus not experience any expectation violations, it is difficult to conceive of a better method. Even testing more magicians (apart from the difficulties in recruiting them) would not have improved the design, since they had not performed the same tricks. Of course, they might know many of the tricks, but still perform them in a different manner and thus not be able to represent and predict the entire action sequence as well as Thomas Fraps. Thus, it seems difficult to imagine actually testing a collective. A potential improvement would be to have, e.g., five magicians, and all of them perform five tricks. That is, in the test condition they will watch 5 self generated and 20 other generated tricks.

Clearly, the idea of expectation violation in magic tricks can be related to the concept of prediction errors. A magic effect is a non-predictable event. The anterior insula, one of the active clusters found, is thought to process prediction errors and risk (e.g., Bossaerts, 2010). Although prediction errors are typically investigated in the context of gambling tasks where participants make actual decisions, based on their predictions about possible outcomes of their decision, this could be transferred to the present situation in which participants might have predicted the outcome of the observed action – and experienced a prediction error in the case of an unexpected outcome (i.e., in the magic clips, but not in the control clips). That we also found activity in the inferior frontal gyrus, a region implicated in risk prediction error processing and closely connected with the anterior insula (Bossaerts, 2010), supports this view. Leaving the context of risk and reward processing, and focusing on a more general prediction mechanism, Zacks et al. (2007) have introduced the terms "perceptual predictions" and "perceptual prediction error" in their theory of event prediction. This might provide a useful framework to further investigate the special type of expectation violation in magic tricks that was the focus of the present work.

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SUPPLEMENTARY MATERIAL

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Magic and memory: using conjuring to explore the effects of suggestion, social influence, and paranormal belief on eyewitness testimony for an ostensibly paranormal event

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This study uses conjuring to investigate the effects of suggestion, social influence, and paranormal belief upon the accuracy of eyewitness testimony for an ostensibly paranormal event. Participants watched a video of an alleged psychic seemingly bending a metal key by the power of psychokinesis. Half the participants heard the fake psychic suggest that the key continued to bend after it had been put down on a table and half did not. Additionally, participants were exposed to either a negative social influence (a stooge co-witness reporting that the key did not continue to bend), no social influence, or a positive social influence (a stooge co-witness reporting that the key did continue to bend). Participants who were exposed to the verbal suggestion were significantly more likely to report that the key continued to bend. Additionally, more participants reported that the key continued to bend in the positive social influence condition compared to the other two social influence conditions. Finally, believers in the paranormal were more likely to report that the key continued to bend than non-believers.

Keywords: magic, memory, suggestion, social influence, paranormal belief

INTRODUCTION

For centuries, magicians have amazed audiences by apparently defying the laws of nature. Such effects were based upon a deep understanding of lay psychology but until recently, with few exceptions, academic psychologists have largely ignored the insights that the art of conjuring can provide to help understand the workings of the human mind. Thankfully, as this special issue demonstrates, this situation is changing. One of the ways in which the art of conjuring can be of service to psychological science is by providing means to study a range of psychological phenomena such as perception and memory. The experiment described in this report is one such example.

Over several decades, a great deal of research has demonstrated the unreliability of memory and in particular the fallibility of eyewitness testimony. Many kinds of memory distortion effects have been investigated including those due to the presentation of post-event misinformation (e.g., Eakin et al., 2003) and the use of misleading questions (e.g., Loftus, 1975) and even the formation of detailed false memories for complete episodes (e.g., Loftus and Pickrell, 1995). Recently, researchers have turned their attention to a particular form of misinformation effect known as memory conformity (e.g., Wright et al., 2000, 2009; Gabbert et al., 2003; Gabbert and Hope, 2013). Memory conformity is said to occur when an individual memory report of one person becomes more similar to another person's following their discussion of an event.

In forensic contexts, similar accounts from multiple witnesses are likely to be accorded greater evidential weight than an uncorroborated account from a single witness. While such an assumption may be defensible, it fails to recognize that multiple witnesses to an unusual event such as a criminal act are very likely to discuss the event before any formal investigation takes place. Information exchanged during such discussions may potentially change or add to original recollections of what happened. Researchers have investigated how memory recall of pairs of eyewitnesses can become distorted if the two witnesses discuss what they believe to be the same event. Gabbert et al. (2003) had pairs of participants watch a video of a staged crime recorded in such a way that crucial details that were available on one recording were not available on the other and vice versa. For example, one version of the video showed a young woman actually steal some money whereas it was not clear in the other version if she had done so as it was filmed from a slightly different viewpoint. Dyads in one condition discussed the event prior to recall while participants in a control condition did not. It was found that a significant number of participants erroneously included items of information in their report of the event that had been acquired as a result of discussion with a co-witness. For example, many of the participants who had not actually seen the young woman take the money mistakenly reported that they had seen this act following the discussion. These findings were replicated by Wilson and French (2004).

In addition to reports of criminal acts, the accuracy of eyewitness testimony is also crucially important in assessing reports of ostensibly paranormal experiences (OPEs) and other anomalous events (French, 2003; French and Wilson, 2006). Anomalistic psychologists have argued that most reports of OPEs can be plausibly explained in non-paranormal, typically psychological, terms and specifically that cognitive biases known to characterize human thought may lead many people to believe they have experienced something paranormal when in fact they have not. Although a wide range of cognitive biases are potentially of relevance in this regard (French, 1992; French and Wilson, 2007; French and Stone, 2014), memory-related biases are amongst the most important. French (2003) and French and Wilson (2006) presented comprehensive reviews of investigations of the accuracy of eyewitness accounts of OPEs, concluding that anecdotal reports of such events should be treated with considerable caution in light of the proven unreliability of memory in such circumstances.

Wiseman and Morris (1995), for example, compared the recall of believers and disbelievers in the paranormal for the details of pre-recorded "pseudo-psychic" demonstrations, such as apparent metal-bending by psychokinesis. Believers tended to have poorer recall of the details of the demonstrations, particularly those details that would give some indication of the type of sleight of hand that was used to achieve the effects. Perhaps not surprisingly, the believers rated the demonstrations as being more "paranormal" than disbelievers.

Poor recall of the events taking place in séances was demonstrated as long ago as 1887 by Hodgson and Davey (1887), with similar findings being reported by Besterman (1932) and more recently by Wiseman et al. (1995). In all such studies, all of the effects were achieved by the use of trickery based upon accounts from fake mediums. However, the accounts provided by eyewitnesses were often so inaccurate that, taken at face value, they would defy rational explanation. Once again, important details of the events that would have provided clues as to how the effects actually had been achieved were simply not recalled accurately.

Wiseman et al. (2003) examined the effects of suggestion during fake séances. In their first experiment, around a third of the witnesses erroneously reported that a stationary table had moved during the séance following a suggestion from the fake medium to this effect. Believers in the paranormal were more likely to misreport such movement than disbelievers. Believers were shown to be more susceptible to suggestion than disbelievers in a second set of fake séances too, but only when the suggestion was congruent with their belief in the paranormal. For example, if the fake medium suggested that an object had not moved when in fact it had (by trickery), believers were no more likely to accept the suggestion than disbelievers. Overall, around one-fifth of the participants believed they had witnessed genuine paranormal phenomena. As Wiseman et al. (2003) point out, it is unclear whether the verbal suggestion directly affected the participants' perception of the event, their memory of the event, or both. It is even possible that neither perception nor memory was affected and that the results were due to demand characteristics, but the end result is the same: a large minority of the participants were willing to report that stationary objects had moved and that they had witnessed genuinely paranormal events.

Wiseman and Greening (2005) explored the power of verbal suggestion in another ostensibly paranormal context. In two experiments, participants were shown a videotape of an alleged psychic bending a key using apparent psychokinetic ability but in fact using sleight of hand techniques. Participants in one condition heard the psychic suggest that the key continued to bend after being put down on a table, whilst those in a second condition did not. The findings revealed that those in the suggestion condition were significantly more likely to report that the key had indeed continued to bend (even though it had not). The size of this effect was considerable, with around 40% of the participants in the suggestion condition reporting that the key continued to bend compared to virtually no one in the no-suggestion condition. Somewhat surprisingly, in the light of findings from the séance studies, no differences were found between believers in the paranormal and disbelievers in either experiment. In the second experiment (but not the first), those who erroneously reported that the key continued to bend were more confident regarding their recall than those who correctly reported that it did not. Interestingly, they were also significantly less likely to remember hearing the actual verbal suggestion provided by the fake psychic.

Recent studies have applied memory conformity paradigms to the study of OPEs on the assumption that witnesses of such events are very likely to discuss what they saw and one person's report may influence the memory of other witnesses. Thus, if one witness to a séance, for example, was initially unsure whether a particular object had or had not moved during the séance, confident testimony from a fellow witness that it did may be sufficient to alter the first witness's report of the event. Wilson (2006) used the same basic paradigm as that used by Gabbert et al. (2003) but with videotapes of two 2.5-min clips of a pseudo-psychic demonstration of apparently psychokinetic ability. Both clips contained essentially the same sequence of events but each included one important piece of information missing in the other clip, information that gave an indication of how the effect was achieved. In the first clip, for example, a fork used in a fork-bending demonstration is clearly handled by the alleged psychic and in the second, the fork clearly goes out of view. As with the previous study, the focus of interest was the degree to which the participants' recall was distorted as a result of discussion with a co-witness. Once again it was found that a substantial majority of participants included crucial items of information about the event they witnessed that were most likely to have been acquired as a result of such discussions. This study therefore demonstrated that, as predicted, memory conformity effects do in fact occur in apparently paranormal contexts.

This general line of research is important for two main reasons. The first is that it provides an explanation of reports of various OPEs in terms of known psychological factors. Opinion polls repeatedly show that a large proportion of the population believes in the paranormal and a sizeable minority claims to have had direct personal experience of paranormal events. But, with a few notable exceptions, psychology has had little to say about the origins of such beliefs and experiences until fairly recently. We strongly believe, in line with other researchers within anomalistic psychology, that it is not enough simply to speculate upon the various psychological factors that may underlie reports of OPEs. It is important to support such accounts with empirical evidence and the current research is aimed at doing precisely this with respect to the factors of verbal suggestion and memory conformity.

The second main reason for carrying out such research is for what it can tell us about memory more generally. For example, most previous research into the reliability of eyewitness testimony has been carried out in a forensic context, often involving the use of staged crimes and so on. Apart from the obvious importance in terms of generalisability of studying such effects in a different context, investigating the reliability of reports of OPEs under controlled conditions offers an ideal opportunity to demonstrate the effects of pre-existing beliefs upon perception and memory. By their very nature, OPEs are often inherently ambiguous and it is precisely in such circumstances that we would expect top-down influences upon perception (French, 2001) and memory (French, 2003; French and Wilson, 2006) to be most pronounced.

The choice of belief in the paranormal as a means of exploring the influence of top-down processes on cognition is particularly appropriate for several reasons. In addition to the inherent ambiguity of most OPEs, (i) paranormal belief is prevalent in all societies, (ii) belief in the paranormal is very important in many people's lives and such beliefs have strong emotional ties (e.g., the belief in life after death) and (iii) paranormal beliefs often form part of a larger set of beliefs and attitudes toward such things as religion, science and indeed mankind's place in the universe. Furthermore, standard scales are available to measure the level of paranormal belief making it an ideal choice for this type of investigation.

The current study aimed to replicate and extend previous studies of verbal suggestion and memory conformity by systematically manipulating both the presence or absence of a verbal suggestion as well as the type of social influence exerted by a co-witness. Replication of such effects is crucially important in light of current concerns regarding poor replicability within psychology (see, e.g., Pashler and Wagenmakers, 2012; Ritchie et al., 2012). The study is based upon Wiseman and Greening's (2005) demonstration of the power of verbal suggestion in the context of an alleged demonstration of psychokinetic metal-bending. Using the same video clip as that used in the original study, participants viewed a fake psychic apparently using psychokinesis to bend a key. After the psychic had put the bent key down, half of the participants heard the fake psychic suggest that the key continued to bend while the other half did not hear the suggestion. It was hypothesized, in line with the findings of the original study, that those in the suggestion condition would be more inclined to report that the key continued to bend in comparison to participants in the no-suggestion condition.

Furthermore, each participant was also exposed to one of three types of social influence from a co-witness. One-third of the participants were exposed to a "negative" social influence, insofar as the co-witness, during a post-event discussion, reported that the key did not continue to bend. Another third of the participants were not exposed to any social influence, as they did not discuss the demonstration at all. The final third of the participants were exposed to a "positive" social influence, in that the co-witness, during the post-event discussion, reported that the key did indeed continue to bend. The co-witness in the negative and positive social influence conditions was in fact a stooge. It was hypothesized, based upon previous memory conformity research, that the genuine participants in the positive social influence condition would be more inclined to report that the key continued to bend than those in the no social influence condition, whereas those in the negative social influence condition would be relatively less inclined.

Even though Wiseman and Greening (2005) did not find any difference between believers in the paranormal and disbelievers in terms of tendency to report that the key continued to bend, it was hypothesized in the current study that the former group may show this tendency more strongly on the basis of previous research including studies of susceptibility to suggestion in the séance room.

A number of individual difference measures have been shown to be correlated with both paranormal belief and tendency to report anomalous experiences on the one hand and susceptibility to various kinds of memory distortion on the other, including susceptibility to false memories (French, 2003; French and Wilson, 2006). This suggests that at least some reports of anomalous events may be based upon false memories. Dissociativity, for example, has been shown in a number of studies to correlate with paranormal belief (e.g., Irwin, 1994; Pekala et al., 1995; Wolfradt, 1997; Makasovski and Irwin, 1999; Rattet and Bursik, 2001) and the tendency to report a wide range of paranormal and anomalous experiences (e.g., Richards, 1991; Ross et al., 1991; Ross and Joshi, 1992; Pekala et al., 1995), as well susceptibility to false memories (e.g., Eisen and Carlson, 1998; Hyman and Billings, 1998; Winograd et al., 1998; Heaps and Nash, 1999; Ost et al., 2005; Wilson and French, 2006). One possible explanation for the link between dissociativity and susceptibility to false memories is that, by definition, high scorers on measures of dissociativity experience more disruptions in the integration of thoughts, awareness, and memory. Such individuals may therefore be more prone to accepting externally presented information as autobiographical memories.

The relationship between dissociativity and suggestibility is complex, but several studies have reported a significant correlation using a variety of measures of suggestibility (see Eisen and Lynn, 2001; Eisen et al., 2002). Therefore, given the known correlation between paranormal belief and dissociativity, a measure of dissociativity (the Dissociative Experiences Scale, DES) was administered in order to allow the assessment of possible effects of dissociativity upon the dependent variables in this study.

Compliance (or eagerness to please) has also been shown to be related to susceptibility to false memories (e.g., Ost et al., 2002, 2005). It might be expected that in the current experiment, where, depending upon the allocated condition, participants may be exposed to social influence in terms of the initial verbal suggestion from the fake psychic and/or the comments of the stooge, level of compliance would be related to the degree to which participants report that the key continued to bend. Therefore, the current study also measured compliance, using Snyder's (1974) Self-Monitoring Scale (SMS).

The current study complied with the ethical guidelines of the British Psychological Society and ethical approval to conduct the study was granted by the Ethical Committee of the Department of Psychology, Goldsmiths College, University of London.

MATERIALS AND METHODS

PARTICIPANTS

One hundred and eighty undergraduates and college employees from Goldsmiths College, University of London, took part in the study. Participants were 144 females and 36 males with a mean age of 24.41 years (SD = 3.45) and an age range of 18–57 years. All participants responded to a poster advertising for involvement in an experiment where participants would be asked to judge the paranormal abilities of a professed psychic. Participants received either course credit or £5 for their involvement.

DESIGN

This study generally employed a 2 × 3 × 2 factorial design with Verbal Suggestion (suggestion vs. no suggestion), Social Influence (negative social influence vs. no social influence vs. positive social influence), and Belief Group (believers vs. non-believers), as between-group factors. The primary dependent variable was scores on item 3 of a Fixed Response Questionnaire (FRQ3) asking participants to rate their degree of agreement with the statement "After the key was placed on the table, it continued to bend" (see below for details).

MATERIALS

Videotape

The videotape used in the study was supplied by Richard Wiseman and is the same videotape as that used in Wiseman and Greening's (2005) experiments. Two versions of the tape were used. In the *suggestion* version of the tape the film consists of a 2-min clip of an interviewer and "psychic" sat at a table with several objects such as cutlery and keys in front of them. The interviewer briefly introduces the psychic and invites him to perform a demonstration of his powers using any of the objects of his choice. The psychic then picks up a key and appears to use his psychokinetic powers to bend the key to a 25° angle, in fact achieving this effect by the use of sleight of hand. He then places the key back on the table and suggests that the key is in fact still bending, even though it is not. The *no verbal suggestion* version of the tape is identical to the *suggestion* version but part of the soundtrack was removed so that participants did not hear the verbal suggestion. The fake psychic used in the demonstration was in fact a magician who had worked professionally for many years using sleight of hand techniques.

Questionnaires

Fixed Response Questionnaire. This is the 4-item questionnaire used by Wiseman and Greening (2005) and consists of statements concerning the film. Two of the statements are filler items, e.g., "The interviewer touched the items on the table." Responses to the third item (FRQ3) were used as the main dependent variable in the study: "After the key was placed on the table, it continued to bend." The fourth item on the questionnaire asked participants to what extent they considered the demonstration involved paranormal forces. For each item, participants were asked to provide their response on a 7-point scale from 1 (*Definitely No*) to 7 (*Definitely Yes*). Participants were also asked to rate their confidence in their answers on a similar scale from 1 (*not at all confident*) to 7 (*very confident*).

Forced-choice version of the Australian Sheep-Goat Scale. This is a widely used scale that consists of 18 statements relating to the three core concepts of parapsychology: extrasensory perception, psychokinesis, and life after death. The statements refer to belief in and alleged experience of the paranormal and respondents are awarded no points for a "false" response, one point for a "don't know" response, and two points for a "true" response (allowing for a maximum score of 36). Note that this scale was preferred to the unstandardized Belief in the Paranormal Questionnaire used by Wiseman and Greening (2005) because it has known validity and reliability (e.g., Thalbourne and Delin, 1993; Thalbourne, 1995, 2010) and it allowed comparison with other research in this area (e.g., Wilson and French, 2006). Scores on this scale were used to allocate participants to belief groups.

Dissociative Experiences Scale. This scale, designed and developed by Bernstein and Putnam (1986), consists of a 28-item self-report questionnaire. A typical example would be: "Some people have the experience of finding new things among their belongings that they do not remember buying." Respondents are asked to circle a box to indicate what percentage of the time this event happens to them, ranging from 0 to 100% at 10% intervals. Each item is awarded a score between 0 and 100 and the mean score is then calculated across the 28 items. The scale has been shown to have good psychometric properties (Dubester and Braun, 1995) and internal consistency (Norton et al., 1990).

Self-Monitoring Scale of Expressive Behaviour. This scale, developed by Snyder (1974), is a 25-item true–false questionnaire consisting of items such as "When I am uncertain how to act in a social situation, I look to the behavior of others for cues" and "My behavior is usually an expression of my true inner feelings, attitudes, and beliefs." The score on this scale indicates the extent to which respondents rely on cues from others in deciding how to behave in social situations as opposed to relying upon personal values. One point is awarded for every response in line with such tendencies.

PROCEDURE

All participants were told that they were to judge the paranormal powers of a professed "psychic" who had claimed to the Psychology Department that he could demonstrate psychokinetic ability. Participants were allocated to one of the six experimental conditions produced by crossing the two factors of Verbal Suggestion (suggestion vs. no suggestion) and Social Influence (negative social influence vs. no social influence vs. positive social influence). To maintain comparability across all experimental conditions, all participants were tested in pairs. In the *positive* and *negative social influence* conditions, one of the apparent participants was in fact a stooge playing the part of a co-witness, whereas in the *no social influence* condition both participants were genuine. Participants in the *suggestion* condition watched the video with an audible commentary throughout, whereas those in the *no suggestion* condition were not presented with the verbal suggestion from the fake psychic.

In the *no social influence* conditions, both participants watched the video and were then asked to complete the questionnaires. In the *positive* and *negative social influence conditions*, the stooge and the participant arrived at the testing room at the same time. Both watched the video but were then told to discuss the details of the film together. In order to facilitate this discussion, the stooge and the real participant were asked to complete a short questionnaire consisting of four questions relating to the film. These included three filler questions, e.g., "What was the psychic wearing?" and the crucial question, i.e., "Did the key continue to bend after it had been placed on the table?" Participants were told to complete this brief questionnaire together. The stooge was instructed to speak first and to lead the discussion, either maintaining that the key had continued to bend and that paranormal forces had been at work (in the *positive* condition) or that the key had not continued to bend and that no paranormal forces were involved (in the *negative* condition). After the discussion the participants independently completed the other questionnaires.

At the end of the experiment, all participants were debriefed fully. Participants in the *positive* and *negative social influence* conditions were asked if at any time they had suspected that their fellow co-witness was a confederate of the researcher. However, no participants reported that they had been suspicious of the stooge. To maintain continuity the same stooge took part in all the trials.

RESULTS

Participants were first classified into Belief Groups on the basis of a median split of Australian Sheep-Goat Scale (ASGS) scores, with those scoring more than 10 classified as believers and the rest as disbelievers in the paranormal. It is common practice in studies comparing high and low paranormal belief groups on performance measures to divide the groups using a median split on the belief measure as done by Wiseman and Greening (2005) and in the current study. Although this approach runs the potential risk of failing to detect real effects because information is lost by converting a continuous variable to a binary variable (MacCallum et al., 2002), one can be certain that any effects identified with this approach would also be found using alternative methods such as multiple regression. Indeed, results from the current study were also analyzed using multiple regression techniques and the pattern of results found was identical to that reported below. However, it was felt that the effects found were described more clearly using the results of ANOVAs.

In order to check that unintended sampling bias had not been introduced by splitting our sample in this way, three 2 × 2 × 3 ANOVAs were carried out on the scores from the ASGS, DES, and SMS, respectively, each with Belief Group, Verbal Suggestion, and Social Influence as between-group factors. As would be expected given the method of allocation to belief groups, ASGS scores were significantly higher for believers (mean = 18.25, SD = 4.80) than disbelievers [mean = 3.78, SD = 3.05; $F(1,168) = 562.26$, $p < 0.001$]. Also, as expected given the known correlation between paranormal belief and dissociativity, DES scores were significantly higher for believers (mean = 36.99, SD = 15.44) than for disbelievers [mean = 28.05, SD = 16.12; $F(1,168) = 12.81$, $p < 0.001$]. Interestingly, SMS scores were also significantly higher for believers (mean = 12.51, SD = 3.65) than disbelievers [mean = 10.87, SD = 4.08; $F(1,168) = 6.04$, $p = 0.015$]. No other main effects or interactions from any of the three ANOVAs were statistically significant. ASGS scores correlated significantly with both DES scores ($r = 0.278$, $p < 0.001$) and SMS scores ($r = 0.180$, $p = 0.016$) across the sample as a whole.

Next, responses to FRQ3 were analyzed using a 2 × 2 × 3 ANOVA with the same factors as those used in the previous analysis. This analysis revealed a significant main effect of Verbal Suggestion, with participants who heard the suggestion giving higher ratings on FRQ3 (mean = 3.92, SD = 2.02) than those who did not [mean = 2.56, SD = 1.74; $F(1,168) = 32.40$, $p < 0.001$]. A main effect of Social Influence was also found [$F(2,168) = 22.01$, $p < 0.001$]. Using Bonferroni-adjusted t-tests, it was shown that positive social influence produced higher ratings on FRQ3 (mean = 4.43, SD = 1.96) than either negative social influence [mean = 2.50, SD = 1.54; $t(118) = 6.02$, $p < 0.001$] or no social influence [mean = 2.78, SD = 1.94; $t(118) = 4.63$, $p < 0.001$]. However, the two latter conditions did not produce significantly different ratings [$t(118) = 0.89$, *n.s.*]. Finally, believers in the paranormal gave significantly higher ratings on FRQ3 (mean = 3.75, SD = 1.97) than disbelievers [mean = 2.75, SD = 1.93; $F(1,168) = 9.94$, $p = 0.002$]. No significant interactions were found.

In light of the significant differences between belief groups on scores for the DES and SMS, these variables were entered as covariates in the main analysis of responses to FRQ3 in order to ascertain whether any differences found between belief groups could be accounted for in terms of differences between the groups on these variables. Therefore responses to FRQ3 were analyzed using a 2 × 2 × 3 ANOVA with the same factors as those used in the previous analysis, but with the inclusion of DES and SMS scores as covariates. This analysis revealed a significant main effect of Verbal Suggestion, with participants who heard the suggestion giving higher ratings on FRQ3 (mean = 3.92, SD = 2.02) than those who did not [mean = 2.56, SD = 1.74; $F(1,179) = 32.05$, $p < 0.001$].

A main effect of Social Influence was also found [$F(2,179) = 21.06$, $p < 0.001$]. Using Bonferroni-adjusted t-tests, it was shown that positive social influence produced higher ratings on FRQ3 (mean = 4.43, SD = 1.96) than either negative social influence [mean = 2.50, SD = 1.54; $t(118) = 6.02$, $p < 0.001$] or no social influence [mean = 2.78, SD = 1.94; $t(118) = 4.63$, $p < 0.001$]. However, the two latter conditions did not produce significantly different ratings [$t(118) = 0.89$, *n.s.*].

Finally, even with DES and SMS scores entered as covariates, believers in the paranormal gave significantly higher ratings on FRQ3 (mean = 3.75, SD = 1.97) than disbelievers [mean = 2.75, SD = 1.93; $F(1,179) = 7.89$, $p = 0.006$]. DES and SMS scores were not significantly related to responses on the FRQ3 in this analysis. Once again, no significant interactions were found.

Following Wiseman and Greening (2005), participants were then allocated to two groups depending upon their responses to the FRQ3. Those who responded with either a 5, 6, or 7 were allocated to the *key continued to bend* group. The rest were allocated to the *key did not continue to bend* group. The numbers and percentages in each group across experimental conditions are presented in **Table 1**. Chi-square analyses between group and suggestion within each social influence condition revealed

Table 1 | Numbers and percentages of participants in the *key continued to bend* and the *key did not continue to bend* groups across experimental conditions.

	Key continued to bend group	Key did not continue to bend group
Negative social influence		
Suggestion	7 (23.3%)	23 (76.7%)
No suggestion	2 (6.7%)	28 (93.3%)
No social influence		
Suggestion	10 (33.3%)	20 (67.7%)
No suggestion	0 (0%)	30 (100%)
Positive social influence		
Suggestion	18 (60%)	12 (40%)
No suggestion	12 (40%)	18 (60%)

Table 2 | Mean confidence ratings (SDs in parentheses) given to item FRQ3 by participants in the *key continued to bend* and the *key did not continue to bend* groups across experimental conditions.

	Key continued to bend group	Key did not continue to bend group
Negative social influence	4.56 (1.59), $N = 9$	5.53 (1.84), $N = 51$
No social influence	6.20 (1.48), $N = 10$	5.24 (1.62), $N = 50$
Positive social influence	6.07 (1.02), $N = 30$	4.73 (1.82), $N = 30$

a highly significant effect ($\chi^2 = 12.0$, df = 1, $p = 0.001$), in the no social influence condition (thus replicating Wiseman and Greening, 2005) with 10 participants (33.3%) reporting that the key continued to bend if given the verbal suggestion compared to none in the no-suggestion condition. Neither of the other chi-square analyses was significant. It is worth noting that the percentage of participants in the suggestion condition reporting that the key continued to bend was decreased to 23.3% in the negative social influence condition and almost doubled to 60% in the positive social influence condition ($\chi^2 = 6.9$, df = 1, $p = 0.009$).

Wiseman and Greening (2005, Experiment 2) found that those reporting that the key continued to bend were more confident about the accuracy of their report than those who reported that it did not (although this result was not found in their first experiment). Responses to item 3b of the FRQ in the current study, indicating confidence in the accuracy of participants' reports on FRQ3, are presented in **Table 2**. These data were subjected to a 2 × 3 ANOVA with Bend Group (did continue to bend vs. did not continue to bend) and Social Influence Group as between-groups factors. No significant main effects were found but a highly significant interaction was revealed [$F(2,179) = 5.25$, $p = 0.006$]. Further exploration of this interaction, using three Bonferroni-adjusted t-tests, revealed only one significant effect: participants in the positive social influence condition who reported that the key continued to bend were far more confident in their ratings than those who reported that the key did not continue to bend [$t(58) = 3.51$, $p = 0.001$]. The same general trend was evident for those in the no social influence group although the opposite trend was evident for those in the negative social influence group, i.e., in the latter condition, those reporting that the key

Table 3 | Number and percentages of participants in the *demonstration was paranormal* and the *demonstration was not paranormal* groups across the experiment as a whole, broken down by Belief Group and Bend Group.

	Demonstration was paranormal	Demonstration was not paranormal
Believers		
Key continued to bend	13 (39.4%)	20 (60.6%)
Key did not continue to bend	7 (12.7%)	48 (87.3%)
Disbelievers		
Key continued to bend	1 (6.2%)	15 (93.8%)
Key did not continue to bend	2 (2.6%)	74 (97.4%)

continued to bend were relatively *less* confident than those who reported that it did not. A 2 × 2 ANOVA using the same factors as those in the previous analysis but excluding the positive social influence group revealed that the interaction between Bend Group and Social Influence was still significant [$F(1,119) = 5.13$, $p = 0.025$].

Wiseman and Greening (2005) did not report any analyses of responses from the fourth item on the FRQ (FRQ4), dealing with the degree to which participants believed the demonstration, including the initial key bending by sleight of hand, involved paranormal forces. FRQ4 data from the present study were subjected to a 2 × 2 × 3 ANOVA with Belief Group, Verbal Suggestion, and Social Influence as between-group factors. Not surprisingly, believers in the paranormal gave higher ratings (mean = 3.32, SD = 1.64) than disbelievers [mean = 1.87, SD = 1.18; $F(1,179) = 44.38$, $p < 0.001$]. Perhaps more surprisingly, higher ratings were given by participants exposed to the verbal suggestion (mean = 2.90, SD = 1.73) than those who were not so exposed [mean = 2.26, SD = 1.39; $F(1,179) = 9.57$, $p = 0.002$]. The generally low levels of ratings of paranormality should, however, be noted.

Participants were then allocated to groups on the basis of whether they did or did not believe the demonstration involved paranormal forces. Those scoring either 5, 6, or 7 on FRQ4 were allocated to the *demonstration was paranormal group* and the rest were allocated to the *demonstration was not paranormal group*. The numbers and percentages in each group across the experiment as a whole are presented in **Table 3**. Across the experiment as a whole, 49 out of 180 participants (27.2%) reported that the key continued to bend and 23 (12.8%) believed they had witnessed something paranormal in the demonstration as a whole. Of the 88 believers, 33 (37.5%) reported that the key continued to bend and 20 (22.7%) believed they had witnessed paranormal forces in action. Note that this implies that many of the believers who reported that the key carried on bending did not believe that this particular demonstration involved genuine paranormal forces, presumably believing instead that it was based upon some form of trickery. Of the 92 disbelievers, only 16 (17.4%) reported that the key continued to bend and only 3 (3.2%) of those classified as disbelievers reported that they had witnessed paranormal forces in action. Presumably, this tiny percentage of "disbelievers" who believed they had witnessed a genuine paranormal event had been so classified because they did not believe in life after death and/or

ESP even though, evidently, they did believe in psychokinesis. It is interesting to compare the interpretation of the demonstration between the belief groups for those participants who reported that the key did continue to bend. Of 33 believers who reported that the key continued to bend, 13 (39.4%) reported that the demonstration was paranormal. Of 16 disbelievers who reported that the key continued to bend, only one (6.2%) reported that the demonstration was paranormal ($\chi^2 = 5.8$, df = 1, $p = 0.016$). Clearly, disbelievers were much more likely to opt for a non-paranormal explanation even if they believed they had seen the key carry on bending.

DISCUSSION

The results of this experiment largely confirm the basic finding of Wiseman and Greening's (2005) experiments; that is, in this context, a relatively mild verbal suggestion from a fake psychic that a bent key continued to bend after it had been placed upon a table was sufficient to lead a substantial number of witnesses to erroneously report that the key had indeed done just that. In the no social influence condition in the current experiment, the condition most similar to that used by Wiseman and Greening (2005), one-third of the participants reported continued bending, compared to 39.13% in their Experiment 1 and 36.54% in their Experiment 2. Also in line with Wiseman and Greening's (2005) findings, no participants in the *no suggestion* and *no social influence* condition reported continued bending.

The current study extended the findings of the original experiments by incorporating an additional social influence component into the design. When a stooge co-witness insisted that the key continued to bend, 60% of the participants agreed. When the stooge co-witness insisted that the key did not continue to bend, the percentage who reported that it did was substantially reduced, but even then 23.3% reported that it did. This is a powerful demonstration that it is not only what witnesses to an ostensibly paranormal event believe that they have actually perceived at the time that determines their subsequent reports but that such reports will also be influenced by discussion with co-witnesses in line with findings from memory conformity research.

We also found one result that was not in line with the findings of the original experiments by Wiseman and Greening (2005). In the current study, believers in the paranormal were found to be more likely to report that the key continued to bend compared to disbelievers. Wiseman and Greening (2005) considered two possible explanations for their failure to find any difference between belief groups. First, they considered the possibility that previous studies reporting an association between paranormal belief and suggestibility might be mistaken, possibly reflecting a "file-drawer" effect in which a few studies finding a spuriously significant relationship between these two variables had been published but that they should be considered in the wider context of a possibly much larger number of studies that had tried and failed to find such an effect and had therefore never been submitted for publication. Second, they suggested that paranormal belief may correlate with certain kinds of suggestibility but not the form of suggestibility involved in their key-bending experiments. The current findings would argue against both of these suggestions. It appears that the type of suggestibility involved in both the original experiments and the current study is indeed correlated with paranormal belief. The most likely explanation for the discrepancy between Wiseman and Greening's (2005) findings in this regard and the findings of the current study is our decision to use the ASGS as a measure of paranormal belief. Furthermore, the belief-related effects found were not explicable in terms of differences between the belief groups on the DES and SMS measures.

Wiseman et al. (2003), in the context of discussing the effects of suggestion on eyewitness reports in the séance room, acknowledge that it is often difficult to determine whether verbal suggestion directly affects the perception of the event, memory for the event, or both. It is even possible that neither is affected and that the results are due to demand characteristics. Thus, it is possible that the verbal suggestions during the séance directly influence the perception of the witnesses in such a way that those witnesses who are exposed to such suggestions actually perceive stationary objects to be moving in real time. Alternatively, it is possible that the witnesses did not actually perceive the stationary objects to be moving at the time but that their memories of the event were affected by the verbal suggestions when, 2 weeks later, they received a questionnaire asking them to recall details of the séance. By that time, their memory for the séance would be beginning to fade and, in their attempts to reconstruct the details of what happened, they may have blended the fake psychic's suggestions in with their blurred memory of the original event in such a way that they now recalled stationary objects as moving. Finally, it is possible that at the time the participants completed the recall questionnaire, they did not actually believe that the stationary objects had moved at all, but simply reported that they did, perhaps believing that this would please the investigators.

The results of the current study can perhaps cast some light upon these competing explanations. We begin by acknowledging that self-report data alone can never definitively distinguish between perceptual effects and memory effects. Even if we ask participants to tell us what they are perceiving as events unfold before them, there will always be a slight delay, perhaps only a fraction of a second, between the perception of the events and the subsequent report. Thus it is always possible to argue that the perception of the events was fundamentally veridical but the memory of the event was somehow distorted. In fact, however, the general position of modern cognitive psychology is that perception and memory are constructive processes and that both will be influenced by bottom-up influences (i.e., raw sensory input) and top-down influences (e.g., beliefs, knowledge, expectations). Thus perception itself is heavily dependent upon memory. When considering ostensibly paranormal events then, both perception (French, 2001) and memory (French, 2003) are likely to be influenced by a variety of top-down influences and thus both perception and memory are likely to be influenced by verbal suggestions that alter expectations.

In considering the experimental set-up used by Wiseman and Greening (2005), it appears that participants completed the FRQ immediately after viewing the video, thus minimizing the possibility that the effect is due to the type of blending of a blurred memory of an essentially accurate perception with the memory of the suggestion, as described above. Although a direct effect upon the actual perception of the event is entirely consistent with Wiseman and Greening's (2005) data, the possibility of an explanation in terms of demand characteristics remains.

The data from the current study demonstrate unequivocally that social influence provided *after* the video had been viewed was sufficient to alter witnesses' reports of what they saw. Fully 40% of the participants in the positive social influence condition reported that the key continued to bend even in the absence of a verbal suggestion to that effect from the fake psychic. Furthermore, of those participants who did receive the verbal suggestion, the percentage of participants reporting that the key continued to bend was markedly affected by the reports of the stooge co-witness. Such effects are only explicable as either memory effects or in terms of demand characteristics.

We do not feel that demand characteristics provide a parsimonious explanation of our findings when the responses to item FRQ3b are considered. Data relating to the confidence expressed in the memory report indicate that in both the no social influence and the positive social influence conditions, participants erroneously reporting that the key continued to bend expressed higher levels of confidence than those who did not report that the key continued to bend, thus replicating Wiseman and Greening's (2005) Experiment 2. In both cases, confidence levels were extremely high (>6 on a 7-point scale). This clearly indicates that expressions of confidence in the accuracy of reports of OPEs should not be taken as any kind of indication of reliability. The lowest confidence ratings in the experiment came from those participants in the negative social influence condition who reported that the key continued to bend and those in the positive social influence condition who reported that it did not. It seems likely that the former group really did perceive the key as continuing to bend and were prepared to stick to that view despite a forceful stooge arguing that it did not. The latter group, on the other hand, did not report that the key continued to bend but their confidence in that view was clearly shaken by a forceful stooge arguing that it had. In both cases, the responses of participants seem to be more in line with participants trying their best to give honest accounts of what they saw rather than behaving in accordance with demand characteristics.

Finally, there is another level at which the influence of beliefs comes into play. The overall interpretation of the demonstration as evidence for the paranormal was, as one might expect, strongly related to paranormal belief. Considering first the believers, it is worth noting that the vast majority did not consider that the demonstration involved paranormal forces—even if they reported that the key continued to bend. Even so, a much higher proportion of believers than disbelievers reported that they had witnessed paranormal forces in action (around 40% of those who reported continued bending of the key). The disbelievers, on the other hand, were much less likely to report that the key continued to bend and, even if they thought it did, they were much less likely to opt for a paranormal explanation. Across the experiment as a whole, of 49 participants who reported that the key continued to bend, only 14 thought that the demonstration involved paranormal forces. The others, presumably, thought that it was some kind of trick, a tendency found much more strongly amongst the disbelievers than amongst the believers. This is not unreasonable, given that such an effect could have been produced by either special effects or by the use of a trick key. It is even possible that some participants realized it was a simple effect of suggestion but were honest enough to admit that it had worked on them. It would be of interest in future studies to ask such participants directly for their explanation of the effect. It would also be of interest in future investigations to include conditions in which the key really does appear to bend to investigate whether disbelievers are prone to deny such events.

It should be noted that one difference between the two social influence conditions and the no social influence condition in the current study was that the former involved discussion of what had been witnessed whereas the latter did not. It is therefore possible that this might have influenced the results in some way, e.g., in terms of differential delay in recall, differences in the number of retrieval attempts, etc. We do not feel this was a major methodological problem with our study as these factors were matched across the positive and negative social influence conditions and thus the impact of different types of social influence are clearly demonstrated by our results. However, we would recommend that similar studies in future replace our current no social influence condition with one that does involve discussion with the stooge participant and the use of the short (4-question) questionnaire ostensibly to facilitate the discussion. The difference would be that the stooge would be presented as someone who has not themselves seen the video clip and ostensibly is simply acting as a facilitator.

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Priming psychic and conjuring abilities of a magic demonstration influences event interpretation and random number generation biases

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Magical ideation and belief in the paranormal is considered to represent a trait-like character; people either believe in it or not. Yet, anecdotes indicate that exposure to an anomalous event can turn skeptics into believers. This transformation is likely to be accompanied by altered cognitive functioning such as impaired judgments of event likelihood. Here, we investigated whether the exposure to an anomalous event changes individuals' explicit traditional (religious) and non-traditional (e.g., paranormal) beliefs as well as cognitive biases that have previously been associated with non-traditional beliefs, e.g., repetition avoidance when producing random numbers in a mental dice task. In a classroom, 91 students saw a magic demonstration after their psychology lecture. Before the demonstration, half of the students were told that the performance was done respectively by a conjuror (magician group) or a psychic (psychic group). The instruction influenced participants' explanations of the anomalous event. Participants in the magician, as compared to the psychic group, were more likely to explain the event through conjuring abilities while the reverse was true for psychic abilities. Moreover, these explanations correlated positively with their prior traditional and non-traditional beliefs. Finally, we observed that the psychic group showed more repetition avoidance than the magician group, and this effect remained the same regardless of whether assessed before or after the magic demonstration. We conclude that pre-existing beliefs and contextual suggestions both influence people's interpretations of anomalous events and associated cognitive biases. Beliefs and associated cognitive biases are likely flexible well into adulthood and change with actual life events.

Keywords: magical beliefs, magical thinking, magic, paranormal beliefs, belief formation, cognitive biases

INTRODUCTION

Magical thinking refers to a thinking style that "*involves reasoning based on some sort of misconception about, causality, or about natural laws more generally*" (Woolley, 1997 p. 993). Piaget (1927) showed that up to the age of about 12 years, magical thinking forms a major part of children's inner world (but see Rosengren and Hickling, 1994 for earlier estimates). Despite refinements to this early claim, recent evidence still suggests that children show a more blurred distinction between reality and imagination than adults (Rosengren and Hickling, 1994; Woolley, 1997; Subbotsky, 2010). With increasing age, magical thinking is assumed to dissipate. For example, children from the age of 5 years replace magical explanations increasingly through rational explanations when seeing magic tricks (Rosengren and Hickling, 1994). This developmental perspective goes hand in hand with the views that adults have become rational thinkers shaped through personal, educational, and societal growth (Rosengren and Hickling, 1994).

While these perspectives might be comfortable in our Western, highly educated society, they are not supported by studies investigating magical and paranormal beliefs and experiences in the wider adult population[1]. For instance, only about 10% of the general US population would label themselves as being skeptical toward the paranormal (Rice, 2003). In Europe, 90% of a Swiss sample reported having exceptional experiences (Landolt et al., 2014), and the German public seems pretty open-minded about exceptional experiences, and more than half of the German public report having had such experiences (Knittel and Schetsche, 2012). Moreover, after experiencing anomalous events, Western adults typically deny magical beliefs on an explicit level, but frequently acknowledge implicitly, that an anomalous event had occurred (e.g., turning a drawing into a real object; Subbotsky and Quinteros, 2002; Subbotsky, 2004). Overall, magical beliefs differ widely between individuals of different ages (Rosengren and Hickling, 1994; Subbotsky, 2004) as well as between individuals of the same age (Johnson and Harris, 1994; Subbotsky and Quinteros, 2002). Once these beliefs are established, they seem to be persistent, and factors such as education do surprisingly little to diminish the propensity for these beliefs (Walker et al., 2001; Dougherty, 2004; Genovese, 2005).

[1] Based on a recent review, we will treat magical, paranormal, superstitious, and supernatural beliefs interchangeable (Lindeman and Svedholm, 2012).

Apart from the observation that magical beliefs are common, they seem to go along with specific cognitive biases. For instance, individuals high as compared to low in magical beliefs more frequently see patterns in random noise (Brugger et al., 1993; Blackmore and Moore, 1994), show enhanced illusory face perception (Riekki et al., 2013) or misjudge the probability of events (Brugger et al., 1990; Bressan, 2002). Moreover, believers are more likely to accept bogus personality descriptions (Mason and Budge, 2011), report on events that have never occurred (Tsakanikos and Reed, 2005) and need more time to understand the truth in sentences that violate core knowledge (Lindeman et al., 2008). Such cognitive biases might link with the propensity of magical believers for remote associative processing (Gianotti et al., 2001), fantasy-proneness (Sanchez-Bernardos and Avia, 2006), and openness to experience (Ross et al., 2002). Thus, the literature suggests that magical beliefs are common, highly stable (like trait-like individual differences), and go along with particular cognitive biases and personality variables. Moreover, magical beliefs have likely been established in early childhood. Given this conclusion, it is surprising that relatively little is known about the formation of such beliefs and the causal role of associated cognitive biases.

It is possible that little is known about magical belief formation, at least from adults, because they are considered trait-like, presumably established in early childhood. Yet, there are numerous anecdotal reports that magical thinking can emerge in adulthood, often as a consequence of actual life events. For instance, individuals who experienced near-death-experiences consequentially turned into religious and/or spiritual believers (TrueSpritWorship, 2011, 2013). Freud (1946) reports in one of his Introductory Lectures how his interactions and experiences with patients made him open toward the existence of telepathy and thought-transference. Being initially very critical and skeptical, he changed his opinion following numerous case studies on dreams and the occult. He said "*If one regards oneself as a skeptic, it is as well from time to time to be skeptical about one's skepticism*" (p. 73). Later on he notes that "*[b]ut I am not concerned to seek anyone's favor, and I must suggest to you that you should think more kindly of the objective possibility of thought-transference and therefore also of telepathy (...) it seems to me that one is displaying no great trust in science if one cannot rely on it to accept and deal with any occult hypothesis that may turn out to be correct*" (p. 75). These examples illustrate that actual life events can turn formerly skeptical thinkers into magical believers, and that belief formation can occur in adulthood.

In the laboratory, we are aware of a few studies that have investigated the impact of anomalous experiences on individuals' magical beliefs. For instance, verbal suggestions enhanced the subjective experience of anomalous events in a fake séance room (Wiseman et al., 2003), in a film presenting psychokinetic abilities (Wiseman and Greening, 2005), or the impression of being observed in a supposedly "haunted" room (Bering et al., 2005). Subbotsky (2004) examined whether adults' causal beliefs are affected by the presentation of anomalous (magical) causal events. When exposed to a magic trick within a magical context (mind-over-matter magic spell), adults were unwilling to accept that the magic action (spell) could have caused the anomalous event. When the anomalous event was not presented within a magical context, but an unrelated event was executed during the anomalous event (e.g., switching a light on and off), adults were prone to causally link the unrelated event with the anomalous event. Thus, while rejecting the possibility of anomalous events explicitly, adults' implicit behavior showed that the possibility of an anomalous event was nevertheless acknowledged (Subbotsky, 2001).

Most relevant to our study, Benassi et al. (1980) argued that both the public and scientists can be fooled into attributing psychic powers to ordinary and amateur magic routines, and that attributed psychic powers might prevail, even when the performer labels himself as a conjuror. In their study, a magician presented magic tricks in the classroom. The magician was either introduced as a psychic (psychic condition) or a magician (magician condition). After observing the demonstration, participants in the psychic as compared to the magician condition explained the event more strongly via psychic abilities. While this experimental manipulation is promising in showing that framing influences how people interpret an anomalous event, the authors did not assess magical beliefs and reasoning about the event before and after the demonstration. This omission renders causal inferences difficult. Yet, overall this is a promising approach to investigate how actual life events influence our magical beliefs in adulthood.

In sum, the studies above show that experiencing anomalous events can change people's magical interpretations (and potentially beliefs). These events might also influence cognitive biases that are commonly associated with trait-like magical beliefs. Empirical evidence for such causal claims is still missing. Our aim was to investigate whether the exposure to a magical demonstration, and its contextual presentation (framing), would influence (i) how the event is interpreted (psychic event, conjuring trick, religious miracle, see also Benassi et al., 1980), (ii) self-reported traditional (religious, henceforth TB) and non-traditional (e.g., magical, paranormal, henceforth NTB) beliefs (Tobacky, 2004), and (iii) judgments of event likelihood (repetition avoidance in a random number generation task; Brugger et al., 1990). Former studies have found stronger repetition avoidance in believers in the paranormal compared to skeptics (Brugger et al., 1990), and as the mental number generation task can be performed in a classroom, it was deemed ideal for the current context. In our study, students saw the same magic demonstration and received either the psychic information or the magician information (random allocation, in written format; see also Benassi et al., 1980). As participants saw the same demonstration, but having received different contextual information, we could investigate whether this framing results in more psychic explanations, NTB, and repetition avoidance in the psychic as compared to the magician group.

MATERIALS AND METHODS

PARTICIPANTS

The psychology lecture of that day was attended by 91 students (17 male) with a mean age of 20.5 years (SD = 4.12 years). This gender distribution is common in psychology courses. All students were first year Psychology undergraduate students at

Goldsmiths – University of London who participated for course credits. The study was approved by the departmental ethics board, and each participant provided written informed consent prior to the experiment.

SELF-REPORT BELIEF QUESTIONNAIRE

We used the 26-item revised Paranormal Belief Scale from Tobacky (2004). This scale can be divided into seven subscales measuring Traditional Religious Belief, Psi, Witchcraft, Superstition, Spiritualism, Extraordinary Life Forms, and Precognition. The four traditional religious belief items were summed so to represent the TB score, and the remaining items to represent the NTB score. Item examples include "Some psychics can accurately predict the future" (NTB), "Mind reading is not possible" (NTB), and "There is a heaven and hell" (TB). Items are formulated such that participants are asked to answer along a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). Accounting for reverse coded items, the scores are summed so that higher scores reflect greater beliefs. We had no *a priori* prediction that the different NTB subscales would be differentially sensitive to our manipulation. To account for the possibility that TB (or practices) are nevertheless more sensitive to cultural influences than NTB (MacDonald, 1995; Orenstein, 2002) we summed the scores for the TB score ($n = 4$ items) and the remaining items into the NTB score ($n = 22$ items).

EVENT INTERPRETATION

Benassi et al. (1980) asked participants to write down "comments opinions and reactions about what they had seen," and then scored this qualitative data according to whether participants thought the performer was a psychic, magician or whether it contained religious-demonic themes. Instead of collecting qualitative data, we asked participants to rate on a 7-point Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree), whether the performance was accomplished through (1) paranormal, psychic or supernatural powers (psychic explanation), (2) ordinary magic trickery (conjuror explanation), or (3) religious miracles (religious explanation). We included the religious miracle measure as it allowed us to compare NB with the extent to which the event was explained using religious explanations. Secondly, Benassi et al. (1980) the only comparable study, asked about religious explanations. Thirdly, it provided us with a control condition (not all beliefs should be endorsed to the same extent).

MENTAL DICE TASK (BRUGGER ET AL., 1990)

Participants received written and verbal instructions to imagine throwing a dice each time they heard a beep and to write down the number that they imagined being on top of the dice (66 trials). Thus, every second for 66 s, we presented a beep produced by a computer, and the participant was expected to write down a number for each beep. We calculated the repetitions in the number sequence (i.e., 1-1, 2-2, 3-3). If the number generation would be entirely random we would expect participants to produce on average 11 repetitions. Previous research has shown that we avoid repetitions, and that this repetition avoidance is even stronger for individuals with high as compared to low NTB (Brugger et al., 1990).

PSYCHIC DEMONSTRATION

The psychic demonstration was performed by a professional magician and member of the Magic Circle (http://www.themagiccircle.co.uk). The magician selected a volunteer from the audience. This female volunteer was asked to write down the names of five people who were alive and one deceased person on six pieces of paper. The magician then placed the pieces of paper upside down on the table and placed a lit candle on each of the notes. The magician explained that he was able to use his spiritual powers to contact the dead and asked the volunteer to blow out all of the candles. Approximately 20 s after the candles were blown out, one of them re-ignited and it was the candle that was on top of the piece of paper associated with the deceased person. The candle (i.e., the magician) was correct.

PROCEDURE

Figure 1 shows a diagram of the sequence of events. The experiment was conducted as part of a lecture series on current issues in psychological research and was framed as a demonstration into psychic abilities. In more detail, participants had attended a lecture on the science of magic (given by Gustav Kuhn) prior to the actual experiment (see first event in **Figure 1**). In this lecture, Gustav Kuhn discussed how misdirection can be used to study visual attention. Subsequently, participants were separated by at least one seat and were instructed to refrain from communicating with fellow students throughout the experiment. At this point, all participants were primed to experience a real psychic demonstration (second event in **Figure 1**), i.e., Gustav Kuhn gave them the following verbal briefing. "*As you will be aware, the Anomalistic Psychology Unit at Goldsmith has a keen interest in investigating psychic abilities. Over the years we have carried out numerous experiments to test whether the claims made by psychics hold up on closer*

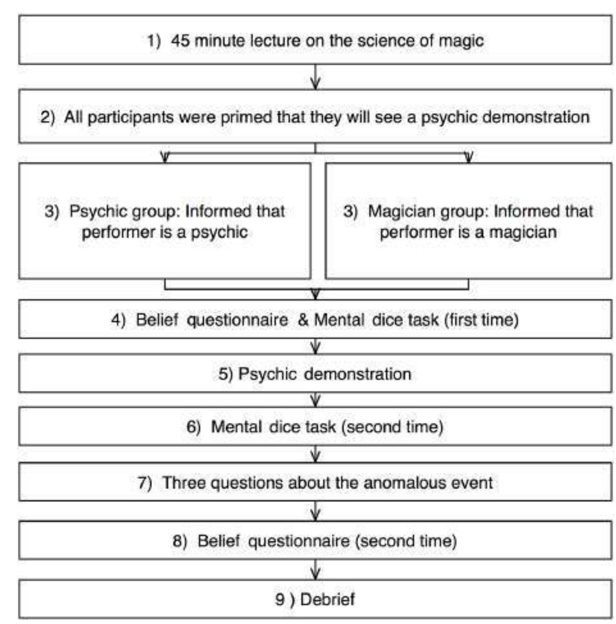

FIGURE 1 | Schematic demonstration of the sequence of events for participants in the magician and in the psychic groups.

scrutiny. Whilst most of the individuals tested so far generally fail these tests, we were very fortunate in that we did find one person who passed most of the preliminarily tests (8/10). His name is Lee and whilst not perfect, his performance was significantly better than chance (p < 0.0032). Lee has told us that he has been developing a presentation of his psychic abilities, and has asked us if he could present it to you and get your opinions and reactions. I thought that this would be very interesting, and so I agreed to let him do it." [Overall, and in particular the last sentences, instructions were paraphrased from Benassi et al. (1980)*]*. After these general instructions, participants were given a work booklet that contained all of the questionnaires and some additional information. Participants were randomly assigned to the magician or psychic condition (third event in **Figure 1**).

Contextual framing instruction for the magic demonstration: the instruction stated that the anomalous demonstration was carried out by a magician pretending to do a fake psychic demonstration, and they read the following statement: "*Some magicians can perform exactly what psychics claim to be doing using ordinary stage trickery." In fact, Lee is not a real psychic, but a professional magician and member of the Magic Circle. What you are about to see is a demonstration of Lee's conjuring skills.*

Contextual framing instruction for the psychic demonstration: the instruction stated that the anomalous demonstration was carried out by a true psychic. They read the following statement "*Lee has worked as a Psychic for several years." Lee is very highly regarded by the European Psychic Society and has astonished numerous well-known scientists by demonstrating his psychic abilities under tightly controlled conditions.*

Immediately afterward, participants filled out the belief questionnaire (Tobacky, 2004; **Figure 1**). Subsequently, they were asked to perform the mental dice task (Brugger et al., 1990; fourth event in **Figure 1**). Once completed, the lecturer introduced the students to the magician who performed the psychic demonstration (fifth event in **Figure 1**). After the demonstration, the students were asked to perform the mental dice task again (Brugger et al., 1990; sixth event in **Figure 1**). Subsequently, they were asked three questions on how they explain the event (seventh event in **Figure 1**): (1) *Whether the performance was accomplished through paranormal, psychic or supernatural powers (psychic explanation), (2) what they have seen has been accomplished by ordinary magic trickery (conjuror explanation), and (3) what they have seen has been accomplished by a religious miracle (religious explanations.* Finally, participants completed the belief questionnaire again (Tobacky, 2004; eighth event in **Figure 1**), before being fully debriefed about the purpose of the experiment (ninth event in **Figure 1**). Here, the magician explained the method behind the effect.

RESULTS

Five participants provided incomplete data on the mental dice task and were excluded from further analysis.

RELATIONSHIP BETWEEN CONTEXTUAL FRAMING AND INTERPRETATION OF THE EVENT

To investigate how the two groups interpreted the causes of the anomalous event, we performed a 3×2 ANOVA (analysis of variance) on the explanation ratings with explanation (psychic, conjuror, religious) as within-participant factor and instruction group (psychic, magician) as between-participant factor (**Table 1**). This ANOVA showed a significant main effect of explanation, $F(2,178) = 163$, $p < 0.00005$, $\eta = 0.65$. *Post hoc t*-tests indicated that participants provided higher conjuror explanation ratings than psychic and religious explanation ratings, respectively (all *p*s < 0.0005). Moreover, the psychic explanation ratings were higher than the religious explanation ratings ($p < 0.00005$). There was no significant main effect of group, $F(2,178) = 0.00$, $p = 0.985$, $\eta = 0.000$, but a significant group by explanation interaction, $F(2,178) = 6.35$, $p = 0.002$, $\eta = 0.067$. Participants in the psychic group gave higher psychic explanation ratings than participants in the magician group, $t(89) = 2.04$, $p = 0.044$. On the other hand, participants in the magician group gave higher conjuror explanation ratings than participants in the psychic group, $t(89) = 2.77$, $p = 0.007$. There was no significant group difference for the religious explanation ratings, $t(89) = 0.69$, $p = 0.50$ (**Table 1**). Thus, the contextual framing influenced participants' psychic and conjuring explanations, but not religious explanations, which were low for both groups (**Table 1**).

RELATIONSHIP BETWEEN BASELINE BELIEF AND INTERPRETATION OF THE EVENT

We correlated participants' belief scores before the anomalous event with the explanation ratings after the anomalous event (psychic, conjuror, religious; **Table 2**). TB and NTB scores were both significantly correlated with the Psychic and Religious explanation ratings (**Table 2**). Thus, the higher individuals' beliefs, the more likely were psychic and religious explanations (see also Orenstein, 2002). We also observed a significant correlation between NTB scores and conjuring explanation ratings. The more individuals reported NTB, the less likely were conjuring explanations.

Table 1 | Mean psychic, conjuror, and religious explanation ratings ranging from 1 (strongly disagree) to 7 (strongly agree) for the psychic and the magician group separately.

	Psychic explanation		Conjuror explanation		Religious explanation	
	M	**SD**	***M***	**SD**	***M***	**SD**
Psychic	2.82	1.85	5.02	1.70	1.64	1.14
Magician	2.11	1.48	5.89	1.27	1.47	1.20

Table 2 | Pearson correlation coefficients when correlating belief scores (NTB, TB), as assessed before the anomalous event, with the three explanation ratings for the event, as assessed after the anomalous event (*$p < 0.05$; **$p < 0.0005$).

	NTB scores	TB scores
Psychic explanation	0.48**	0.41**
Conjuring explanation	−0.26*	−0.08
Religious explanation	0.33**	0.41**

EFFECT OF CONTEXTUAL FRAMING AND ANOMALOUS EVENT ON EXPLICIT BELIEFS

We investigated whether contextual framing and exposure to the anomalous event influenced participants' TB and NTB as assessed before and after the demonstration. We made the following assumptions. Firstly, we can attribute group differences in belief scores assessed before the demonstration to contextual framing effects. Secondly, we can attribute group differences in belief scores as assessed after the anomalous event to the experience itself combined with the contextual framing.

We subjected the TB and NTB scores to separate ANOVAs with instruction group (psychic, magician) as between-subject factor and time (before, after) as repeated factor. The ANOVA on TB found no significant main effect of group, $F(1,89) = 0.028$, $p = 0.87$, $\eta = 0.000$, no main effect of time, $F(1,89) = 2.15$, $p = 0.15$, $\eta = 0.024$, and no group by time interaction, $F(1,89) = 2.15$, $p = 0.15$, $\eta = 0.024$ (**Table 1**). The ANOVA on NTB showed a marginal, yet non-significant main effect of group, $F(1,89) = 2.63$, $p = 0.055$ (one-tailed), $\eta = 0.029$, and no significant time by group interaction, $F(1,89) = 0.25$, $p = 0.64$, $\eta = 0.002$. The main effect of time was significant, $F(1,89) = 5.70$, $p = 0.019$, $\eta = 0.060$, wherein NTB scores before the anomalous event were higher than the NTB scores after the event (**Table 3**).

EFFECT OF CONTEXTUAL FRAMING AND ANOMALOUS EVENTS ON RANDOM NUMBER GENERATION

We performed a 2×2 ANOVA with group (psychic, magician) as between-subject factor and time (before, after) as repeated factor on the number of repetitions. We found a significant main effect of group, $F(1,89) = 3.74$, $p = 0.028$ (one-tailed) $\eta = 0.040$, no effect of time $F(1,89) = 0.015$, $p = 0.90$, $\eta = 0.000$, and no group by time interaction, $F(1,89) = 0.046$, $p = 0.83$, $\eta = 0.001$ (**Figure 2**). The main effect of group emerged from the magician group producing more repetitions than the psychic group. If numbers were generated entirely randomly, we would expect 11 repetitions. As shown in **Figure 2**, participants produced fewer than the expected 11 repetitions. Pearson correlations showed no significant correlations between repetition avoidance (before the anomalous event) and TB scores ($r = 0.074$, $p = 0.49$) and NTB scores ($r = 0.01$, $p = 0.93$).

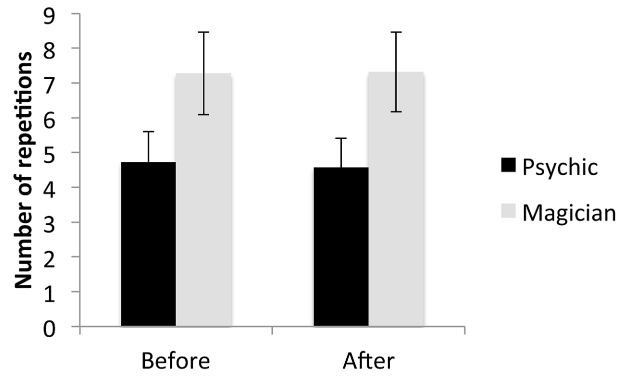

FIGURE 2 | Mean number of repetitions in the mental dice task before and after the demonstration of the anomalous event as a function of the contextual framing condition (error bars denote standard errors).

DISCUSSION

We investigated whether exposure to an anomalous event changes people's beliefs and associated cognitive biases (i.e., impaired judgments of event likelihood). Students observed a magic demonstration in a classroom setting and half of the participants were told that the performer was a magician whilst the others were told he is a psychic. Subsequently, participants were asked how they interpreted the demonstration (psychic, conjuring, religious explanations). Participants also filled in a self-report belief questionnaire and performed a random number generation task (mental dice task) before and after the demonstration. Our results showed that (i) participants gave explanations in predicable ways (the psychic group gave more psychic explanations than the magic group; the opposite was true for conjuring explanations; religious explanations were overall low and did not differ between the psychic and the magic group), (ii) baseline belief scores correlated with explanation ratings (higher TB and NTB scores correlated with psychic explanations, higher TB scores correlated with more religious explanations, and higher NTB scores but not TB scores correlated with less conjuring explanations), (iii) the anomalous demonstration had little influence on self-reported beliefs (NTB were lower after as compared to before the demonstration), and (iv) individuals in the psychic group showed stronger repetition avoidance than individuals in the magician group.

We will first discuss the role of contextual framing on our dependent measures, (i.e., the NTB scores and repetition avoidance), because the exposure to anomalous events seemed to have little influence on peoples' NTB and associated cognitive biases. It is possible that exposure to anomalous events has no impact on NTB and repetition avoidance. While counter to our predictions, this conclusion would support the notion that NTB are well-established in adulthood and show little change, not even with scientific education (Walker et al., 2001; Dougherty, 2004; Genovese, 2005). Before accepting that NTB and associated cognitive biases are fixed and do not change with experience and context, we conjecture alternative explanations that could account for what we observed.

Firstly, the explanation ratings after the anomalous demonstration indicate that the contextual framing influenced people's experience of the event, or at least their verbal reflections. When

Table 3 | Mean belief scores (TB, NTB) before and after exposure to the anomalous event for the psychic and the magician group separately.

	Traditional religious belief				Non-traditional religious belief			
	Before		After		Before		After	
Group	*M*	SD	*M*	SD	*M*	SD	*M*	SD
Psychic	3.85	2.01	3.85	2.10	2.88	1.13	2.77	1.10
Magician	3.84	2.34	3.71	2.19	2.52	0.91	2.44	0.94

the event was framed as a psychic demonstration, participants gave more psychic explanations than when it was framed as a magic demonstration. The reverse was found for conjuring explanations. These results coincide with those reported by Benassi et al. (1980), who similarly, showed that contextually framing a psychic demonstration influenced subsequent event explanations. These observations are supported by independent studies. For instance, verbal suggestions enhanced the subjective experience of anomalous events in a fake séance room (Wiseman et al., 2003), in a film presenting psychokinetic abilities (Wiseman and Greening, 2005), or in a supposedly "haunted" room (Bering et al., 2005). Subbotsky (2001, 2004) also showed that seemingly skeptical adults demonstrate behavior that implicitly indicates the possibility of anomalous explanations. Moreover, when given hints to explain anomalous events through illusory correlations, many of these seemingly skeptical adults appreciated explanations suggested by such correlations. Whilst the effect of framing did not result in significantly different NTB scores, the trend was certainly in the predicted direction, and our experimental design may have simply lacked sensitivity in picking up these differences (see also limitation section).

Secondly, the results from the mental dice task indicate that the contextual framing was effective. Contextual framing influenced a cognitive bias that has previously been associated with trait-like magical beliefs, i.e., repetition avoidance in a random number generation task (Brugger et al., 1990). More precisely, participants in the psychic group showed a higher level of repetition avoidance than participants in the magician group. This group difference was found irrespective of whether they had seen the anomalous event or not. Thus, cognitive biases associated with beliefs are probably not stable cognitive biases but are influenced by the contextual information and situation. Admittedly, given our initial hypothesis, we predicted that the difference would be particularly apparent in the psychic group after rather than before the anomalous event demonstration. Yet, the demonstration itself did not result in any change in belief scores or cognitive measures, indicating that these measures seem too well-established to change with the one-off anomalous experience. The one-off contextual framing event, on the other hand, was sufficiently powerful to transiently change individuals' perception and appreciation of the event (Benassi et al., 1980; Bering et al., 2005; Wiseman and Greening, 2005). Presumably, the contextual framing event might be so powerful that the subsequent anomalous experience had no additional impact on the dependent measures. Alternatively, the actual anomalous experience may have been too simple to exert any measurable effects. Future studies should test these possibilities. Particular suggestions and reflections on the powerfulness of the anomalous event demonstration are detailed in the limitation section.

A final observation worth discussing is the drop in NTB scores after the anomalous event demonstration. We assume that this drop in NTB scores reflects a psychometric artifact resulting from a repetition bias or response bias, rather than the anomalous event itself. Previous studies showed that magical ideation was relatively unstable over a 2 years period (Meyer and Hautzinger, 1999) and that magical ideation was lower in a group that had received the contextual information that the questionnaire associates with psychosis as compared to a group that had received the contextual information that the questionnaire associates with creativity (Mohr and Leonards, 2005).

LIMITATIONS

If one takes the original hypothesis, we can conclude that the contextual framing was a powerful manipulation while the anomalous event demonstration was not. In comparison to Benassi et al. (1980) our participants were generally far more skeptical about the anomalous event. Benassi et al. (1980) asked participants to write down comments, opinions, and reactions about what they had seen. These comments were later scored according to whether the individual indicated that he/she thought that the performer was a psychic or a magician. It is impossible to directly compare this qualitative data with our own, but the fact that 77% of their participants in the psychic condition came up with psychic explanations illustrates that the majority of participants attributed the anomalous event to a psychic cause. This is in stark contrast to our own data, where on average participants "slightly" to "moderately" disagreed with the idea that the anomalous event was accomplished through psychic powers. It is likely that our magic demonstration might have been less striking, and by inference less influential on beliefs and cognitive biases, than the contextual framing manipulation. For instance, Benassi et al. (1980) used a whole range of psychic demonstrations (mindreading, teleportation, metal bending). We, on the other hand, used a simple magic trick that could (with some training) be performed by novice magicians. Thus, future magic demonstrations should include several tricks and extend the demonstration in duration. Moreover, we tested participants in a classroom subsequent to a psychology lecture on the science of magic. Thus, these students were fully aware that the experimenter (Gustav Kuhn) has a keen interest and experience in conjuring. It is likely that our participants were more skeptical about the authenticity of the psychic performance than a naïve audience would have been. Moreover, as our participants were predominantly female, we cannot guarantee that our results generalize to males.

In addition, our participants received the actual contextual framing instructions in written format. We do not know whether they read this instruction properly or not. In Benassi et al. (1980) participants in the two groups were tested at two different occasions receiving the instructions verbally by the experimenter. As it is impossible to guarantee that each performance is identical, we favored the model in which all participants are exposed to the same performance, but participants are given different written instructions. Despite these caveats and methodological differences between studies, we suggest that the overall methodological approach is promising. In particular, despite the simplicity of our magic trick, the classroom setting, having just had a lecture on the science of magic, our participants did not fully dismiss a psychic explanation.

For future studies, we also suggest to consider the context in which an anomalous event is performed. For example, a spiritual reading carried out in a real séance room is likely to be more powerful than when the same demonstration is presented in a classroom context (Wiseman et al., 2003). Moreover, true séances are typically carried out by people with a very strong conviction in the phenomena (Wiseman et al., 2003), something our magician somewhat lacked. Another concern is the repeated use of the belief questionnaire in short succession. Ideally, participants would receive different belief questionnaires that are yet comparable in what they measure, or even better, a well-established belief questionnaire would be split into two comparable halves so that the first half could be provided prior to the presentation and the other half subsequent to the presentation. Due to the comparability of the two halves, the change in scores could be assessed directly. Finally, we might find stronger effects for non-student populations as suggested by the findings of Bressan (2002). Her findings indicated that links between impaired probability judgments and paranormal beliefs are less pronounced in students than in regular workers of varying education.

We outline another concern not covered extensively so far. Benassi et al. (1980) performed a between-subject design in which participants in the psychic group were tested at a different occasion to those tested in the magician group. The formulation of the contextual framing was matched for the first part of the instruction, but differed later between conditions. The magician aimed to perform the demonstration comparably across the different testing sessions. In our study, we preferred to make sure that each participant saw exactly the same performance so that possible performance differences or audience effects would not differ between the magician and psychic group. We formulated the instructions such that they would be suggestive but be free of personal opinion. Indeed, in Benassi et al. (1980) some instructions included a personal judgment of the experimenter. The verbatim instruction in the psychic instruction included for example "I thought that would be interesting, even though I'm not convinced personally of Craig's or anyone else's psychic abilities, so I agreed to let him do it" (p. 3). In the strong magic condition, the experimenter added "In his act, Craig will pretend to read minds and demonstrate psychic abilities; but Craig does not really have psychic abilities, and what you'll be seeing are really only tricks" (p. 3). We do not know to what extent such different formulations add to the observed results by enhancing or attenuating possible effects. However, the careful matching of verbal instruction is advisable.

CONCLUSION

The present study investigated whether the exposure to an anomalous event would result in a change in NTB and associated cognitive biases. We take the current findings as promising evidence that exposure to an anomalous event (or its announcement) can influence participants' evaluation of the event together with associated cognitive biases. We conclude that such findings are key to showing that magical beliefs and associated cognitive biases are flexible, not necessarily trait-like, and that this flexibility is possible well into adulthood. We discuss the necessity to further evaluate which types of demonstrations are powerful to lead to belief change if not belief formation. In any case, the current paradigm is promising in showing causal (rather than correlational) factors in belief change, belief formation and the role of associated cognitive biases in these processes.

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Expertise among professional magicians: an interview study

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The purpose of the present investigation was to analyse interviews of highly regarded Finnish magicians. Social network analysis ($N = 120$) was used to identify Finland's most highly regarded magicians ($N = 16$). The selected participants' careers in professional magic and various aspects of their professional conduct were examined by relying on semi-structured interviews. The results revealed that cultivation of professional level competence in magic usually requires an extensive period of time compared with other domains of expertise. Magic is a unique performing art and it differs from other professions focusing on deceiving the audience. A distinctive feature of magical expertise is that the process takes place entirely through informal training supported by communities of magical practitioners. Three interrelated aspects of magical activity were distinguished: magic tricks, performance, and audience. Although magic tricks constitute a central aspect of magic activity, the participants did not talk about their tricks extensively; this is in accordance with the secretive nature of magic culture. The interviews revealed that a core aspect of the magicians' activity is performance in front of an audience that repeatedly validates competence cultivated through years of practice. The interviewees reported investing a great deal of effort in planning, orchestrating, and reflecting on their performances. Close interaction with the audience plays an important role in most interviewees' activity. Many participants put a great deal of effort in developing novel magic tricks. It is common to borrow magic effects from fellow magicians and develop novel methods of implementation. Because magic tricks or programs are not copyrighted, many interviewees considered "stealing" an unacceptable and unethical aspect of magical activity. The interviewees highlighted the importance of personality and charisma in the successful pursuit of magic activity.

Keywords: expertise, expertise in magic, performing, professional satisfaction, reflection, creativity, professional magician

INTRODUCTION

Magicians have acquired a unique set of skills that allow them to create illusions of the impossible, and in recent years scientists have become interested in exploring this expertise to further our understanding of cognition (Kuhn et al., 2008; Rensink and Kuhn, 2014). To date, relatively little is known about how this expertise develops. Magic differs significantly from other domains of expertise (e.g., music, stand-up comedy) in that most learning takes place in personal practice that is embedded within informal social networks (Rissanen et al., 2010, 2013), and thus with very little formal training (i.e., magic schools). Without formal training, it is difficult to determine the skills needed to perform magic well.

In most other domains (e.g., sport, chess), expertise can be objectively measured through formal competitions. While there are several national and international magical competitions, it is commonly known that most of the best magicians do not participate in these competitions. Moreover, the skills and techniques required to win a magic competition often vary from those used by professional magicians. For example, although fellow magicians can be deceived, it is much harder to deceive people who have sophisticated knowledge about conjuring methods (Lamont and Wiseman, 1999). Moreover, the tricks that are typically used to fool fellow magicians are often very different from the ones performed to entertain lay people. When performing for fellow conjurers, magicians typically use methods that are far more technical and impressive (e.g., difficult sleight of hand, difficult mental skills, complex methods), than when performing for a lay audience. A further problem in studying magical expertise is that conjuring involves a wide variety of skills. For example, a magician must have a wide range of psychological skills, such as the ability to use external cues and signs (e.g., reactions, applause, verbal feedback) to infer about the audience's mental state (e.g., experience of the effect, whether they detected the method). Similarly, the magicians must be able to use psychological techniques to effectively misdirect the audience, and thus prevent the audience from noticing the method used to create the effect. Many of these misdirection techniques have been documented and described (e.g., Kuhn et al., 2014), and effective deception requires a solid understanding of these psychological principles. Other skills involve motor skills (e.g., sleight of hand), technical insights (e.g., abstract knowledge of magic techniques), as well as performance specific techniques (e.g., comedy, dance).

We consider the pursuit of magic as a specific form of expertise that involves sophisticated skills and well-organized professional knowledge of conjuring performed at the highest national and international standard (Ericsson and Charness, 1994; Chi, 2006; Ericsson et al., 2009). Expertise has been investigated in many fields such as science, arts, and sports (Ericsson, 1996, 2003, 2006; Ericsson and Starkes, 1996; Faulkner et al., 1998). Magicians are entrepreneurs who need to master diverse bodies of skills and competencies.

Although magic has some commonalities with other performing arts, it relies heavily on secretive knowledge and competence, which is disseminated within a network of experienced magicians. Newcomers become magicians by participating in their "community of practice" (Lave and Wenger, 1991) sharing knowledge and fostering conjuring skills, and the expertise develops through the guidance of experts. Advanced magical knowledge can only be accessed once junior magicians have established trust-laden relations with practicing magicians. Developments in social media and the Internet have substantially changed the knowledge transfer amongst magicians. The sharing of online videos of performances and magic tutorials has had profound impacts on how new tricks and techniques are learnt. For example, it is far easier to learn complex sleight of hand and misdirection techniques by observing a magician on video, than by reading abstract descriptions in a book. Moreover, much of magic relies on subtleties that are difficult to describe in text and thus video resources provide much additional information about techniques as well as presentation styles that were previously unavailable. Magic chat rooms and online videos allow magicians to exchange ideas and develop new tricks. The Internet has made much of the material more accessible, and it has also led to a rapid acceleration by which new tricks and methods are shared amongst magicians and the general public. Not all of these developments have, however, been positive. These online resources have facilitated the copying of entire magic routine and the easy access of magic material has also facilitated exposure of magic methods to the general public. As such professional magicians can no longer rely on their secret method and must adapt their methods and performance to stand out as a professional performer (Swiss, 2001). Maintaining a high degree of expertise requires the experts to update their knowledge and develop new tricks and entertainment programs.

Performing magic in front of a live audience is the magicians' core activity. According to Ortiz (2006), magical activity involves three elements. The first is the technology of magical methods. It requires magical instruments, for instance, in the form of sleights, gaffs, and psychological ploys that assist in creating a magic effect. Magical instruments and methods enable magicians to prevent the audience from discovering the ways of completing the trick; the resulting secrecy plays an important role in bringing about a magical experience for the audience. Second, it is also essential to have showmanship to highlight the dramatic, emotional, and magical power of the performance. A crucial element between method and showmanship is effect design; that is the astonishing and mysterious leap from the initial to the final condition that is at the core of the magical process. The field of magic is very wide and involves various genres from stage illusions, manipulations, close-up magic, street magic, comedy magic, mentalism, psychological illusionism, theatrical mentalism, and bizarre magic (Landman, 2013). The magic genres are diverging specific effects played for the audience and the performers cultivate corresponding images and brands in relation to the public. Continuous audience feedback from more or less successful performances and personal and collaborative post-performance reflection are important forces that drive development. Achieving a top level skill requires one to enter difficult situations and systematically practice at the upper echelons of one's proximal development rather than only acting in one's zone of comfort (Hatano and Inagaki, 1992; Bereiter and Scardamalia, 1993; Hakkarainen et al., 2004).

The purpose of the current paper was to examine the nature of a professional magician's expertise through a semi-structured interview. We focused on the following four questions:

(1) Through what stages does the expertise of a professional magician develop?
(2) What are the distinctive features of magical expertise?
(3) What is the role of magical tricks, performance, and audience in professional pursuit of magic?
(4) To what extent do professional magicians share their achievement and pursue novelty and innovation?

METHODS

PARTICIPANTS AND THE CONTEXT

Data about the magicians' networking relations were collected via questionnaire based on the members of the national magician network. Participants were asked to indicate, in relation to each other, those community members who they rate highly as a performing magician. The questionnaire was submitted to 148 known Finnish magicians who had been identified by the first author and three professional magicians (response rate = 81%). A social network analysis that focused on analysing centrality of the participation was conducted (Borgatti et al., 2002). The magicians' peer evaluations were used to create indicators by nominating respected magicians. Analyses indicated that social recognition was not correlated with age. **Figure 1** presents a social-network graph regarding social recognition of magic expertise.

Black nodes represent the interviewed professional magicians ($N = 16$). White nodes represent the other actors of the magical field ($N = 104$). The size of nodes is determined according to in-degree regarding professional recognition.

On the basis of the social-network analysis ($N = 120$), 16 key experts were selected for a semi-structured theme interview using several criteria. We contacted 17 of the most highly rated magicians, though three were unavailable for an interview. Most of the magicians are males and there are only a few female ones. Because of that, we decide to include to the interview sample also two female magicians. Although one of them was peripherally located, she was selected for interview because of being considered as a

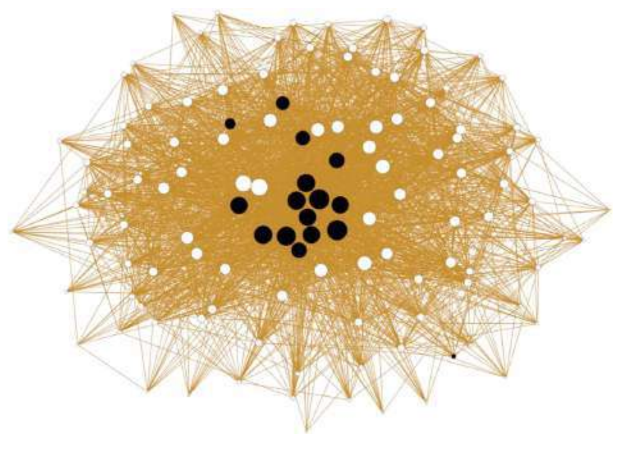

FIGURE 1 | Social-network graph regarding social recognition of magical expertise ($N = 120$).

rising star excelling in national and international competitions. All participants were professionally active, healthy, and successful in national and/or international competitions. In order to protect the anonymity of the participants (M1–M16), some of the information (e.g., gender) is not reported in the present article. The interviews were carried out in Finnish and the data reviewed by all Finnish authors. We do not reveal identities of the participants because interviewees were promised that the interview data will be reported anonymously.

INTERVIEW METHOD AND ANALYSIS OF DATA

Various aspects of the selected magicians' professional expertise were examined through a semi-structured interview (Kvale and Brinkmann, 2009). In accordance with an egocentric network interview (Marsden, 2002; Palonen, 2006; Hogan et al., 2007), the participants were asked to draw a timeline of their professional careers. In addition, they were asked to name important people for their career; this was used to ground interview questions regarding collaborators and other significant networking partners. The interviews were usually carried out at the participants' homes and took place between April 2009 and May 2011. The interviews took from 57 min to 3 h and 37 min, depending on the length of the individual's career and the articulacy of the interviewee.

The interviews were transcribed word by word and analyzed qualitatively using ATLAS.ti 6.2 (see atlasti.com). This program allows the researcher to present the transcribed interview text in one column and thus identify and mark qualitatively differing text segments. The code of the text segment is presented in another column. Working with these two columns representing, respectively raw interview data and associated coding, it is possible to refine the coding system across successive cycles of analysis. Initially, the interviews were read several times to get an overview of central contents and themes. Next, text segments relevant to purposes of the present investigation were categorized into the same hermeneutic category to exclude irrelevant material, such as detailed personal recollections of one's career. In order to identify the central themes, we created ATLAS.ti codes for text segments corresponding to the main interview and research questions. If an interviewee did not answer an interview question in the associated context, it was searched from other parts of the transcribed interview and coded accordingly. If a text segment did not correspond to the interview questions, it was given a code describing the content as comprehensively as possible. Across the analysis new emergent code, such as internet, audience and performance was generated. The main themes identified consisted of: (1) orientation to magic, (2) professional development and personal networks, (3) professional profile and the development of expertise, (4) performance and relation to audience, (5) creation of novelty and innovation. Each of the categories was analyzed in detail to identify sub-themes. The data were categorized independently by two coders who repeatedly met, compared their observations, and sorted out disagreements. From the coded data, we identified reoccurring themes and examined frequencies of corresponding text segments. Subsequently, the data were analyzed to find common themes and distinguishing features in accordance with a theory-informed, data-driven approach (Frank, 1995, 1996, 1998; Fereday and Muir-Cochrane, 2006). Interesting observations, occurring during the analysis, were documented in associated ATLAS.ti memos. Finally, the data were screened for quotations and compressed descriptions regarding various aspects of magician activity. The quotations were selected in researcher meetings to describe the findings by using respondents' own words. In the interviews, the participants reported their first contact with magic, the development of a professional profile, growth of their professional knowledge and competence, and reflected both on importance of old traditions and development of new magic tricks and programs. The analysis focused on examining strategies and experience performance, experienced professional satisfaction, the development of interviewees' professional profiles, and their creation of new tricks and performances. The egocentric networks were visualized by Cytoscope program (2012) that integrated the presentation of all interviewees' partially overlapping personal networks and structures of their relations. Table 1 (Appendix) presents a summary of the interview data analyzed.

RESULTS

The results section is organized as follows: First, we will examine development of magical stage expertise, focusing on the magician's career. Second, we will analyse networking partners and factors related to pursuit of magic at the professional level. Third, we will address central aspects of magical expertise according to the interviewees' accounts. Finally, we will reflect on the interviewees' overall idea of being a professional magician and its essential dimensions on the basis of the analyzed data.

TRAJECTORIES FOR BECOMING A PROFESSIONAL MAGICIAN

The interviewees ($N = 16$) were asked to reflect on their trajectories for becoming professional magicians. **Figure 2** illustrates different stages of the developing expertise in magic from first contact (I), time of starting a serious pursuit of magical expertise (II), beginning of a professional career (III), and establishing a stable professional career (IV).

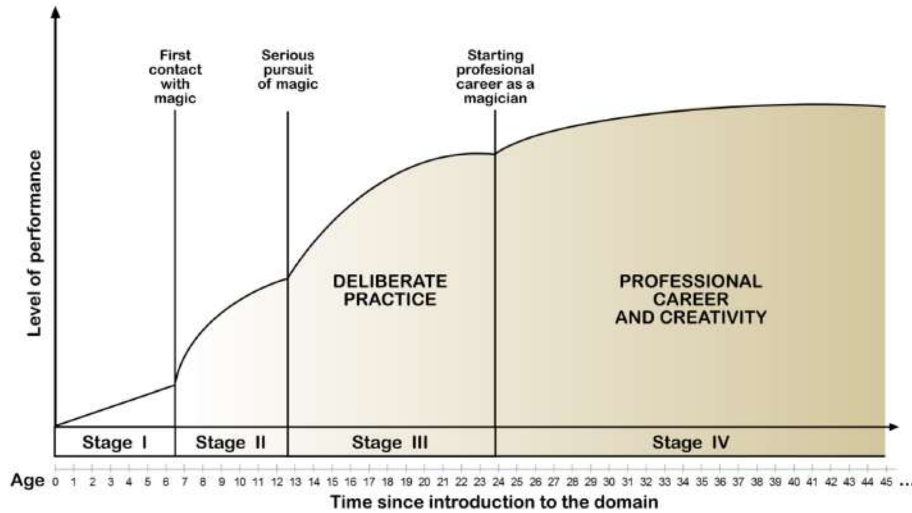

FIGURE 2 | Trajectories for becoming a professional magician (adapted from Ericsson, 2003) as retrospectively reconstructed on the basis of the present interview data. Characterizes average developmental trajectory of the interviewees ($N = 16$) based on their retrospective accounts. Stage I: From birth to first contact with magic ($M = 7$; $SD = 2.5$); Stage II: Serious interest ($M = 6$; $SD = 4.9$). Stage III: Deliberate practice ($M = 11$; $SD = 5.5$). Stage IV: Reaching a professional level and pursuing further professional development ($M = 23$; $SD = 9.8$).

The interviewees reported having their first contact with magic, on average, at age seven; all except one were between 4 and 9 years old. The first experience involved watching a magic show, experiencing a magic trick or reading a magic book; interest in magic emerged from such an influential experience encouraging the first efforts in enjoying performing magic tricks and gradually developing competencies (Bloom, 1985; Ericsson, 1996). In stage II, the interviewees' serious interest arose between the ages of 7–13 leading to a more deliberate pursuit of skill development. Initially, the development of competency was fast and involved seeking support from more competent peers and adult experts, such as fellow magicians, professionals, and personal mentors. Intensive, deliberate practice was initiated, on average, at the age of 13. In accordance with the 10-year rule (Ericsson et al., 1993), participants reported having deliberately practiced magic for more than 10 years ($M = 11.1$, $SD = 5.5$). When reaching a relatively high level of expertise (stage III), participants were able to initiate professional careers as magicians. On average, professional careers started at the age of 24. The youngest professional magician was aged 16, and the oldest was 34.

A great deal of effort was needed to establish a stable career and cultivate an original and distinctive profile as a magician. All respondents working as professional magicians, except for one retiree, have been doing so for 22 years. The development of expertise continuously improves during the career, requiring the continuation of acquiring skills. Participants reported utilizing workshops, occasional courses, lectures, magical clubs, peers, mentors, books, videos, and the Internet when cultivating their craft (Jones, 2011). The Finnish magic associations play an important role by organizing annual workshops, national and international competitions, and publishing a national magic magazine (Jokeri). As indicated below, several respondents emphasized the importance of sustained professional development without which expert level cannot be maintained in a changing environment.

Figure 3 describes egocentric networks of the interviewees and people who have played significant roles in their career. The data revealed that several of the respondents had collaborated with each other during their careers. The interviewees referred to 127 people altogether who had influenced their careers. The networking partners consisted of foreign contacts, persons significant for the development of their careers, masters and mentors who trained them, as well as close colleagues and collaborators. Overall, the Finnish magic community is rather tightly organized around a core consisting of a few central persons, although centralization of the network is not very high. The level of connectivity may be affected by place of residence, age, and professional contacts. Three out of four respondents reported that they had designated mentors or masters who played an important role across their career, especially in the beginning. Some participants established international careers and became famous in other countries after winning international competitions; one of them had a personal network separated from the others. A female magician is located outside of the main body of the network because of having worked in a foreign country (the rising star); this is the reason for having her own network separated from those of the other 15 interviewed magicians. The present investigation reveals that although magicians tend to practice and function individually, they have much contact with fellow magicians and external experts. Beyond magicians, collaborators included an actor, conductor, customer manager, manager, producer, agent, speaker, and theater director. Magicians collaborate by following each other's performances, assessing new tricks, giving feedback on magic shows, and sharing their knowledge and competence. Mutual trust is important for professional development and cultivation of expertise. Currently, mobile connections, social media,

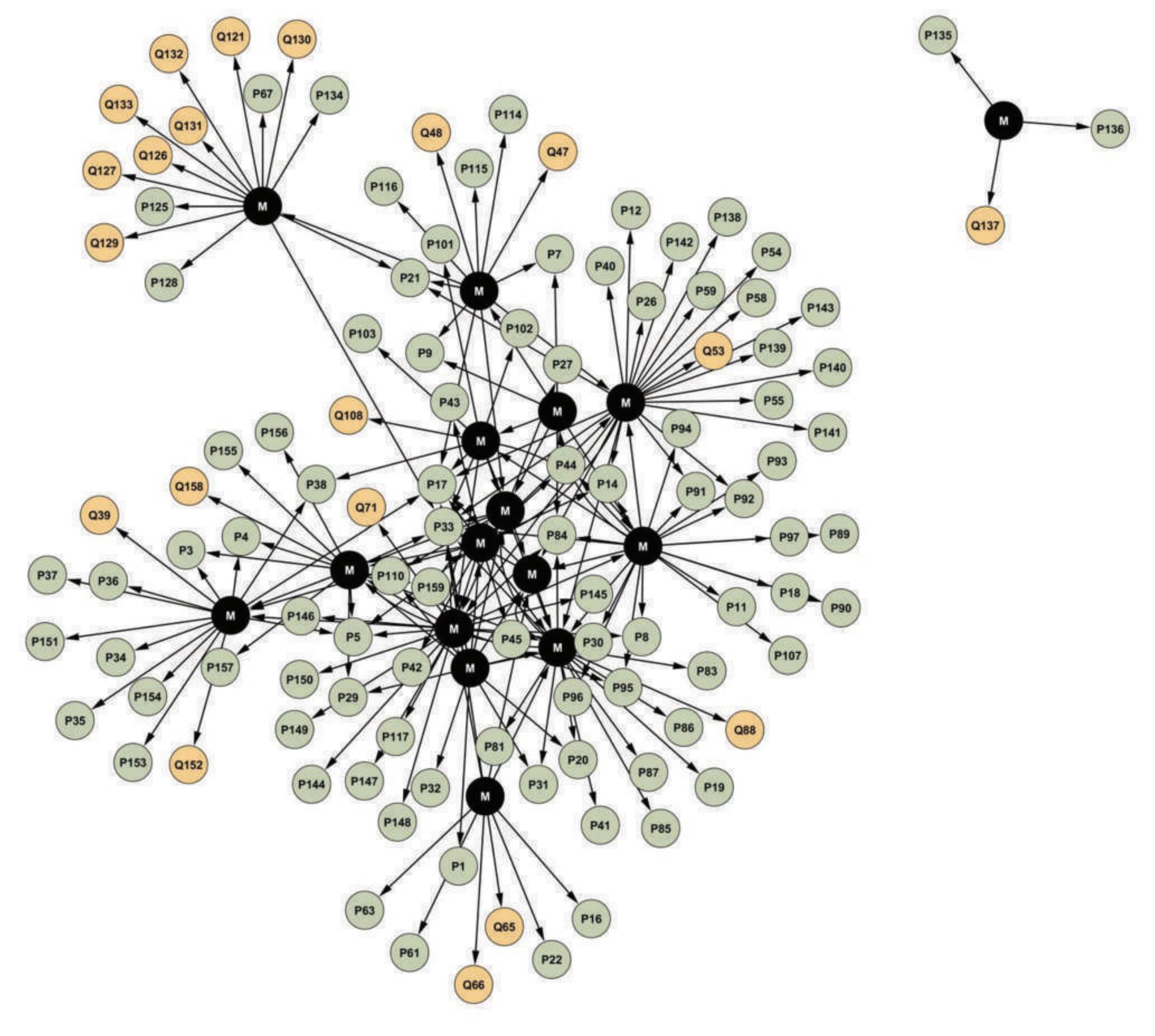

FIGURE 3 | Egocentric network of the interviewees and people significant for their careers. M (black nodes) represents the interviewees; P (green nodes) represents magicians significant to a career in magic; Q (yellow nodes) represents other significant persons.

and the Internet facilitate professional interaction and sharing of knowledge.

PROFESSIONAL MAGICIANS' CENTRAL DOMAINS OF ACTIVITY

It was noted that a magician's professional expertise develops through deliberate practice (Ericsson et al., 1993, 2007; Ericsson, 1996, 2009). Their multi-faceted competencies require integration of knowledge and skill to support flexible functioning in varying performance situations and environments. The interviewees reported that successful functioning as a magician requires professional passion, building of networking relations, guidance from mentors, tapping into cultural resources of the field, sharing professional know-how, and creating new tricks and programs. Toward that end, professional magicians reported it necessary to cultivate a versatile set of skills and competencies, such as manual dexterity, motoric skills, the capability to read an audience, manipulation skills, working with animals, creativity, personal charisma, and skills of self-reflection.

The interviewees argued that a magician has to master all of the main elements of magic activity; if one of them is defective or does not work, successful professional performance may not be possible. They stated that a magician must have multiple skills and competencies because the profession includes diverse elements, such as the stage presence, marketing, product development and design, sound and lighting design, script writing, props, costumes, and equipment. Magicians need to be flexible and have the ability to cope with expectations of increasingly heterogeneous and demanding audiences. As experts, magicians need well-rehearsed routines, but those are often not enough; they also need to systematically invest in learning new skills and competencies.

On the basis of the qualitative analysis, we categorized the magicians' professional activity according to three core areas: magic tricks, performance, and audience (**Figure 4**). Designing magic tricks represents the core competency of a magician; magic activity cannot be understood without addressing it. Magic is a performing art; magicians pursue their professional activity by performing magical shows (i.e., product) consisting of a series of tricks and associated performative activities (e.g., stories) in front of an audience. Further, a skilled magician tailors his or her performance according to the audience and functions in close interaction with it. In a successful magical show, the audience, in turn, goes through thrilling experiences. In order to deliver a successful performance, the magician has to take account of and manage a number of different aspects.

The magic trick

We asked the interviewees to reflect on various aspects of their activity, including magic tricks. The participants did not, however, talk that much about magic tricks during the interview extensively; this is in accordance with the secretive nature of the magic culture. In addition, magic tricks are basic to the domain and form a self-evident requirement for professional magicians. The interview indicated, further, that individual tricks were not the professional magician's focus. Although a particular key trick may have a significant role in the performance, the interviewees emphasized the importance of the overall magic show. Yet, there is no magic without magic tricks. The magic trick is the basic tool of astonishing the audience. Both mental and manual skills are combined successfully in performing magic.

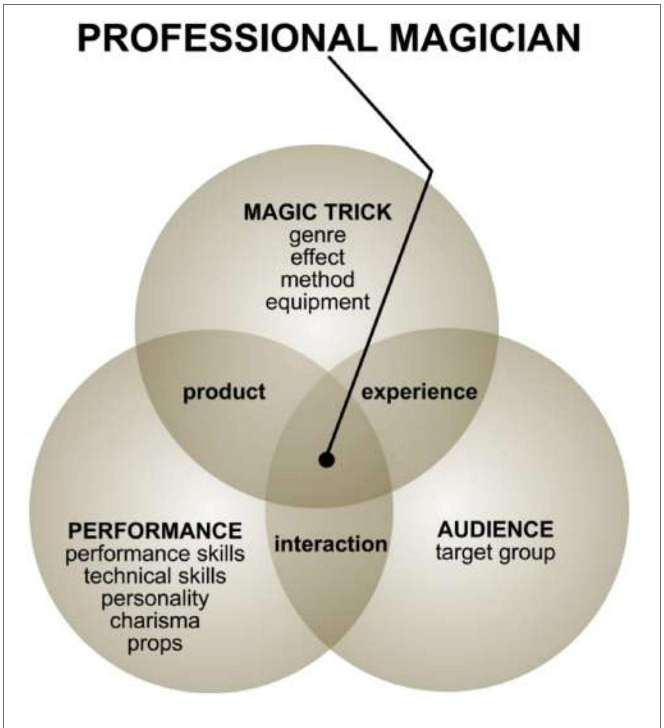

FIGURE 4 | Central themes regarding magical activity occurring in interviews of highly regarded magicians.

Magic emerges from an impossible or unexplainable phenomenon which creates a conflict between what the audience thinks is possible and the event they have just been observed (Parris et al., 2009). The spectator tries to solve the puzzle but a skillfully constructed magic routine does not allow the audience to rationally explain what they have observed and experienced. He or she cannot solve the riddle. The magician relies on misdirection, forcing, or illusion techniques depending on the methods of the trick and the desired effects.

According to M11, it is very challenging to come up with a magical effect: "Coming up with an effect is one of the toughest things to do. Almost always if you've got an effect you come up with a method – you may not be satisfied with it but you come up with something. And it's, if we talk about coming up with something new, it's one of the toughest things to do." M11 tells about ideas that Spanish magician Juan Tamariz has been developing across decades: "Tamariz completed two tricks last summer that he had started working on more than thirty years ago. This goes to show how long it can take to construct these tricks. The process of creating can be such a prolonged birthing process and it can come with a lot of pain, too. So maybe it can be compared to giving birth – it's tough but once it's born, it's a beautiful thing."

Magicians practice their tricks technically so often that performing them in their programs consumes hardly any additional energy. A magician has to select equipment and magical props and customize his or her preferred genre. The impact of magic tricks depends on the presentation as well as interpretation of the effect: "One is the ability to amaze and to make an effect, and to understand that the effect goes from instrument to technique and this is an important point because then it kicks you onto a trajectory that you have to develop. It's very important and then you get kind of naturalness to your performance. You can spontaneously be in a state where you know the performance." (M6)

M9 reported feeling satisfaction when developing new tricks, especially when they are able to deceive colleagues with them. In addition, they believe that life as a magician is relatively free in nature without rigid daily routines: "I get a lot of satisfaction from inventing my own tricks. It is very satisfactory to me. I am pleased to lead this kind of ... so called ... free lifestyle with no schedules or routine based life. It all raises from this chosen profession and this hobby. These are the main things I enjoy. I also enjoy sessions with other magicians, the exchange of ideas. I get great satisfaction from being able to help someone solving a problem; it is a fantastic feeling when you notice that you've been able to help someone else for a change. That's where I get satisfaction, too."

When magicians practice and acquire manual dexterity (hand skills), they try to imprint such sequences of gesture very deeply, often resulting in deep unconscious automatism. The interviews indicated that magicians practicing can be directly compared to that of musicians or acrobats as they spend countless hours trying to reach perfection in some techniques or body movement sequences (Jones, 2011). For a magician, refining the effect may be the most important, although an outsider may not be able to tell the difference: "From an outsider's point of view it may look like there's no difference but you yourself see the differences and then you develop it and look for it. Yeah, you can ask if it makes any sense. It's like… was it Leonardo Da Vinci who said that the divinity is in the details? Working on details, yeah they're developed throughout your whole life or until you get bored, that's a possibility as well. There's no such thing as perfection but you need to strive for it." M15

There are different magic genres with their own distinctive subcultures, and practitioners try to establish hegemony of one form of magic performance over others. The interviewed magicians reported mastering a wide variety of magical genres. These included stage magic that involves manipulations (i.e., sleight of hand), stage illusions (based on huge props with animals or people), comedy magic (making people laugh), and mentalism (demonstrating seemingly superhuman mental powers). Most of the participants mastered various forms of close-up magic which is performed for a small group of people at close proximity. Such performances often use small instruments and objects and involve lots of audience participation. In magic competitions, such performances are assessed according to technical skills, showmanship, entertainment value, artistic impression, originality, and magic atmosphere.

Performance

Many of the interviewees highlighted the distinctive features of a magic performance; the audience expects to experience a miracle and the participants want to be surprised and astonished. When a magic trick is presented in the optimal way, the audience experiences a WOW effect. A magic show is a multifaceted performance where the magician must take into account several partial areas. The interviewed stated that both mental and manual skills are needed for successful magic performances. They emphasized the importance of manual dexterity to fluently perform tricks in various conditions and situations and to elicit maximum response in the audience. It was pointed out that the building of a performance depends on the magician's personality, style of performing, and the tricks which are performed, but it also depends on the audience. The magician has his/her own conscience about how he/she wants to create the illusion that the audience experiences. When a magician performs with lots of speech, he or she must be able to communicate with the audience and make the story understood. In shows built on the usage of birds or illusions, the chosen music and his or her coordinated body movements at the stage carry the show forward.

The interviewees highlighted the importance of the magician's personality and charisma. Many magicians are considered as having "magnetic" personalities that impress people around them, making their extraordinary and supernatural—magical—achievements appear plausible. They are also likely to have strong communicative competencies needed to persuade people to believe, at least partially, that something truly magical is occurring in front of their eyes. One of the respondents believes that personality and charisma are the most important factors in the work of a professional magician: "Everything else you can get through practise, but if you haven't got the personality, then it is just a waste of time. In addition, there is also: ambition, determination and courage to throw yourself into it." (M15)

Some interviewees reported constructing a specific identity around their stage performance that shape and color their shows (Landman, 2013). These characters are often based on inspiring living models (a real person or a performative character). Initially, the character is often appropriated from some professional magician's performance. Later, the magician's own personality and deliberate building of the show start shaping and developing the character. In order to function well, the magician's personality and charisma, nature of the magic show, and the character performance should fit seamlessly together. The magicians deliberately build their own performance character and gradually develop it according to their evolving magic show and live interaction with various audiences, always working to improve it. "I can't be my normal self on the stage, I have to have a character. I need a stage personality, to whom the audience can identify themselves. There are so many things which I understood at the same moment. I started to create a character and it only took a couple of months when I got gigs and the whole system changed. I learned how to act while being on the stage. Then there were times when it didn't work when I was searching for my program, made it better using a lot of trouble in it, it was a great relief when everybody liked it so much." (M15)

When working as a magician, the hope is to entertain, but also to earn a living. Simultaneously, however, stakes for a successful performance are very high because a brand must be shaped to create a reputation and generate new customers: "A gig well done: A hundred times more important than the money I get from it." (M11) It was very important that event organizers are satisfied with the performance and expectations are exceeded for the arrangers as well as the audience. In this regard, the interviewees highlighted the importance of being able to cope with unforeseen and problematic performance situations. The audience and circumstances of performing may cause various surprises.

A magician has to utilize experience accumulated throughout a long professional career to be able to solve various challenging situations; however, the audience may not even notice that something special or out of the ordinary has taken place. Preparing and successfully completing a challenging performance provides its own endorphin kicks: "Of course the adrenaline, if you make the smallest change, everything feels quite different. You are always looking for some kind of kicks from it. Some go to the gym for getting endorphins, we go and seek it from our gigs." (M16) Satisfaction is earned through gained insights and successful performing incredible improvisations: "I get professional satisfaction if some improvised trick has succeeded and I have invented a funny gag in it. It just flashed in my mind and I used it: it turned out to work fine. That's where professional satisfaction comes from." (M4) This respondent also commented on the importance of improvisation in the capacity to negotiate problem situations: "It is essential to have the audience participate in. You may need to improvise in problem situations, for instance when something breaks down."

Audience

The main focus for a magician is the performance in front of an audience. All the respondents highlighted the significance of the audience in the magician's work and in magician culture.

One participant reported: "… [magic] doesn't exist without an audience. There is no magic without an audience, it is crucial. Even more important is to make your assistant enjoy being in front of the audience so that she/he doesn't feel uncomfortable." (M12) The results of practice do not become concrete until the live performance. That is when the magician is able to see which effects and methods really work in practical situations. A magician will tailor their performance to fit the audience. For example, performing for children is very different from performing for a group of adults. A magician needs to identify the group's own language and ways of reacting and tailor his or her performance accordingly.

The audience expects to see and experience an exceptional performance. The magicians reported often being aware of the audience's expectations of them. A magician has his or her own expectations about the emerging performance and is scripting and planning the performance accordingly. There could, however, be unforeseen obstacles related to the audience and the performance stage; this highlights the importance of a professional magician's experience and improvisational capability. A magician has procedures, tools, and practices but needs to be able to modify the performance according to situational requirements. One participant reported, "You should have a good feeling about being on the stage. You are there and the audience is watching you. You don't necessarily do anything, but you know that the thing just runs nicely. You don't do just anything. The audience is looking at you and nobody gets bored. That is the greatest wonder you can ever do." (M15)

There are many kinds of audiences and a magician has to be flexible and able to adapt his or her knowledge according to the situation. A magician needs to get the confidence of the audience, without trust he or she cannot get the expected response. Performances must be partially scripted and controlled in conjunction with situational improvisation to allow the magician to lead the audience in a desired direction. It is essential, in real-time, to be able to heed the audience's behavior and react to it continuously: "In sum, you should notice your audience and surroundings as perfectly as possible." (M5) The audience's reactions and comments, surprising situations, and mistakes/errors of a performance challenge a magician. Improvisation is a productive way of functioning and mirrors professional competence.

The interviewees agreed that positive audience interaction and successful performances are the most important factors for experiencing professional satisfaction. A coherent performance emerges from intensive interaction between a magician and an audience: "Just the moment when [I am] standing before the audience … And it doesn't matter what I am doing there, the only thing that matters is how the people feel it, what they experience inside. It is what they take home with them, what they tell their children or grandchildren … or even what they write in their diaries or in their blogs or wherever… because that's all that matters. Of course I can see it in the professional way: when I walk to the stage it is my job… but it kind of cleans me of everything else, I feel totally free, when it goes at its best, free to everyone, free from all prerequisites, free from anything." (M15)

A magic trick must be deliberately practiced until reaching a level where the technical performance hardly requires any physical or mental energy. The magician's performance differs from other performances in that the audience knows that the performer is trying to deceive them and deliberately lead them astray. A magician is not a true magician if his or her performance does not include any magical effects. The effect experienced by the spectator is the climax of any performance. The magician builds the trick by persuading the audience to see, hear, and think a certain way without understanding the method behind the trick. One respondent states: "I am a conductor and the audience is my orchestra." (M15) The magic is born from a concept created by the magician that spectators try to interpret based on their own personal experiences. The spectators try to solve a riddle, but a cleverly built show does not allow them to rationally understand what they see: "Effect is the impact the performance has on the audience and includes not only the magical effect itself (e.g., disappearance, transformation, penetration, levitation, etc.), but also the emotional and post-performance impact on the audience." (Landman, 2013)

During the performance, constant interaction between the performer and audience is imperative. All magicians emphasized the importance of the audience in their professional activity. One participant reported: "I pay attention to different individuals in the audience thinking about the next trick, and whom I am going to use as an assistant in it – and whom I am not going to use. I also try to imagine what kind of tricks different groups of people would be interested in. I try to watch all the time my audience to know their feelings. Improvisation is one important part of the show and that's why you've got to know the audience to see where it is heading to." (M11)

One of the interviewees stated that observing the audience during a performance should be continuous to ensure optimal interaction between the performer and the audience: "I follow the reactions of the whole audience and try to conceive, in the earliest possible stage, if I need an assistant, whom I am going to choose. You always look at the audience and how they react in your performance. Usually, I try to go, in my performances, like on thin ice, and that's why I try to critically look at the audience to know where we are going in this thing and level." (M10) To summarize, performing in front of audience is a crucial aspect of magic; competent magicians follow an audience reactions very carefully and tailor their activity accordingly.

REFLECTING AND ANALYZING MAGICAL PERFORMANCE

The interviewees addressed their ways of self-reflection and of analysing their performances. The audience's reactions and feedback provided information about whether a new trick is a functional part of the overall performance and whether it needs to be refined or left out altogether. The magicians analyzed and reflected on their performances and the reactions of the audience during different stages of their work: "Performance is already rather demanding training; it is more reflecting on than training. I tried at least twice a week to film especially the novel illusion [of my own] and think what works and does not work in it, and could it somehow be improved." (M4) Such an analytic process appears to be a central tool for the development of their expertise. One participant told the following: "I go to the backstage room and take off my jacket and sit down. I think and go through the performance: how did it go, did it work, or why didn't it work, what should I have done, what did I do wrong and what was working nicely. I kind of make a little analysis of how everything went. Yes I do my own analysis of the gig and pack my things and go to say thanks to the organizer of the performance and start my journey back home. And if it needs more replaying, I do it throughout the driving wondering why I am doing this kind of business. I stop for a cup of coffee and then drive home thinking about how I could have done my show even better. I also speculate about the length of the performance, was it too long or too short, were my choices of the tricks right or wrong and how could I make the performance better." (M10)

Magician M7 does his first analysis immediately after the performance and speculates on the successes and failures: "I try to empty the gig and go through it already in the performance place. But the deeper analysis takes place in a silent and tranquil place. But the proper analysis takes place in the car… If the gig went well, you may not stay in the flow-experience… the next gig will start again from the zero point…If the gig went bad…You have to neutralize it again remembering that the next one will still start from the zero point." Also M16 analyses his performance immediately after the show: "Yes, I go through the performance quickly, as soon as I come out from the stage or wherever I am. I think about it for a while like in a fast rewind mode speculating about how I succeeded, did the tricks go fine or did I make mistakes. Then, of course, I go to meet the organizer and put my things together saying thanks and goodbye. But after every performance, I do think and speculate about how everything went and what I said and try to find out how to improve my performance, or what I should change, and also how the audience has behaved. Every time I go through the performance myself or with someone else, if there is someone who has seen the show."

Magicians who have a partner or an assistant go through the first debriefing and feedback immediately after the performance, either when dismantling equipment or during a return trip. They usually address those aspects that either went well or need improvement: "Earlier, it was very important to speculate and go through the program [when we were planning the program] to see what really is in it and to find out whether there were loose movements which we could drop out. We always had this personal meeting, I always trusted my assistant, and it was very important. Still, after all she follows the development of the situation between me and the audience, she is kind of a background person, as she is not the main hero on the stage." (M2) The magician M1 also reflects after the show about the whole performance and things that happened: "After the gig everything depends on how it went and what kind of a gig it was, then we start to break it down. Me and my wife pack up the gear and throw a few comments about what was good and what went badly in our performance, what worked fine and what didn't, and where we should pay attention to next time."

Four respondents (4 of 16) worked with animals, involving their own set of challenges. One of the participants commented: "Somehow you always go through the performance, especially when something goes a little wrong. Lately, it has happened with the birds. I just lost a few. They just simply got too old. The birds with which I started in the 80 s, they were so old that they just simply died. I lost many birds during a short period just though aging. It made a kind of a gap, because so many key-birds were missing at the same time." (M15)

All magicians emphasized the importance of the audience in their performance because the magical effect emerges only in interaction with an audience. In order to perfect their performances, magicians need to constantly reflect on their magical programs, from individual trick to the overall performance, and gradually expand the repertoire of their activity.

CREATING NOVELTY AND MAKING INNOVATIONS

One theme of the interviews involved magicians' concerns with the pursuit of novelty and innovation. Magicians work in a rapidly transforming environment in which instruments, methods, and performance environment continuously change. We wanted to know why participants changed their tricks and performances and the process for creating new ones. The interviewees were asked to reflect on how they get new ideas, to what extent they transform their performances, and what aspects of their activity change.

New effects are integrated into the performance by incorporating a novel trick or program component to a prevailing show. The magician tests whether the routine needs changes or preparations and whether it is suitable for the overall program or should be abandoned. This helps to ensure that the entire show is under control, that the novel part fits in, and that the program develops gradually as a result of exploring and testing new elements. The show is perfected through refining its smallest details time and time again. M7 reported experiencing the greatest satisfaction when being able to create novelty and take things to new trajectories: "I guess it is inventing something new, bringing in some novelties, and when you notice that it works, it is not repeating the old thing again. There is nothing wrong in that, but you get the biggest kick when you take something totally new and see it working well; that's where the greatest satisfaction comes from, it is quite a different thing."

A great deal of the participant talk related to their performances and consisted of programs of interrelated tricks. Magicians create performance products that are created and presented, so that tricks and magical performances may become commercial products. The respondents develop their expertise by reflecting on current programs, working through difficult aspects, and inventing new tricks and programs. Various external reasons elicit the creation of a novel act. An approaching significant performance and the development of new program force a magician to create something new. Also, a desire to meet the customer's novel expectations provides developmental pressures: "It was mostly that I was on fire because there was a new performance closing, or some TV show to make … I had to develop a lot of new material for them. Sometimes something might inspire me and I want to learn new things all the time, but I had so much pressure from the work to be able to fulfill all my deals and promises. So this is why I had to develop new tricks. It was obligatory." (M1)

When magicians plan new performances, the old magic shows are assessed and reflected upon. Professional gratification is often obtained by having a very good feeling after a successful performance: "For selfish reasons, I reflected that people recognized your work, appreciated it, and recognized me as a successful magician." (M6) Money is, of course, also an important motivation for developing performance and creation of novelty: "The money has been a good starter when something had to be done, but there is always the deadline and a date for everything. When you have promised to give a lecture in America on a certain date, you have to come up with new things to show and tell to the audience there. The working process starts from having a date, and creating something new before that date. The brain gets a message and starts working and something occurs, things start to develop, and inventions occur." (M6)

Dissatisfaction with a routine can motivate the learning and practicing of new magic techniques; you need to change to avoid getting stuck in a rut of old practices: "Maybe it is a little dissatisfaction. I still have not found my own place or ways of expression in magicianship and work, or would I say as a transformer of magic." (M12) Additionally, the will to explore, experience, find something new, and progress one's career can inspire change: "It is the need to experience new things, not to keep jamming in the same place and situation. You must try and find your own borders in magic … " (M15)

Inspirations and pressures to create novelty

One motivation to create novel tricks and routines may start from encountering problems and challenges evolving into the need and desire to learn something new: "(New ideas) come from a strong will to develop when you really want to go forward in some field. It is like a burning fire. Then they just occur, of course you can get inspiration also from others, you can see a trick performed and think, that this point of view would be suitable for another trick … " (M10) Ideas that are not immediately utilized will be reactivated later on enabling the creation of novel ideas: "Well, [new ideas] occur just by reasoning things up… ideas for performance entities, you just have to start solving the problems how to do it well … many technical solutions also occur when you start thinking about a new idea which again raises other new ideas and so on." (M7)

Professional magicians report continuously seeking new ideas and inspirations for magic performance. They revealed that new ideas and fresh models of performance emerge in different ways and from various sources: "Just looking at other performers, which may be stand-up performers or other magicians or even comedy series in TV … Or even sitting in a cafe and looking at people passing by in different situations recognizing humorous potential of emerging situations occurs. It could be everyday life comedy or movies as well." (M4)

Curiosity, interest, and engagement in the field motivate a magician and can be seen by an audience: "Most important is your own enthusiasm. You must love this business. In some stage, you get bored and you feel that you do not have the power to go further. Then you have at least one little new trick which you are excited about. It shows to the audience that you are on fire again." (M4) M15 describes the mentally simulating tricks and performances in his mind: "They may just pop up in your head, or seeing an old trick and inviting a new way of performing it. It may start from music … sometimes I hear a piece of music and think that it would be great to do something using this music. Sometimes it starts from a situation: I think and start developing a trick suitable for a certain event." (M15)

Between appropriation and stealing

Just like any other area of human activity, magic takes place at an interface between tradition and innovation. Magical activity relies on internalization of magical cultural tradition in conjunction with creative externalization involved in creating new tricks and programs. Knowledge creation often starts from observing and following other magicians' performances. M1 finds ideas by following other magicians and observing what they do: "In the way that I watched some Vegas shows like Cirque de Soleil and other magicians, I stole and copied their performances just like all the others did." (M1) Social learning by imitating and modeling colleagues' performances is commonly used as a way of developing new performances.

It is difficult to tell where different tricks stem from in magicianship because the origins are almost impossible to be found: "Of course stealing ideas from others is common (laughing) and changing them so that audience would not notice what had happened. Sometimes, but quite seldom, a pure idea may raise when you are planning something and you find out a new way of executing the idea. An accident, or a surprising event happens, it is like Picasso said, I don't seek, I find." (M6) Experienced magicians will observe their colleagues' performances and reflect on the audience reactions to develop new performance ideas.

The interviewees pointed out that innovation occurring in magic activity often involved restructuring and recombining elements and aspects of already existing tricks and performances: "I can join other's tricks together and create unforeseen entities. This is the way to create something out of almost nothing." (M3) In many cases, a magic effect is borrowed and worked out from an original way of implementing it. Developing new magic effects is very challenging: "Inventing a new effect is the most difficult. Almost every time you have an effect, you can find out the method to carry it out, as well." (M9)

By utilizing and applying old methods concurrently with contemporary methods and instruments, a new creation may materialize: "The best way of creating new things is through connecting old things (tricks) which no one has used for decades. This is the way I find new ideas, through something which already exists." (M11) Respondent M16 reported that he did not find inspiration from following other magicians' performances directly: "I don't get any ideas from conferences of magicians. Pretty seldom I find anything from other magicians' performances either. I get new ideas more indirectly from various cultural sources and happenings: I get quite many ideas from movies, journeys and museums, discussions with really experienced performers. I listen to their stories – all ears: Billy McComb, Reijo Salminen was one of the most important. Books. Leonardo Da Vinci: Complete Works of Leonardo Da Vinci. When you are on a holiday trip where your body rests, the mind often starts to gallop. It happens in a strange culture with no mobile phone around ringing all the time."

The interviewees agreed that it is inappropriate to copy tricks or program components directly from fellow magicians. When taking inspiration from another magician's trick, it must be modified and developed to transform and adapt it. Borrowing other magicians' tricks or programs are unacceptable and seen as "stealing." There was extensive discussion about stealing other magicians' tricks, stories, and program components on a Finnish magician's website (TaikaWeb) that resulted in practically all Finnish magicians signing a commitment to respect other magicians' copyright, original innovations, and creative achievements. Unlike the music or movie industry, the law does not protect magicians and such a collective commitment appeared to be needed. Simultaneously, it was acknowledged that everyone receives inspiration from the magic culture and each other's performances, however borrowed ideas and elements must be creatively adapted and extended.

Faster transmission and sharing of knowledge through the Internet has affected the concurrent requirements for magical activity. It is easier to get access to magic knowhow, have wider audiences, and build national and international reputations much more effectively than before. Also, the magic world and culture have changed from last century's secretive and mystic magic, to become more public, open, and multi-faceted in nature: "Well, it is so that when you read these old books, you have to be able to see them in the context of the time. You must think that 'OK it was done in the 50 s and the world was different in those days.' They had time to take, for example, seven things in a blindfold trick and go through them all one by one. Now if you would do it for example two times, the audience would be bored, Can't he do anything else?" (M5)

Sometimes performances are developed through brainstorming by groups of magicians, which may generate creative ideas to improve quality and create new tricks. Social sharing takes place when receiving inspiration from other magician's shows and transforming their tricks to one's own performance. M7 reported experiencing satisfaction when he/she was able to create a novel trick and take things to new trajectories: "I guess, it is inventing something new, bringing in some novelties, and when you notice that it works, it is not repeating the old thing again. There is nothing wrong in that, but the biggest kick you get when you take something totally into new tracks and see it working well; that's where the greatest satisfaction comes from, it is quite a different thing."

To conclude, successful magicians invest a great deal of time and effort to create original and innovative magical programs. Although they get inspiration from their fellow magicians and capitalize on cultural achievements in the field, they are oriented to creatively adapt and extend such inspirational sources. In order to keep their levels of expertise, and often raise it, successful magicians must deliberately work at the edge of their competencies and break boundaries.

DISCUSSION

The present study addressed various aspects of professional activity of professional Finnish magicians. The interviewees ($N = 16$) were selected because they were nominated by their peers as the most highly regarded magicians in Finland. Qualitative analyses of the interviews revealed that magic is a unique professional field; in spite of requiring years of deliberate practice, practitioners of the field have hardly any formal training. The time from initial contact with the magical culture and becoming a professional expert in the field varied from 7 to 23 years. As there is no formal training system, most of the development takes place through informal communities of practices (Lave and Wenger, 1991). For that reason, creating, keeping up, and developing personal social networks with other magicians and professional experts from various fields play an important role. Cultivation of their expertise takes place with tremendous personal effort facilitated by participation in informal networks. Magicians are entrepreneurs who have to make their living by personally creating their own brand and reputation in a very small and competitive market. In order to survive professionally, the magicians have to master various domains of magic and cultivate versatile performance skills.

Magicians can be very peculiar, yet are often compared with other professionals like actors, musicians, or stand-up comedians. Some of the same characteristics can be found in these professions, but there is no other profession where it is essential to preserve trade secrets. Pursuit of magical performance consists of ingeniously integrated magic tricks that together create an impressive and sometimes astonishing show. Once the tricks are learned, they provide a flexible basis for creating situationally adequate and contextually varying performances that are adapted to specific features of the audience in question. Each trick may be seen as a routine activity sequence that can be triggered with appropriate situational cues, hints, and deliberation.

Magicians calculatingly utilize various techniques for misleading the audience, such as forcing, misdirection, and illusion; the audience observes the magical effect, but the method for the trick is kept secret. Our data revealed that magicians do not willingly reveal the tricks of their trade with anyone beyond a trusted apprentice or colleague[1]. Consequently, it is understandable that the interviewees did not talk much about their tricks or associated technical performance, but concentrated on more general reflections of their performances and shows. They shared experiences of preparing, conducting, and reflecting on their magical performance. They developed expertise by reflecting on current programs, working through difficult or not so optimal aspects of it, and developing new tricks and programs. Today, the revolution of audio/visual and digital technology provides new tools to develop tricks, new channels for performance, and new ways of documenting the performances.

For many interviewees, the audience was the most important aspect of their activity. They were willing to do almost anything to entertain the audience. Toward that end, every interviewee reported investing a great deal of effort reflecting on their performance. A successful performance involves moment-to-moment improvisation combined with well-scripted elements. The interviewees reported frequently adapting their performance according to opportune moments and situations emerging across real-time interaction with their audiences. In many cases such enacted adjustments affected the direction of their subsequent performance. Over time, magicians need their repertoires of tricks to be able to adapt to varying contexts. It may be necessary

[1]Most magicians disapprove of exposure for the sake of exposure (e.g., Swiss, 2001), but are happy to discuss their methods with non-magicians, if there is a scientific (discussion with scientist) or artistic purpose (film/theater producers).

to move to a neighboring area of magic and learn to hybridize very different kinds of tricks as components of a new performance program. One of the interviewees pointed out that pursuing an original line of professional magic may require seeking inspiration from beyond the magic scene, such as theater, opera, music, visual arts, and observing people. Pursuit of innovations requires a strong motivation.

In many cases, external pressures of performance, crises, failures, challenges, seeking personal advantages, or competition may elicit creation of novelty. When earlier performances have become routine, degrees of freedom from the magician provide ample opportunities for knowledge creation. In order to maintain expertise in the rapidly changing world, magicians cannot rely on an old repertoire of tricks but need to function as adaptive experts (Hatano and Inagaki, 1992; Bereiter and Scardamalia, 1993) who invest a part of their resources in learning and creating new tricks. Integrating different tricks and practices often provides unforeseen creative opportunities, fostering innovation and transformation of performances, which expand the magician's repertoire. Combining unexpected routines may also inspire curiosity for developing new ideas. This creation of new effects may come from a desire to investigate or explore novelty-seeking opportunities, or merely a happy coincidence.

Many of the interviewees talked about borrowing and stealing from other magicians. In many cases, a magic effect is copied and developed in one's own way of implementing it. The interviewees were concerned about using tricks, program components, or whole programs from other magicians without acknowledgement. Most magic tricks are not protected by copyright law. This has been a longstanding problem in magic. Most magicians are reluctant to patent their tricks because doing so would give the secret away. During a magic show, magicians very rarely acknowledge the writer or creator of a trick, which is in great contrast to other domains (e.g., music, film, or literature). The interviewees discussed the efforts of the Finnish magic circle to establish ethical norms for professional conduct in magic. Acceptable social sharing involves getting inspiration from other magicians and transforming their tricks by adapting them to one's own performance.

The results revealed that a professional magician's expertise is particularly apparent in challenging and problematic situations. A skilled magician uses the talents and competencies gained through years of experience to solve a problematic situation creatively without drawing attention to the special circumstances. Their professional competence relies on a rich repertoire of tricks, program components, and orienting stories which can be adapted to diverse situations. Their professional expertise likely builds on both procedural skills and declarative knowledge, integrating practical and conceptual mastery of their trade. The present data did not, however, reveal other evidence of conceptual knowledge other than the participants' fluent ways of talking about various aspects of their craft and associated performances.

This study focused on examining the professional expertise of highly regarded Finnish magicians. The nationally representative group of magicians is considered an appropriate sample of the magic community in general. A limitation of the present exploratory investigation was that only the participants' verbal reports and retrospective reflections regarding their professional practices were addressed. Although this is justifiable when pursuing one of the few studies of professional magic activity in Finland, it should be taken into consideration while interpreting the results. The participants are likely to provide reliable and valid accounts regarding only those aspects of their activity that rely on deliberate and conscious information processing, such as preparing, managing, and reflecting on their performances. Tacit and automated aspects of motor performance in magic tricks were not addressed in the interviews. The data do not directly represent magic practice, but rather the participants' meta–level reflections.

All participants had long careers and were interviewed only once. Information about various stages in the development of their expertise provided only a partial and fragmentary picture of the actual process (Reis and Gable, 2000). It would be desirable to carry out future investigations by repeatedly documenting various aspects of a magician's learning, activity, and development. It is possible that participants' interpretations of socially desirable aspects of professional magical activity have colored their interview responses. The interviewer was himself a magician; the participants could have revealed different aspects of their professional activity to another kind of investigator. Nevertheless, the respondents were professionally highly-regarded magicians and their interviews provided very coherent and comprehensive views about various aspects of their activity.

Research on magical expertise is provoking increasing international attention, scientific discussion, academic research, and artistic activity. The results of the present investigation assist in understanding and explaining the nature of magical expertise, the systematic development of magicians' training, the adoption of creative practices that support the continuous development of expertise, the sharing of magical knowledge and competence, and the utilization of social and cultural capital for professional magicians and mentors. From a wider perspective, this study may contribute to the broad field of expertise and skilled performance. It appears that understanding expertise in such a specialized area as magic, once better understood, may have implications. The term "expertise" has been dominated by such arenas as medicine, and a wider set of data, from an area with its particular requirements, may provide for strengthened foundations for expert research.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: http://www.frontiersin.org/journal/10.3389/fpsyg.2014.01484/abstract

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Magically deceptive biological motion—the French Drop Sleight

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Intentional deception, as is common in the performance of magic tricks, can provide valuable insight into the mechanisms of perception and action. Much of the recent investigations into this form of deception revolve around the attention of the observer. Here, we present experiments designed to investigate the contributions of the performer to the act of deception. An experienced magician and a naïve novice performed a classic sleight known as the French Drop. Video recordings of the performance were used to measure the quality of the deception—e.g., if a non-magician observer could discriminate instances where the sleight was performed (a deceptive performance) from those where it was not (a veridical performace). During the performance we recorded the trajectory of the hands and measured muscle activity via EMG to help understand the biomechanical mechanisms of this deception. We show that expertise plays a major role in the quality of the deception and that there are significant variations in the motion and muscular behaviors between successful and unsuccessful performances. Smooth, minimal movements with an exaggerated faux-transfer of muscular tension were characteristic of better deception. This finding is consistent with anecdotal reports and the magic performance literature.

Keywords: magic, perception, biological motion, deception, deception detection

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1. Introduction

Science and magic live on opposite ends of the empirical spectrum. The scientific community relies on a controlled, methodological approach as its guiding principle whereas the magician's motivation rests on the art of deception, frequently by denying legitimate observation. Yet it comes as no surprise that magic provides a fertile ground for the scientific study of perceptual and cognitive processes. Magic plays off of the intuitive rational sense of human cognition. Sleights of hand require skill, dexterity, and coordination, and are thus rooted in psychological phenomena that stem from biophysical foundations. This makes it possible to study specific illusionary actions in a psychological and/or neuropsychological scope to better understand deceptive biological motion and its mis-perception (Binet, 1894; Jastrow, 1896; Hyman, 1989; Kuhn et al., 2008; Macknik et al., 2008; Lamont and Henderson, 2009).

Magic relies on a broad set of mechanisms and processes to carry out its illusory effects. These include mechanical or physical manipulation (e.g., the deformed position of the assistant, facilitated by the "special" table, in Selbit's "Sawing Through A Woman") as well as psychological and cognitive manipulation or exploitation (e.g., the assumption of good continuation of the aforementioned assistant). Successful illusions will involve some combination of these. Investigations of these mechanisms use an equally broad range of techniques, focusing on the social and attentional cues that accompany such illusions (e.g., Kuhn and Land, 2006), the perceptual mechanisms involved in deception (e.g., Barnhart, 2010), perceptual-motor mechanisms (e.g., Cavina-Pratesi et al., 2011) and the underlying neuropsychological mechanisms (see Macknik et al., 2008, for an extensive review).

The universe of events and techniques that constitute the realm of "magic" is extensive. The domain of sleight of hand magic provides a constrained and well defined behavioral and experimental environment in which to explore these processes and mechanisms. For example, Cui et al. (2011) have used this paradigm to investigate the attentional behavior of the audience, showing that social cues may not be necessary to effectively convey deception. Of course, there are two parties involved in these magical transactions—the deceiver and the deceived. Jastrow (1896) performed a series of tests on sleight of hand magicians to determine if they had perceptual and mechanical skills "above and beyond" that of the lay public. Indeed, for the limited sample available several differences appeared, some positive (auditory sensitivity, simple reaction time) but others were the same or negative (complex reaction time, acuity, tactual perception). More recently Otero-Millan et al. (2011) investigated the deceptive qualities of motions, focusing on the performers' contributions to the deception. In this spirit, our interest lies in the entire interaction of performer and audience. What aspects of deceptive biological motion are controlled by the performer and what parts are the audience's share?

So-called "misdirection" is the fundamental platform on which sleight of hand magic rests. The magic literature frames misdirection as a method of controlling the observer's attention (Nelms, 1969/2000; Lamont and Wiseman, 2005) and suggests several techniques for achieving it. As suggested above, this attentional control can arise from a variety of sources, ranging from overt social cues ("Hey! Look over there!") to subtle, practiced, and precise perceptual-motor manipulations. Thus, magic can help us disentwine how the *performance* of the action contributes to the *perception* of that action. To properly do so, one must isolate and examine the physical mechanism of the deception to understand and identify the psychophysical characteristics of deceptive biological movements. Johansson (1973) presented a framework for understanding the perception of biological motion that has resulted in a number of studies by Troje and others Troje (2002); Troje et al. (2005) on the use of biological motion information for identification of identity and intent. The field of sports-science has embraced this technique, typically to study anticipation in competitive scenarios (Müller et al., 2006; Abernethy, 2008; Huys et al., 2008; Possidente et al., 2011; Diaz et al., 2012) and, by extension, the nature of deceptive motion (Farrow and Abernethy, 2003; Jackson et al., 2006).

Along with intentional misdirection, it is instructive to consider the effects of dynamic occlusion and predicted outcome location. Wexler and Klam (2001) highlight the gestalt principle of good continuation (also see Barnhart, 2010) and its prevalence when viewing illusionary movement. Perceptual behavior consistent with good continuation is present from infancy (Quinn and Bhatt, 2005), suggesting that this assumption may be responsible for some of the illusory phenomena found in prestidigitation. Similarly, Soechting et al. (2001) address deceptive movement and anticipated location. Given the findings that a moving background affects the perceived direction of a target in motion (e.g., the Duncker Illusion), participants were asked to follow a target moving in a straight line, which became occluded by a band of randomly moving dots, and point to the predicted outcome of the line. The expected pointing errors correlated with the Duncker illusion. The participant's eye movements were concentrated in the lower border of the occluded area once the target vanished and attempted to maintain fixation in this zone. Due to the random horizontal movement of the occlusion dots, fixation from the desired lower border was altered which correlated to pointing errors. This amodal completion-like effect is also present temporally in magic performances that involve deceptive transfer of items from hand to hand (Beth and Ekroll, 2014).

Finally, it is informative to examine the broader intention of biological movement (Michotte, 1963; Király et al., 2003). One such study examined the recognition onset of sign language across deaf signers, hearing signers, and non-signers (Arendsen et al., 2007). The results show that the intention of sign language gestures can frequently be derived solely from the initial hand motion. Given this, we predict that the initial phases of a deceptive motion may also incorporate information necessary for identifying deceptive intent.

What are the quantifiable differences between veridical and deceptive motion in sleight of hand magic and can we tease out the deceptive characteristics?

2. The French Drop Sleight

A commonly used magic sleight of hand illusion known as the French Drop Sleight (FDS) is used for the current study. Successful performance of the FDS results in the illusion of a small object vanishing. The illusion is created by starting with a small object (typically a coin) in one hand, while the opposite hand approaches and connects, appearing as if the object is being grasped, while actually maintaining the coin in the original hand, demonstrated in **Figure 1**.

The deception is achieved by covertly dropping the object from the thumb and forefinger of the initial hand, into the palm as the empty hand masks the drop by appearing to grab the object.

In reality there are two possible outcomes of this action: a veridical situation, where the object is *actually* transferred from one hand to the other, and a deceptive one where the object remains in the original hand.

When performed convincingly, this illusion is thought to be effective for two primary reasons: (1) social cues and automatic preconception, (2) instinctual gestalt principles applied to the motion Nelms (1969/2000). In the case of (1), an onlooker, unsuspecting of the FDS about to be performed, viscerally assumes the coin is going to be transferred between hands due to it being the most overt and cognitively logical outcome given the visual information presented. Effect (2) suggest that, when presented with a motion that entails partial obstruction, as is the case with FDS, the brain instinctively applies the gestalt principle of good continuation to aid in filling in the gaps omitted from the visual field (Quinn and Bhatt, 2005; Barnhart, 2010; Beth and Ekroll,

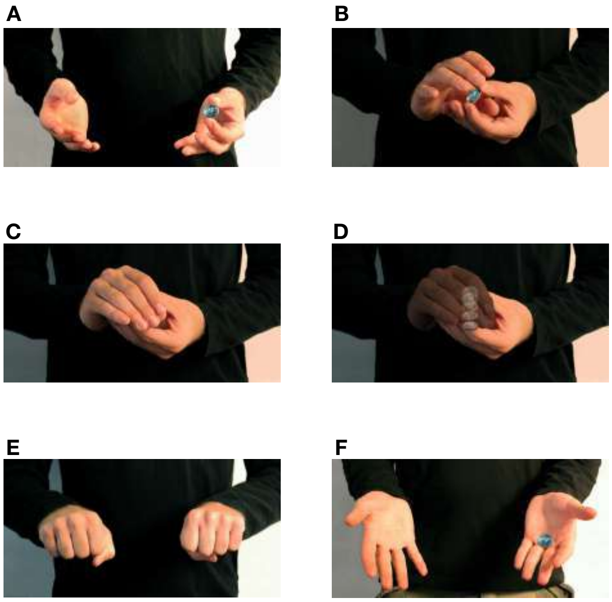

FIGURE 1 | Performance of the French Drop Sleight. (A) Starting position of the French Drop sleight. The object to be "vanished" is held in one hand, with the both hands held in an open fashion to demonstrate to the viewer that there is nothing concealed. **(B)** The empty hand is brought to the gripping hand, typically with the thumb and index finger positioned as if to grab the object. **(C)** In the typical performance of the FDS the object is concealed, as if it were grabbed by the fingers and thumb of the approaching hand. **(D)** In reality, the coin is dropped into the palm of the gripping hand, simultaneously with a faux grasping motion of the approaching hand. In our experiments, depending on the stimulus condition, the coin was either *actually* grabbed (the "veridical" condition) or was dropped (the "deceptive" condition). **(E)** The hands are separated and the observer is asked to chose which hand is presently holding the coin. **(F)** The actual location of the coin is revealed.

2014). Thus, a skilled magician takes advantage of this automatic process by performing the FDS in one fluid motion instead of its constituent phases.

In addition to the above quantifiable mechanisms, a third mechanism is postulated, that of the transfer of muscular tension between the two hands (Teller, Personal Communication). The tension of one's hand when holding a coin is markedly rigid when compared to the free hand and this can be exaggerated for effect. This is thought to be exploited by the magician as he appears to take the coin. His hands transfer the tension (but not the coin) across hands, further cementing the illusion of the coin being exchanged.

3. Experiment 1

To effectively use the FDS as a model of biological deceptive motion it is first necessary to assess the salience of the sleight itself. Here we use a signal detection based technique to quantify its detectability.

To investigate skill-related variations our experiments use two magicians, a complete novice as well as an experienced performer. By noting variation between skill levels we hypothesize that salient elements of the deception are revealed by comparison.

3.1. Method

An expert and novice magician were filmed performing the FDS with two outcomes. First, a deceptive condition where the coin was not transferred between hands, and second, an equivalent veridical condition where the coin was transferred. Subjects were instructed to watch each film clip and respond by indicating which hand they thought the coin was in at the finish.

3.1.1. Subjects

A total of 13 subjects participated in Experiment 1. All were Skidmore College students and received credit toward the research requirement of their Introductory Psychology course.

3.1.2. Stimuli

The stimulus material consisted of 68 movie clips. These movie clips were filmed using two different skill-levels of magicians—a novice and an expert.

The expert has been performing the FDS for 10+ years while the novice had not performed the FDS before this experiment. There are numerous variations and styles of the FDS, therefore the expert magician trained the novice the mechanics of the maneuver and provided critical observation during a 1-week learning period. This ensured that the motions of the two magicians were similar at least at a coarse level. Both performers had the same dominant hand (right).

There are significant social cues and misdirection that can be employed to enhance the performance of a successfully deceptive FDS. For example, imploring the observer to keep a close eye on one hand or the other serves to direct or misdirect attention. Further deception can take place via head and eye movement of the magician, again directing the attention away from where the "business" of the trick is taking place. Since we are interested solely in the biological motion aspects of the FDS we have removed these potentials for social cuing in this and the following experiments.

Each magician wore a long sleeved black shirt and performed in front of a black backdrop. The image frame was cropped such that only the chest, arms, forearms, and hands were visible (See **Figure 1** for an example of the framing). During filming, the magicians performed 20 repetitions of the FDS as well as a veridical variation of the motion where the coin is actually exchanged into the implied hand. Of the 20 repetitions, the amateur dropped or mishandled the coin on three takes, resulting in 17 usable performances. We took the first 17 usable takes from each performer in each condition for a total of 68 clips.

The clips were then edited using iMovie (Apple Inc.) to exclude any extraneous motion at the beginning and end and a two second black buffer was added pre- and post-clip as well as a two second "respond now" screen to allow for the subjects' response. Each clip averaged 8 s, including the buffer and response cue, and had no sound track. The final stimuli were rendered as 640 × 480 movies at 29.97 fps, compressed using the Quicktime (Apple Inc.) "Video" compression codec in high quality.

Figure 1 illustrates the extent of the motion shown in each trial.

The 68 clips were presented twice, in two blocks with a brief break between. In the first block subjects were shown the result of the trial after responding. We refer to this phase as the "reveal" as demonstrated in **Figure 1F**. This provided the subject with feedback as to the accuracy of their response so as to establish best-performance as well as to facilitate learning any "tells" or consciously detected cues that would facilitate the detection of the sleight. In the second block subjects were shown the same set of 68 clips but not shown the reveal. In both blocks the conditions were fully randomized across performer and condition.

Examples of the performance clips can be seen at http://vimeo.com/user20016520/fds.

3.1.3. Procedure

The subject was seated approximately 57 cm from a 58 cm (23") iMac (Apple Inc.). No chin-rest was used, thus observers had free motion of their heads. The video clips of the performance took up the entire screen. They were presented with a written explanation of the experiment as well as verbal reiteration from the experimenter. Subjects were instructed to view each clip and respond by indicating which hand they believed the coin was in. Responses were recorded by the participant on a printed response sheet. They were shown the first block of 68 trials (featuring the "reveal" feedback), followed by a short break, then shown the second block, without feedback.

3.2. Results and Discussion

A comparison between the feedback and no-feedback conditions, using Wilcoxon's signed-ranks, shows no difference in detection across the within-performer conditions, $W = 28, p = 0.41$ for the novice and $W = 27, p = 0.62$ for the expert. This further demonstrates that no significant learning takes place via the feedback of the "reveal." This suggests that, at least for these presentation conditions, whatever information used for making decisions about the presence or absence of the coin was readily available.

Observers detected the correct ending hand for the novice's performance an average of 74.2% of the time $S.E. = 3.6\%$ with $d' = 1.18$, 95% CI [0.91, 1.45], a moderately effective detection performance. On the other hand, detection for the expert performance was only slightly above chance at 55.9%, $S.E. = 7.7\%$ with $d' = 0.32$, 95% CI [0.17, 0.51]. Thus, as would be intuitively expected, subjects are much better at determining the outcome when the FDS is performed by the novice, as opposed to the expert.

The detection criterion is negative in both cases, $c = -0.17$, 95% CI [-0.22, -0.11] for the novice performer and $c = -0.43$, 95% CI [-0.57, -0.29] for the expert. This shows a response bias *toward assuming deception* in veridical presentation conditions. More specifically, judging that the coin is *not* taken when in fact it is. Thus, subjects assumed deception across both performers. While this is not terribly surprising—that observers watching a potentially deceptive performance are predisposed to assume deception—the bias is strongest in the expert presenter condition. Since we only used two performers it is possible that the observers internalized the stereotypical motion or some other cue, such as characteristics of the hands, during the initial block with the reveal. Subsequently, these cues may have indicated that an effective performance was afoot and the observers assumed deception.

4. Experiment 2

The results of Experiment 1 establish the strength of the illusion as well as the effect of expertise on its performance. These results are not particularly surprising—they confirm our intuition and phenomenological experience of the deception and the effect of the caliber of the performance. This established, our remaining experiments probe the nature of the motion and the potential cues that serve to cause the deception.

We first investigate the individual phases of the motion so as to establish at what point the deception tends to takes place. Arendsen et al. (2007) have used sign language gestures, broken into naturally defined phases. The salience of the global sign is then evaluated during their isolated (e.g., partial) presentation. The current experiment adapts this technique. We divide the full-motion stimuli of Experiment 1 into three phases defined as: approach, capture, and retreat. As in our previous experiment, subjects watch each clip and respond by indicating which hand they expected the coin to end in.

4.1. Method

The method used in Experiment 2 is identical to that of Experiment 1—Clips of the FDS performance were shown and subjects were told to predict the hand the coin would result in. However, different stimuli were used- partial clips of the motion representing one of three phases of the overall FDS instead of the original clips of the whole motion.

4.1.1. Subjects

A total of 21 subjects participated in Experiment 2. All were Skidmore College students and received credit toward their Introductory Psychology course. One subject was excluded due to extensive errors in recording responses, leaving 20 subjects.

4.1.2. Stimuli

Experiment 2 uses the performance stimuli from Experiment 1 without the feedback (e.g., "reveal") after the postcapture retreat phase. As with Experiment 1, performances from both novice and expert performers are used. These 68 clips are split into three phases of motion—the approach, the capture, and the retreat, illustrated in **Figure 2**. This resulted in a set of 204 movie clips. The three phases characterize the motion—inflection—motion sequence.

Across performers, conditions and performances the motion took $\bar{x} = 3.2, s = 0.2$ s from the onset of the approach to the end of the retreat. The capture phase (from the initial obscuring of the coin until the separation of the hands) took an average of 0.9 s across performers and conditions.

To create the individual clips, the onset and termination of the motion were marked in the time-coded video, then transition time points were established by centering a 0.9 s window over the capture phase. The average location of these events as observed by the three authors and an additional lab member were used to define the three phases.

Figure 2A illustrates the approach phase, consisting of the motion of the hands from the start position to the position immediately before the two hands begin to overlap. The discrete positions are shown in **Figures 2A,B** respectively. **Figure 2B** shows the capture phase, consisting of the portion of the motion where the two hands overlap, either grabbing the coin or performing the deception. The discrete positions of the capture phase are shown in **Figures 1B,C**. Finally, **Figure 2C** shows the retreat phase, consisting of the motion from the end of the grabbing motion to the finish position. These positions are shown in **Figures 1C–E**.

4.1.3. Procedure

To familiarize the subjects with the FDS they were first shown a demonstration set of 12 full-length performances. These performances included the veridical and deceptive conditions, performed by the novice and expert magician including the reveal. They were then instructed that they would see pieces of the motion and were told to predict which hand they expected the coin to end up in at the end of the motion. Since Experiment 1 showed no effect of feedback all trials were run without revealing the actual result.

The 204 trials were broken into two blocks of 102 clips with a short break provided between blocks. Responses were recorded by the subject manually as in Experiment 1.

4.2. Results and Discussion

The resulting d' for Experiment 2 are shown in **Figure 3**. Overall, and as with Experiment 1 there is a clear difference between the novice and expert magician.

Overall, as with Experiment 1, the experience of the performer had a significant effect on detection ($d'_{novice} = 0.5$, $d'_{expert} = -0.1$) but, the overall detectability decreases since subjects are only shown "snippets" of the extended trick. A repeated measures ANOVA shows a significant effect of expertise [$F_{(1, 114)} = 7.49, p < 0.01, \eta^2 = 0.50$] and an interaction between expertise and motion-phase [$F_{(2, 114)} = 3.1, p < 0.05, \eta^2 = 0.22$].

There is no effect for either the novice or expert magician during the approach phase of the motion, ($d' = 0$) for both performers. The capture phase, however, yielded a significant effect with the expert magician eliciting more false alarms among participants ($d' = -0.2$) and the novice inducing a higher percentage of hit responses ($d' = 0.88$), reinforcing the effect for skill level as well as highlighting the phase which contains the most variance across magicians. The novice, to a lesser degree, also elicits a higher sensitivity among participants during the retreat phase, while the expert remained at chance levels during this phase ($d' = 0.07$). Therefore, it is likely that the expert performed the trick with the same motion, regardless of condition, where the novice "showed his hand" not only during the actual "move" (e.g., coin exchange) but afterward as well.

What is it about the post-move motion that gives the trick away?

5. Gross Hand Motion and Grasp Force

Experiments 1 and 2 demonstrate an effect for the performers' skill level and identify the segment of the motion that accounts

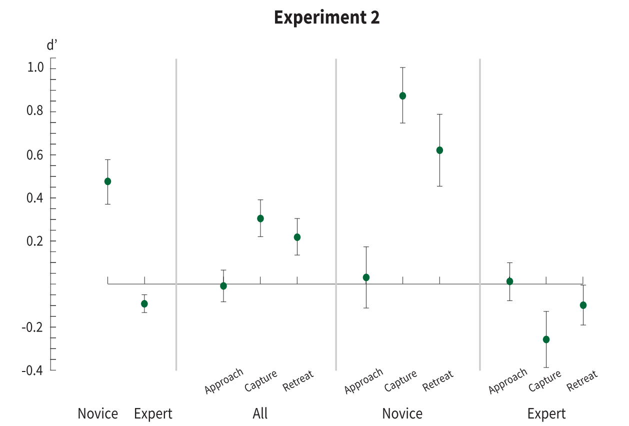

FIGURE 3 | *d'*s by presenter and phase of motion, lower values indicate a more successful deception. Error bars show the 95% CI. As with Experiment 1 there is a clear difference between the efficacy of the novice and expert performer, overall. When the motion is broken down into its constituent parts we see a clearer delineation. Overall, detectability was roughly at chance for the approach-phase but improved during the capture- and retreat-phases. The differences between the expert and novice performer are extreme—the expert is able to deceive with nearly no detection, while the novice reveals the location, most saliently in the capture-phase, but also in the retreat-phase as well.

FIGURE 2 | The three phases of the FDS. (A) The approach phase consists of the motion from the initial presentation to the preparation to grasp (or perform the grasp deception) the object, e.g., the progression from **Figures 1A,B**. **(B)** The capture phase consists of the portion of the motion from the preparation to grasp to the occlusion of the object, e.g., the progression from **Figures 1B,C**. **(C)** The retreat phase consists of the motion from the object's occlusion to the finishing hand positions, e.g., the progression from **Figures 1C–E**.

for the largest difference in deceptive ability between the novice and expert performer.

We would next like to explore the characteristics of the motion that serve to induce this deception. Cavina-Pratesi et al. (2011) have shown that, when the object to be grasped is present (e.g., not absent with the grasp pantomimed), the grasp motions during a deceptive performance closely match those of veridical performance of the task. Our previously described experiments use a single novice and a single expert magician, making a statistically sensitive assessment of generic differences between novices and experts impossible. Still, it is informative to examine characteristics of the performers' kinematic and muscular differences in the hope that they may elucidate some aspect of the performances that differentiate the skill levels.

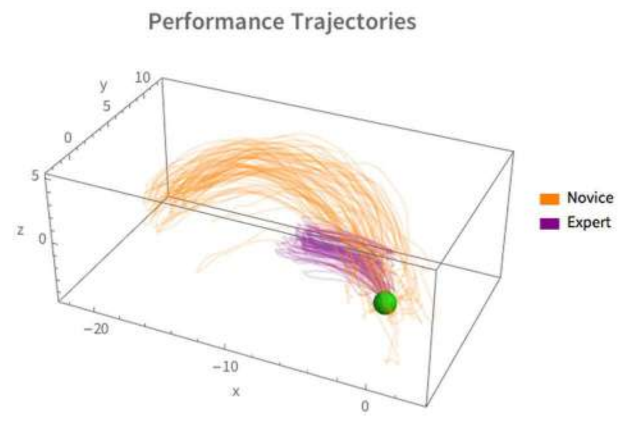

FIGURE 4 | Trajectories of the "working" hand for novice (orange) and expert (purple) performers, collapsed across performance type (e.g., deceptive and veridical) and viewed from in "front" of the performer. All units are cm. The green sphere represents the position of the hand at the start. The spread of trajectories for the expert show a more economical set of trajectories, while the novice move a greater distance and has a characteristic arc not present in the expert's trajectory.

5.1. Gross Hand Motion

We first examine the global trajectory of the hands during the performance of the FDS. We hypothesize that the motion of the expert will be more consistent, as suggested by (Cavina-Pratesi et al., 2011), regardless of deceptive or veridical presentation. The novice should exhibit more variability and, potentially, inconsistency between the two presentation conditions.

5.1.1. Apparatus and Material

To gather position and pose during the FDS motion, a Polhemus 3Space Isotrak II (Pohlhemus, Inc.) motion tracking system was utilized. This is a 6-axis system, capable of providing position $\{x, y, z\}$ and pose $\{pitch, roll, yaw\}$ information at a temporal resolution of 60 Hz, an angular resolution of 0.1°, and a spatial resolution of 0.5 cm. Position and pose was acquired from the Isotrak via a USB-serial port converter, using an Apple MacBook Pro running Mac OS X.

The performing magician was outfitted with the Isotrak transmitter unit on the topside of the "working" (the gripping, right) hand. The corresponding cable was secured to the forearm using Velcro bands to prevent interference with the motion. The same large white coin was utilized during the performance of the FDS as in the previous experiments.

5.1.2. Procedure

Each magician performed twenty deceptive and twenty veridical trials in a random interleaving. By randomly specifying the trials we hoped to avoid a patterned, stereotypical motion as a result of repetitively performing the same task.

5.2. Results and Discussion

Figure 4 shows the overall trajectories of the working (e.g., right) hand for both performers, novice in orange and expert in purple. The green ball represents the beginning of the move. The difference in trajectories is qualitatively clear—the expert uses a more compact, less variable, linear motion whereas the novice has a broader, more variable motion that consists of a considerable arc. Indeed, sometimes exaggerated features of a performance add more "presence" and, often times, more "reality" to a performance (For an example from the world of animation, see Thomas and Johnston, 1981, where they discuss the effects of exaggeration on the perception of realistic movement). However, as shown in Experiments 1 and 2, the performance of the novice was not convincing, and therefore the exaggeration likely proved more of a distraction than an enhancement.

To successfully carry out the FDS it is important that the motor performance not belie the true location of the coin. Therefore, there should be no perceptible difference between the deceptive and veridical conditions. If, on the other hand, there is a perceptible difference between trajectories the subjects could use those differences inform their judgments.

To investigate this, we computed the variance in the working-hand trajectories using a Principal Component Analysis (PCA) based technique, similar to the methods of Todorov and Jordan (2002) and Diaz et al. (2012). Briefly, the trajectory is normalized in time such that each trial takes place on the interval $t_{norm} = [0, 1]$. This normalization means that the approach-phase begins at $t_{norm} = 0$, the capture-phase occurs around $t_{norm} = 0.5$, and the retreat-phase finishes by $t_{norm} = 1.0$. The normalized trials are resampled using linear interpolation and the resulting hand-position x, y, z coïdinates subjected to PCA. The variability of the derived components is then computed between performance conditions over the time course of the motion.

For both expert and novice, veridical and deceptive conditions, >99% of the variance was accounted for by the first principal component. A summary of the variability accounted for by this component over the course of the motion is shown in **Figure 5**.

Across the timecourse of the motion the novice showed significantly greater variability, on average, than the expert ($U = 33,925, p < 0.001, r = 0.81$) with a median variance of $Mdn_{novice} = 9.94$ cm and $Mdn_{expert} = 1.48$ cm. For the novice performer there is a significant difference in variability between presentation conditions ($U = 7668, p < 0.0001, r = 0.61$) whereas for the expert there is no significant difference between presentation conditions ($U = 4350, p = 0.17$).

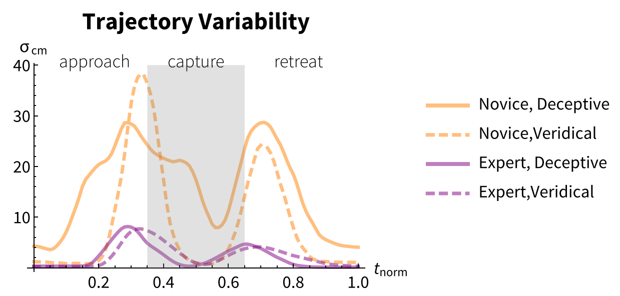

FIGURE 5 | Total variability across the timecourse of the normalized motion. The first principal component is shown for each magician and each performance condition, orange and purple representing the novice and expert as in **Figure 4**. Solid lines represent the deceptive presentation and broken lines represent the veridical condition. The "capture" phase is denoted by the gray background, the approach to the left and the retreat to the right. On average the novice shows much more variability between trials than the expert. The expert shows less variability between trials between conditions than the novice.

These findings reflect that, at lest for these two performers: (1) the expert's motion was more consistent between trials *and* between the veridical and deceptive presentations, (2) the novice's motion was more variable overall and (3) there was significant motion variability between the veridical and performance conditions.

5.3. Grasp Force

Finally, we investigate the grasping behavior of the two performers. Anecdotal evidence suggests that tension transfer is a crucial element of the FDS deception (Teller, Personal Communication) and empirical results Cavina-Pratesi et al. (2011) further support the notion that magicians' grasp can have an effect on the perception of sleight-of-hand performances.

During an effective performance of the FDS the muscular tension needed to hold the coin in one hand is apparently "transferred" to the grabbing hand. Here we consider the act of simulating (or exaggerating) the muscle tension and its effects on the performance success of the two magicians.

5.3.1. Apparatus and Material

A BIOPAC (BIOPAC, Inc.) amplifier / data acquisition system, connected to a Macintosh Mac Book Pro running Mac OS 10.8 was used to collect the EMG data.

Each magician was outfitted with three electrodes on the anterior side of each forearm. The placement of the electrodes was based on the location of the *flexor digitorum superficalis* muscle and surrounding flexor muscles (Hoozemans and van Dieën, 2005). This corresponded with two electrodes on the upper wrist, one on the distal medial wrist, and one proximal on the lateral side. A third electrode was secured proximally on the forearm as a baseline to eliminate noise during the EMG recording. Finally, the electrodes and their leads were wrapped with a neutral colored Ace bandage, along the upper forearm, to limit their movement and potential for distraction. The performers' hands remained unobstructed and unencumbered.

5.3.2. Procedure

As with the motion tracking, each magician performed twenty deceptive and twenty veridical trials in a random interleaving. By randomly specifying the trials we hoped to avoid a patterned, stereotypical motion as a result of repetitively performing the same task.

5.4. Results and Discussion

EMG results are shown in **Figure 6**. As with the motion experiments, the individual trials were normalized on a time interval of $t_{norm} = [0, 1]$ and the EMG voltages for each *flexor superficiallis* resampled. Unlike the trajectory, we have also renormalized the EMG voltages. This is due to changing skin conductance and other difficult to control variation sources. These result in a wide variation of the the absolute voltages commensurate with grasping and releasing. For this, we used the "baselines" of a relaxed grasping finger pose, with and without the coin present. These are reflected by a $v_{norm} = 0.0$ for the relaxed grasp and a $v_{norm} = 1.0$ for maximum grasp.

The novice-veridical condition shows a stereotypical EMG response for the assumed FDS behavior. That is, the left hand initially grasps the coin and relaxes when the right hand grabs it. The right hand is initially relaxed and increases with tension after grasping. For the novice, there is a change in the behavior of the right hand in the deceptive condition from its behavior in the veridical condition. A post-experiment debriefing of the expert magician revealed that the idea of tension transfer was presented as part of the novice's training. It appears that the novice is trying but failing to execute this aspect of the FDS.

The expert has a non-stereotypical response in both the veridical and deceptive conditions. The trials start off relatively relaxed, then there is a small amount of a pre-flexing of the right hand with a subsequent relaxation and increasing of tension in the left hand. Note that, at the finish the right hand is more tense in the veridical condition, presumably because it is holding the coin, whereas this is not the case in the deceptive condition. This response suggests an exaggeration of the muscle tension since, at $t_{norm} = 0.0$ the grasp force is, by definition, sufficient to hold the coin. As the trial proceeds, the coin is grasped more firmly before the capture-phase, and the subsequent retreat-phase shows this exaggeration as well.

It is most informative to examine the *difference* between the deceptive and veridical conditions. Presumably, in order to hide the result the magician should have as little difference as possible between the performance conditions. We took the squared difference of the normalized EMG voltage at each timepoint in the performance, shown in **Figure 7**.

The novice magician has a significantly higher overall difference throughout the trick (with the exception of a brief instant during the capture-phase) whereas the expert has little difference between the two grasp magnitudes until the very end of the performance. This is reflected in the overall difference $Mdn_{novice} = 0.31$ vs. $Mdn_{expert} = 0.02$, $U = 8220$, $p < 0.0001$, $r = 0.90$.

Only the novice's veridical condition shows a stereotypical grasping result. The novice's deceptive motion and both of the expert's performance conditions show some other behavior—but, the expert is consistent across both conditions with the exception of the very end of the retreat-phase.

6. Discussion

Experiments 1 and 2 show a fundamental effect for skill level of the French Drop Sleight and isolate the point in the motion where the deception takes place. Variability of observers' detection is greatest during the capture phase of the motion, and to a lesser degree, in the retreat phase. This indicates that aspects of the intention of the motion are likely revealed during the capture phase and to a lesser extent, the retreat phase. On a phenomenological level, one would intuitively assume the deception to occur during the mid-capture phase given that is where the mechanics of the illusion takes place. Conversely, the approach- and retreat-phases are relatively passive and therefore should reveal little about the location of the coin. In fact, as Experiment 2 showed, there *is* something informative occurring during the retreat phase related to the deception. Our results show that the novice is signaling his intention, in some form, during the retreat phase in addition to the mid-capture phase.

To examine the nature of the biological motion of the performers, we further investigated the trajectory and grasp for each magician in our experiment. Ideally, one would assume minimal differences between veridical trials and deceptive trials. Consistent differences could possibly indicate a deception or "tell." As expected, the novice magician's trajectory was more variable than the expert, and significantly different between veridical and deceptive trials. The expert magician performed the FDS with a more compact, economical motion that did not significantly vary between veridical and deceptive trials.

The grip tension in the hand is derived from contraction and relaxation of the *flexor digitorum superficialis* muscle, located in the forearms. A more convincing illusion is thought to rely on

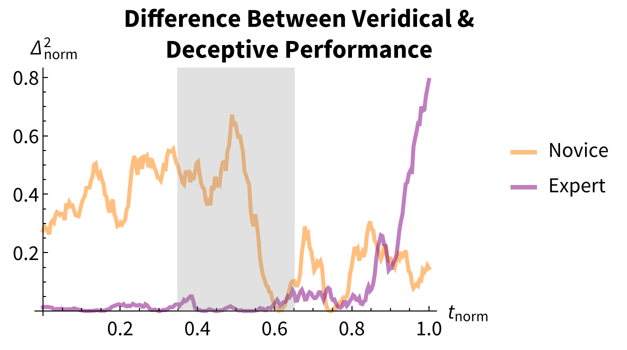

FIGURE 7 | Mean squared difference of the normalized grip voltage between the deceptive and veridical conditions for each magician. The novice magician has a higher overall difference throughout the trick, with the exception at the capture-phase whereas the expert has little difference between the two grasp magnitudes until the very end of the performance.

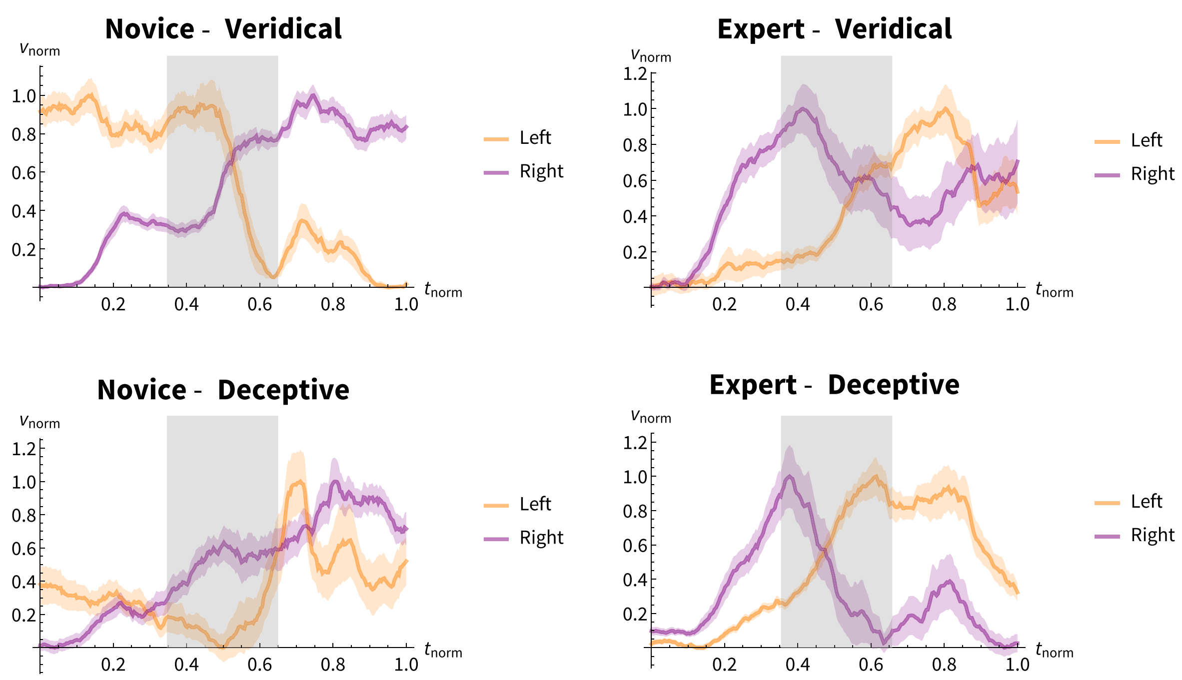

FIGURE 6 | Normalized EMG voltages for the magicians according to performance condition. Orange and purple lines show mean normalized voltages for the electrode on the left- and right-arm *Flexor digitorum superficiallis,* respectively, across 20 trials. Bands surrounding the lines represent ±1*SE*. The capture phase is denoted by the gray box. The novice-veridical condition shows a stereotypical EMG response for the assumed FDS behavior. That is, the left hand initially grasps the coin and relaxes when the right hand grabs it.

a realistic appearing transfer of grip tension between the hands. While our novice failed to smoothly achieve this, the expert showed an similar transfer of grip tension between the hands in both the veridical and deceptive case. Interestingly, the transfer wasn't what one would stereotypically expect when moving an object from one hand to the other, but rather was exaggerated, perhaps as an effort to "sell" the deception.

It is crucial to note two things about our kinematic and muscular findings. First, this is obviously not a representative sample of magicians or FDS performance techniques. The fact that the expert taught the novice ensured some degree of consistency in attempted performance, yet there is certainly more variability to be had in the performance of the FDS. Therefore, it is crucial to not generalize these findings. Second, it is not clear that these kinematic or muscular variations are perceptible by human observers. We present them not as a final explanation of the sources of the detectability but as a suggestion for areas that need further study. One such approach for the kinematic data might take the form used in Diaz et al. (2012) where a minimal representation of the motion is presented (point-light display) with components of the motion systematically masked. The relative detectability of the deception in each case reveals facets of the motion crucial for the deception.

Taken together, the results from these experiments help to uncover the elements which contribute to the successful biological illusionary motion contained in the FDS. Clearly social cues and misdirection play a role in deceptive biological motion as a whole, but such overt clues do not fully explain the psychophysical manifestation of the deception.

7. Conclusion

The current study aimed to identify, isolate, extract, and measure the elements which contribute to the deception demonstrated in the French Drop Sleight of hand illusion. We demonstrated an effect for skill level of magician, highlighted where in the motion the deception occurs, and suggest biomechanical mechanisms contributing to the deception. For these two magicians, the combination of exaggerated tension transfer and a smooth and consistent trajectory path play a significant role in the FDS illusion.

7.1. Human Subjects

This research was approved by the Skidmore College Participant Review Board.

7.2. Data Sharing

The raw data, *Mathematica* and R analyses are available from the corresponding author and on-line at https://academics.skidmore.edu/blogs/flip/ .

Author Contributions

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FP co-designed the studies, wrote the final drafts of the manuscript, and performed all analysis. MN co-designed the studies and wrote the initial draft of the manuscript as his undergraduate thesis. EE co-designed the studies. All authors approve of the final manuscript. Preliminary work was presented at Vision Sciences 2008 and the final study presented at Neuromagic 2012.

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Magic in the machine: a computational magician's assistant

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A human magician blends science, psychology, and performance to create a magical effect. In this paper we explore what can be achieved when that human intelligence is replaced or assisted by machine intelligence. Magical effects are all in some form based on hidden mathematical, scientific, or psychological principles; often the parameters controlling these underpinning techniques are hard for a magician to blend to maximize the magical effect required. The complexity is often caused by interacting and often conflicting physical and psychological constraints that need to be optimally balanced. Normally this tuning is done by trial and error, combined with human intuitions. Here we focus on applying Artificial Intelligence methods to the creation and optimization of magic tricks exploiting mathematical principles. We use experimentally derived data about particular perceptual and cognitive features, combined with a model of the underlying mathematical process to provide a psychologically valid metric to allow optimization of magical impact. In the paper we introduce our optimization methodology and describe how it can be flexibly applied to a range of different types of mathematics based tricks. We also provide two case studies as exemplars of the methodology at work: a magical jigsaw, and a mind reading card trick effect. We evaluate each trick created through testing in laboratory and public performances, and further demonstrate the real world efficacy of our approach for professional performers through sales of the tricks in a reputable magic shop in London.

Keywords: magic, optimization, AI, cards, jigsaw, computer, computational, creativity

1. INTRODUCTION

A good magic trick is enjoyable for the audience; a great magic trick makes it seem, if only for a moment, that a miracle has occurred right in front of their eyes; Ortiz (1994) provides excellent discussions of what constitutes an exemplary trick. Magicians will go to great lengths to perfect a method that results in this type of theatrical impact. Taking into account all the constraints, both physical and psychological, that must be satisfied for a certain trick to exhibit magical qualities, performers will try to construct the best presentation possible. In this paper we refer to trick technology as being the combination of physical and psychological processes underpinning the technical effect. A trick's overall efficacy is dependant not only on the trick technology but also, and perhaps even more importantly, on the theatrical performance of the magician.

In this paper we focus on tricks that exploit mathematical techniques for their operation. The underlying mathematics behind magic tricks has a long and varied history; see Gardner (1956) and Diaconis and Graham (2012). Self-working tricks of these types, which rely on a hidden underpinning mathematical process rather than sleight of hand, can be powerful effects and are often included in card performer's repertoires to provide a break from the constant demands of manual dexterity. Usefully, mathematics based tricks give a clear set of constraints controlling the technical aspects of the trick. The card type and location in a pack can be indexed for example, building up a mathematical model of the physical effect which can be encoded and manipulated computationally.

Props and gimmicks can also provide a significant additional technical element. Props provide both theatrical window dressing and technical support in magic tricks; Christopher and Christopher (2006) describe many uses of such items. Often a prop's perceived role will be as an unassuming presence during performance, for example a simple table on stage, while its real role is fundamental to the method; Mayne (2005) shows how many such objects can be constructed and utilized. A gimmicked prop is one which resides in plain sight, for example a table, but performs some unseen role crucial to the trick's technical performance, for example a secret compartment in the table. Gimmicks that provide important trick technology may also be totally invisible to the audience. Hidden cue cards as memory aids are often deployed in card tricks, as shown in Aronson (1990), and the use of a human assistant who shares knowledge of the mathematical properties of a particular deck of cards underpins many powerful effects; see Kleber and Vakil (2002), Simonson and Holm (2002) and Lee (1950a).

The final element of trick technology is psychological. Human perceptual systems evolved to let us encode information from the surrounding environment. The processes by which this encoding occurs, and the way in which magicians manipulate and exploit these perceptual processes to create magical effects, has recently become an active area of scientific study, notably by Kuhn et al. (2008a). Magic tricks often rely on basic perceptual errors and illusions, many of which are documented by Robinson (1998), and the roles of misdirection and attention in magic have been extensively investigated in Kuhn et al. (2008b). Furthermore, the cognitive characteristics of playing cards such as favored audience choices, a staple of so many magic tricks, have long been of interest, initially to Fisher (1928) and latterly Olson et al. (2012). Related work in computer graphics examines the limitations of the human perceptual system, and how this can be exploited in various ways; see Harrison et al. (2004), O'Sullivan et al. (2003), and O'Sullivan and Dingliana (2001). Only through an understanding of the underpinning perceptual processes and the methods best suited to elicit the desired effect in performance, can magicians build convincing magical effects.

As is clear from the above, and from historical studies, there are multiple ways any one trick can be constructed and performed; Fitzkee (2009) provides a kind of lexicon of magical methods. Combining and recombining the trick technology elements in different ways can lead to different levels of magical impact, and computationally produces a combinatorial explosion in the space of possible solutions that can be difficult for humans to search; there are simply too many ways to put together variants of the trick-enabling elements to be able to try them all out to see which works the best.

Fortunately there are many computational techniques available to perform search and optimization in large data spaces; Russell and Norvig (2009) comprehensively deals with the subject. Genetic Algorithms (GAs), detailed in Goldberg (1989), and Simulated Annealing (SA), summarized in Russell and Norvig (2009), are used extensively in combinatorial problems. The idea of using computer systems as creative assistants, or even as creative entities, has been the subject of previous research, notably by Boden (1998), Bentley (2002), George et al. (1998), and Valstar et al. (2008) amongst many others. There has been some success in the use of Artificial Intelligence (AI) techniques to enhance computer gaming entertainment, by optimizing the mechanics of the games, see Liaw et al. (2013), and also the entertainment produced by the games as a whole, as with Yannakakis and Hallam (2007). To our knowledge, using AI methods to optimize magical effects in conjuring tricks remains a hitherto unexplored domain.

In the remainder of this paper we present a novel methodology for creating new magical effects and variants that relies on combining and optimizing both empirical perceptual and cognitive observations, and a mathematical model of the trick mechanics to generate novel trick technologies. The computer's role is that of a kind of digital magician's assistant that is able to find patterns and configurations that a human magician may struggle to identify. We demonstrate how this flexible approach can be applied to two different types of mathematics based tricks. Specifically we present a magical jigsaw puzzle designed by a GA that uses constraints derived from experiments on the vertical-horizontal illusion, detailed in Robinson (1998), and based upon the existing one dimensional geometric DeLand Paradox effect, documented by Gardner (1956). We also present a mind reading card effect based on cyclical De Bruijn sequences, described in Diaconis and Graham (2012), exploiting existing (Olson et al., 2012) and new empirical observations on the likeability of certain playing cards. Additionally this card trick relies on incorporating a mobile phone prop into the trick technology, which is used during presentation as both a memory aid and a method to reveal a card to the audience.

Finally, we show how we have evaluated the output of this approach to creating new tricks. We conducted experiments to measure the magical impact of the tricks in real life scenarios, and also produced the tricks as commercial products and placed them for sale in a well-known magic shop in London, UK. Sales of the products arguably form an in the wild validation for the methodology.

2. MATERIALS AND METHODS

2.1. CREATING THE MAGICAL

Our trick technology approach to creating new magical effects has three main framework components: a controlled problem domain determined by the type of trick the framework is working on (a formalization of all the elements, physical and psychological, that make up a trick, and a set of constraints placed upon these elements that make the trick viable and hopefully optimal), domain relevant perceptual and cognitive observations of psychological phenomena, and a computational search and optimization engine.

The problem domain needs to be identified and systematized, formalizing the parameters of the type of trick that the computational engine will work toward producing, in effect a mathematical model of the essence of the trick needs to be constructed. During this stage we exploited domain experts, magicians with performance experience, in order to fully understand how and why the type of trick under consideration works, to correctly abstract the various elements without missing crucial steps in the method. This technique of abstracting specialist knowledge to build a model is commonly used in various automated expert systems used for medical diagnosis and financial risk assessment, amongst others; see Russell and Norvig (2009).

The identification and analysis of the problem domain is naturally coupled with elements reflecting the psychological phenomenon being exploited during the trick, for example in the jigsaw trick we describe later we need to include a constraint on maximum line length increases commensurate with a spectator not noticing these length changes. Rather than model this phenomena directly we incorporate such constraints through encoding the results from subject empirical data, that is we run a series of experiments to qualify the effect and incorporate this data function in the overall model.

Finally, it is important to select a suitable search and optimization engine. The specific technique used is determined by the characteristics of the problem domain, and the type of data provided by the empirical investigations. Choosing a suitable technique is informed by previous applications of that technique that are similar in structure; Russell and Norvig (2009) provides many examples. Once the type of trick has been systematized, an effective technique can be identified and deployed.

See **Figure 1** for an overview of the framework components.

2.2. EVALUATING THE MAGICAL - EXTERNALLY ITERATING THE OPTIMIZATION AND EVALUATION LOOP

The computer model is configured to move toward an optimal goal as determined by the constraints of the mathematical model of the trick and the related constraints imposed by the psychological data. Optimization algorithms can find multiple potential

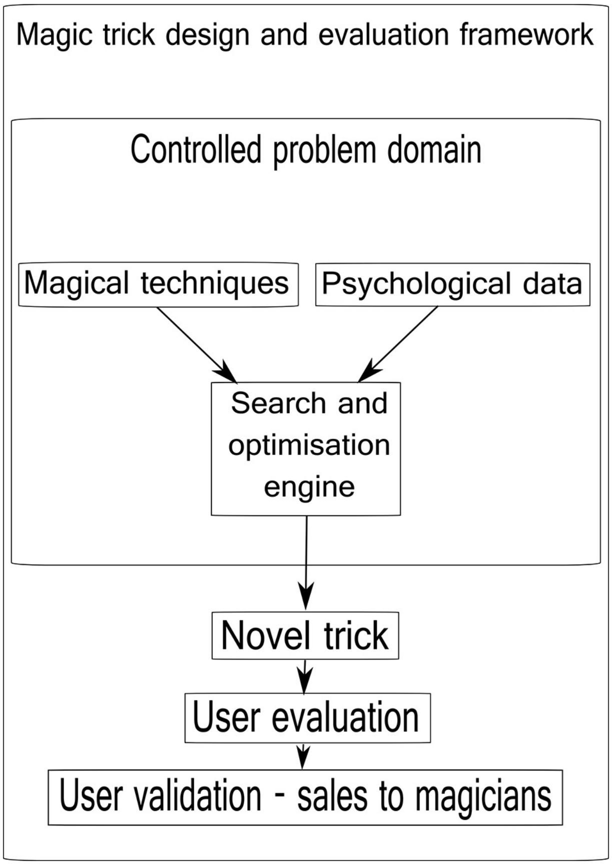

FIGURE 1 | The magic trick design and evaluation framework. Known magical techniques are combined with psychological data relevant to the problem domain (a particular trick) by a computational engine that assists the design and optimization process. A new or optimized version of a trick is output. This trick is then evaluated in the field with performances for real people, and finally sold in a reputable magic shop in London, UK.

solutions, these are referred to as local solutions, as there may exist one overall best global solution the technique does not identify. This issue around recovering a local or global solution is well known, and is dependent on initial conditions used, length of time the algorithm is run, and the algorithm tuning parameters used (see Russell and Norvig, 2009 for detailed discussions). In the case presented here the engine searches this space and the result delivered will be a working candidate for an optimized new trick. However, this working solution may not be the globally optimal solution and may, more importantly, not necessarily translate to a magical effect that performers can easily use. For example, the system may deliver a solution to a card trick that requires twelve cards to be dealt to a spectator, that they must then memorize and return to the magician! While being a solution that satisfies the model programming constraints, this is not a solution that would work in the real world.

Most of these issues are addressed by the psychological constraints imposed on the computer model, however to fully control for such non-practical solutions the outputs of the system need to be evaluated empirically with a real audience. We test the candidate tricks created by our systems by taking them out in to the real world and performing them for an audience. This audience is in essence a bank of experimental subjects who are unaware that what they experience has, in part, been designed by a machine. If necessary, the results from the empirical tests may feedback to the computational design phase, potentially informing the set of constraints used, though this step has not been necessary for the tricks explored in this work; non-computational factors, such as narrative and subtleties during presentation, are naturally refined during the evaluation phase. Once we have a final solution that maximizes the measured magical impact, and is also practical to perform, we undertake a final validation and evaluation of the results through productizing the trick and making it available for sale in a magic shop. This step provides clear evidence as to the viability of the created trick; it is assumed that a trick must reach some basic level of quality before a reputable shop will carry it as stock, and further that its purchase in exchange for money indicates, in a very direct way, the success or otherwise of a product with our specific target user base (magicians).

2.3. MEASURING MAGICAL IMPACT

To test the candidate and final versions of tricks we use an evaluation questionnaire that participants can be asked to complete after witnessing a trick. The intention is to measure their overall experience of the trick—some people dislike magic tricks, even if they are somewhat surprised or amazed by what they have seen. Equally, a participant may know or guess the fundamental techniques at work in a given trick, and therefore not find it to be an especially magical experience, but may still enjoy the particular presentation offered.

We use two scales to capture how much, in general, participants enjoy magic tricks, and also, separately, their enjoyment of the particular trick they have witnessed, we use: an ascending enjoyment scale of 0–4, mapped to the phrases: "Hate(d) them(it)," "Dislike(d) them(it)," "Neutral," "Like(d) them(it)," "Love(d) them(it)." Data gathered about whether participants enjoy magic tricks in general can be used to view the rating of a particular trick in a different light. Someone who genuinely does not like magic tricks is much less likely to enjoy a particular trick and vice versa. It is likely that when asked about how much they enjoy magic in general, participants would likely recall the best experiences they have had of magic, rather than some average they calculate. Thus, if adjusting the rating scores for a particular trick according to a participant's general rating of magic, it is to be expected that the average score for a trick would drop, but may provide a better overall measure. A calibrated rating can be calculated using the formula: $CalibratedRating = TrickRating + (TrickRating - GeneralRating)$. This way, if, for example, a participant dislikes magic in general, but loves a particular trick, the calibrated rating will positively reflect this. This method accentuates weak ratings. A useful measure of how well a trick is received by a group of participants is the difference between the average (mean) rating given to magic in general, and the average (mean) rating given to the particular trick. The smaller the value the better (the theoretical minimum is minus four, though anything close to zero is very good).

We performed experiments ($N = 96$) asking participants to freely choose words to describe their reactions to a range of classic magic tricks, the results of which are shown in **Figure 2**. The intention here was to gather data about the type of descriptive words people use when asked to give a reaction to a magic trick. The participants were recruited from university mailing lists, and from disseminating details of the experiment on Twitter. To simplify the questionnaire, we did not ask for age, gender or country of origin data from the participants. From these words, we observed those most commonly used, and made a selection available on our questionnaire, covering a spectrum of emotions, as choices for participants in our later evaluations of the generated tricks. The distilled list of words participants are asked to select from to represent their reaction to a trick is: Bored, Surprised, Obvious, Neutral, Impressed, Predictable, Amazed.

The holistic summation of the experience provided by these emotional spectrum words provides an additional, qualitative, view of the experience of a trick for a spectator, a measure deliberately separate to the enjoyment rating. We have intentionally not numerically quantified these words. However, more usefully, the words provide additional evidence to the trick designer as to how the trick is received. The quantitative measure of enjoyment provides a way for participants to score the trick numerically, while selecting words allows a spectator to disambiguate that perhaps they enjoyed the trick (high enjoyment rating) but found it predictable. It is arguable that a professional performer would only be satisfied if a trick generated something akin to an "Amazed" response, regardless of the enjoyment rating. It is equally arguable that the rating, how much an audience enjoyed the experience, is the key factor. The intention is to try to understand the way that the tricks are experienced, in a more comprehensive fashion than simply the numerical score of enjoyment.

To further help identify weak points in the trick, subjects were also asked to write freely about any moments when they felt something suspicious might have happened, and about how they thought the trick works.

Collecting this kind of data provides a numerical indication of how much a trick has been enjoyed, and also some more qualitative data about the subjective experience of a generated trick. These observations can be compared to similar data collected from people that have been shown traditional, known to be effective, magic tricks.

Arriving at a measure of what is experienced phenomenologically by someone witnessing a trick is difficult; our approach provides a useful, practical view of a trick's magical and entertainment impact, without the complexity of deeper philosophical questions about the nature of magical experiences.

In the following sections we describe two magical effects, designed using our conceptual framework: a magical jigsaw puzzle, and a mind reading card effect. **Table 1** shows a summary, for reference, for each trick, of the three components necessary to create the trick.

2.4. A MAGICAL JIGSAW

We applied our framework to the problem of making an optimally magical jigsaw puzzle, where printed graphics elements appear and disappear depending on how the same jigsaw is constructed. This jigsaw is based on The Principle of Concealed Distribution, an old technique, first developed seriously in Gardner (1956): the geometrical redistribution of segments of one shape among a number of other shapes such that the magnitude of increase in the area of the remaining shapes is imperceptibly small. The DeLand paradox is an early example of this type of effect, documented by Gardner (1956). An image showing objects is rearranged such that one of the objects appears to vanish, but in fact has been incorporated into an increase in length of the remaining objects. These types of effect were very popular in the late 1800's and early 1900's; Sam Loyd's Get Off The Earth from 1896 followed The Magic Egg by Wemple & Company, from 1880. DeLand's version appeared in 1907.

Converting the one dimensional DeLand paradox to a two dimensional jigsaw allows for greater flexibility in how the shapes can be positioned and redistributed, while simultaneously increasing the sense that something physically impossible has happened; it is typical to assume a jigsaw puzzle can be put together in only one way.

Previous versions of this type of effect have the rectangles displayed vertically in both configurations of the image. We noted the vertical-horizontal illusion reported in Robinson (1998): a line displayed vertically will appear longer than an identically sized line displayed horizontally. A jigsaw puzzle operates in two dimensions, and allows rotations as well as translations of pieces giving the opportunity to usefully exploit this perceptual illusion. We conducted psychophysical experiments to determine the upper limit of rectangle length increase that could be applied before subjects would notice the difference—we investigated the effect on length perception of showing multiple rectangles vertically, followed by multiple rectangles displayed horizontally, and a mixture of the two orientations.

We also investigated the effect of using increasing numbers of rectangles and how this would affect the participant's experience. If too many rectangles are shown they become difficult to count accurately in a reasonable time; the impact of the effect would be diminished as the spectator would be too engaged in counting. Conversely, more rectangles on display can improve the effect, as it is harder for a spectator to determine the method by mentally recombining rectangles. As the trick relies on the subject knowing there are different numbers of rectangles in the two different jigsaw configurations, we conducted experiments to determine the number of displayed rectangles that could be easily counted without error in a reasonable time.

A jigsaw may be made up of different numbers of pieces, of different basic shapes (rectangles and squares). These must all fit together seamlessly with connecting lugs and gaps for each piece, in both configurations. Crucially, a performer needs to be able to construct and then reconstruct the puzzle efficiently, without mistakes. However, more pieces make the method behind the effect harder to resolve in a spectator's mind. We conducted experiments to determine how many pieces could be reliably constructed in a reasonable time.

These factors determine what makes a good jigsaw trick for both the performer and the spectator. There are other issues of a more basic geometrical nature for a jigsaw designer to contend with, such as what shapes of pieces to use, where to place them,

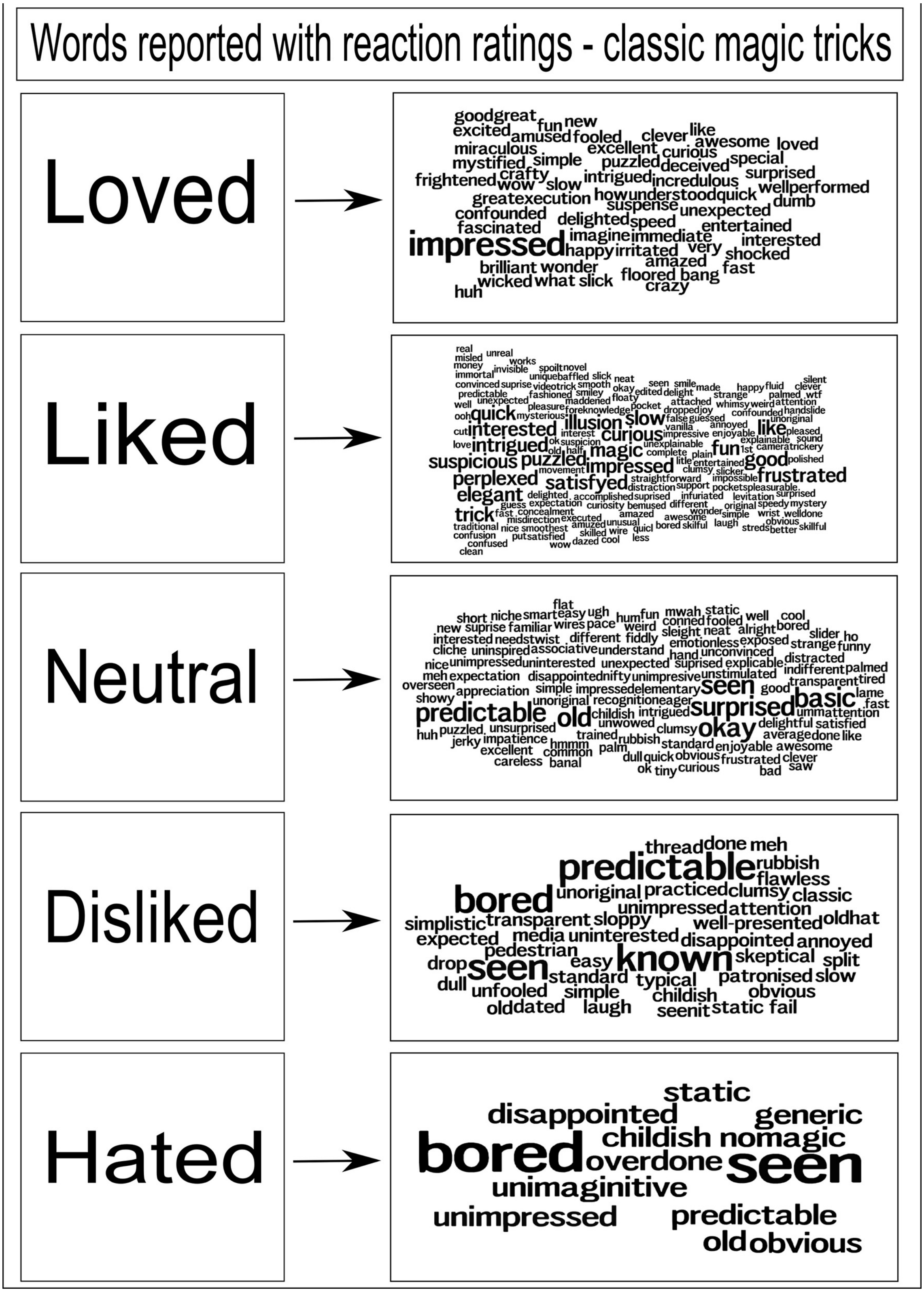

FIGURE 2 | Word clouds representing gathered responses from people shown classic magic tricks. The larger the word, the more often it was reported as a response to a trick. We recorded a participant's rating of a trick, along with their word reactions; each cloud of words shows the words that were recorded for each rating. During development of the evaluation framework, this list was distilled to a core set of words to use. N.B. Initial evaluations, as shown in the section discussing the magical jigsaw puzzle, allowed a greater range of words to be selected.

Table 1 | Summary of psychological data, constraints, and AI technique applied to design each trick.

Trick	Psychological observations	Constraints	AI technique
Jigsaw	1. Threshold of length increase detection for rectangles. 2. Number of jigsaw pieces that can be practically assembled. 3. Number of rectangles easily countable.	1. Physical constraints on jigsaw pieces that make up two viable puzzles. 2. Optimal targets for each of the three psychological components, with upper bounds outside of which solutions are unacceptable: (a) Length increase. (b) Number of jigsaw pieces. (c) Number of rectangles.	1. Genetic Algorithm. 2. Rectangle packer (to generate tilings).
Card trick	1. Likeable cards. 2. Cognitive visibility of mobile phone gimmick prop.	1. Cyclical sequence of cards defined by user specified categories. 2. Min/max depth of generated tree. 3. Positioning of special (e.g., Liked) cards.	1. Simulated Annealing procedure.

and where to position the lugs and gaps on each piece to make viable puzzles. Further, where each rectangle must be positioned so that after rearrangement the desired decrease in the number of rectangles is achieved.

For a human designer, this leads to an intractable combinatorial explosion of possibilities for jigsaw designs. However, GAs are excellent optimizers for such challenges, as shown in Goldberg (1989). GAs are able to perform searches through large, complex problem spaces that contain (undesirable) local optima. The jigsaw is in fact a multi-objective optimization problem; conflicting constraints mean there is not necessarily a single solution where each objective is optimal; a balance may need to be struck.

We used data from our psychophysical experiments as objectives in the GA's fitness function. A range of values for each of the constraints will result in workable, though not optimal, solutions. Other parameters affect the viability of each candidate solution during the design process; for example, a basic requirement is that the pieces of the jigsaw must fit together to form the same basic overall shape, covering the same surface area (i.e., no gaps).

The model, encoded as a binary bit string by the GA, that represents each candidate jigsaw solution consists of:

1. Basic overall shape and size of jigsaw (e.g., NxN square).
2. Number of jigsaw pieces.
3. Shape and size of each piece.
4. Configuration of lugs and gaps on each edge of each piece.
5. Number of whole rectangles on the first jigsaw configuration.
6. Size of rectangles.
7. Co-ordinate positions and orientations of pieces in each of the two jigsaw configurations.
8. Co-ordinate positions and orientations of rectangles on the initial jigsaw.

A discretized co-ordinate system was used for all sizes, positions, and orientations.

The specific constraints used in fitness evaluation are detailed below. Hard constraints (denoted [HARD]) are those that define a viable jigsaw (i.e., a candidate solution that does not meet the hard constraints is not a valid solution; e.g., there may be lugs that do not have a gap to slot into). Optimization constraints (denoted [OPTI]) are those to be minimized or maximized to search for the best, as defined, magic jigsaw:

1. [HARD] Area of first and second jigsaw solution covered by generated pieces. This should cover the same area as the defined shape of the desired solutions, with no gaps.
2. [HARD] Number of pieces that are fully connected by jigsaw lugs in the first and second jigsaw solution. All lugs must connect to a gap. No spare gaps.
3. [OPTI] Number of whole rectangles of the required size on the second jigsaw. Minimize this number (this defines how many rectangles have "vanished").
4. [OPTI] Number of rectangle fragments on the second jigsaw. Minimize this (zero is optimal).
5. [OPTI] Spatial distance of rectangles from configurable points on the jigsaws. Pleasing designs cover the surface of the puzzle more evenly (relevant to the spectator).
6. [OPTI] Total number of jigsaw pieces, scored from a scale mapped from experimental data (relevant to the performer and the spectator). Eight pieces is defined as optimal. Minimize the deviation from this.
7. [OPTI] Total number of rectangles, scored from a scale mapped from experimental data (relevant to the spectator). Minimize this.
8. [OPTI] Rectangle orientation score for each jigsaw, scored from a scale mapped from experimental data (relevant to the spectator). Optimally all rectangles on the first solution are vertical, while all on the second are horizontal.

This type of multi-objective problem needs a specialist GA algorithm; we used a NSGA-II (Deb et al., 2002) derived GA coupled with a rectangle packing algorithm (Lodi et al., 2002). Rectangle packers are used to efficiently pack shapes into containers. We applied the standard NSGA-II algorithm with the constraints outlined above, using the rectangle packer to generate valid candidate puzzles from a given set of basic shapes. The algorithm converges to solutions in less than fifty generations of the GA's iterative process—the number of pieces and number of rectangles increases the complexity. The computation time to design the example featured was approximately 2 min on a desktop PC with an Intel Core i5 processor.

See **Figure 3** for an overview of how the framework was applied to the jigsaw design problem.

With this optimization configuration our automated system is capable of synthesizing the various geometric and perceptual elements we have discussed to design novel jigsaw tricks to flexible specifications.

2.5. JIGSAW RESULTS

By way of illustration we have chosen one of many outputs possible from the jigsaw design system. The jigsaw created by the system is an eight piece interlocking puzzle showing twelve rectangles on its surface; after rearranging the pieces the surface displays only ten rectangles. Here we show a design themed around Egyptian mythology, where the rectangles have become "spells" cast between pairs of hands. See **Figure 4**. During the puzzle's reconstruction, the remaining rectangles are larger than those in the original image but an observer should not notice this length increase.

Using the method of constant stimuli, described by Laming and Laming (1992), we determined the absolute threshold of the amount of change in the length of rectangles able to be perceived. This threshold is defined as the amount of change in length that participants are able to accurately report for more than 50% of stimuli.

Participants were shown pairs of sequentially presented images, separated by a blank screen. Each pair consisted of an image of six rectangles of either all vertical, all horizontal or mixed orientations, shown for one and a half seconds, followed by a blank screen for 1 s, followed by a second image of six rectangles also of either all vertical, all horizontal or mixed orientations. For each image, all rectangles were randomly positioned on screen with none overlapping. The group of rectangles in the second image would either all be the same length as all those in the first image, or would all increase by a certain percentage. The increase ranged from 0 to 30%, in 5% increments. A pair depicting a certain percentage length increase was shown to the participant ten times; the pairings were displayed with a random order of presentation. The participants were asked only to determine if the lengths of the second set of rectangles had increased in comparison with the rectangles in the first image; a yes or no. The threshold is derived from regression fitting a line to the detection of increase data.

As anticipated, the vertical-horizontal illusion is evident; the largest absolute threshold value of 21.1% size increase was in effect when subjects were shown an image containing all vertical rectangles, followed by an image containing all horizontal rectangles (denoted VH). The complete set of combinations of orientation resulted in the following absolute thresholds (H = Horizontal, V = Vertical, M = Mixed): VH (21.1%), VM (17.0%), MH (16.3%), VV (15.8%), HV (15.3%), HM (14.0%), HH (13.0%), MV (10.1%), MM (9.5%).

These results on length increase echo recent findings from Harrison et al. (2004) on perceptible size increase in the links in an animated articulated figure when attention is not fully

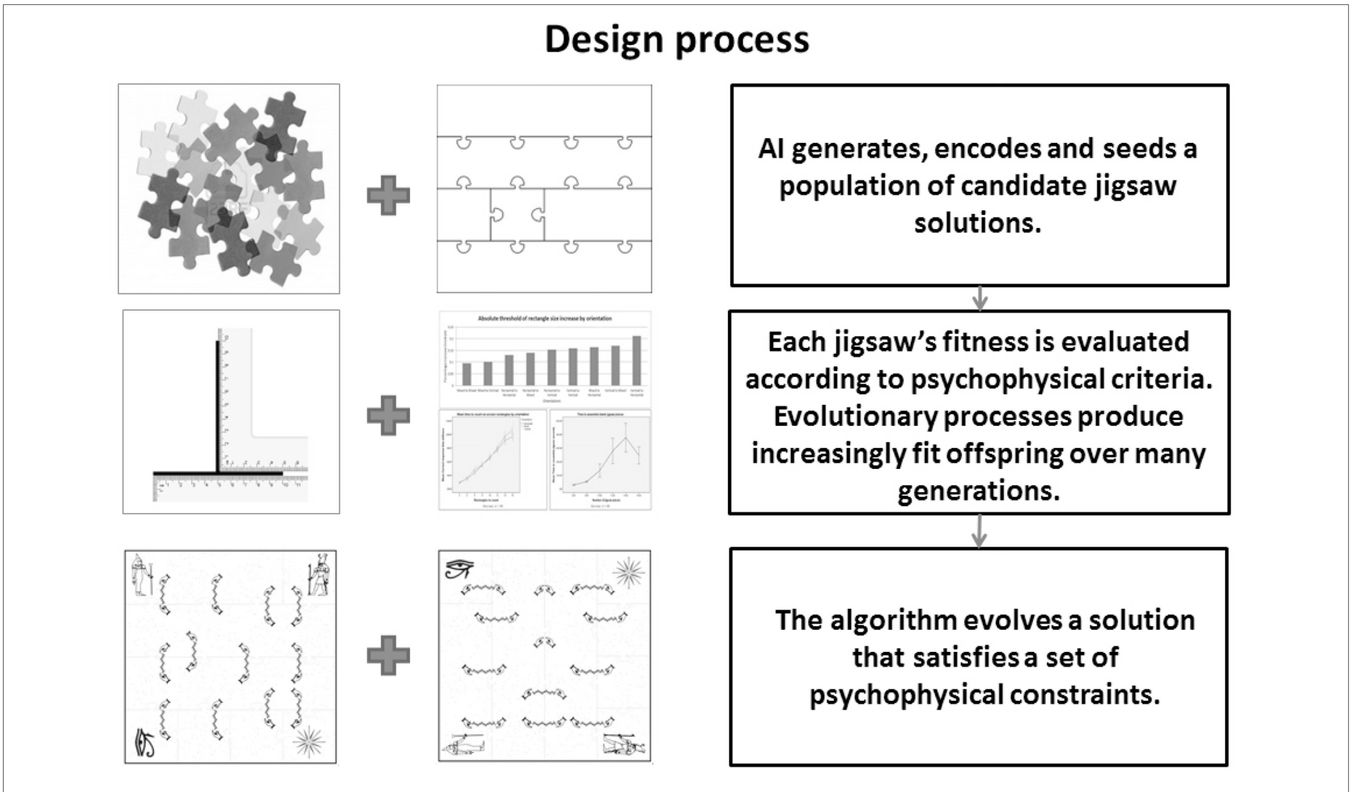

FIGURE 3 | The Genetic Algorithm driven jigsaw design process. Geometric and empirically derived psychological constraints are used by a GA to design a perceptually compelling jigsaw magic trick.

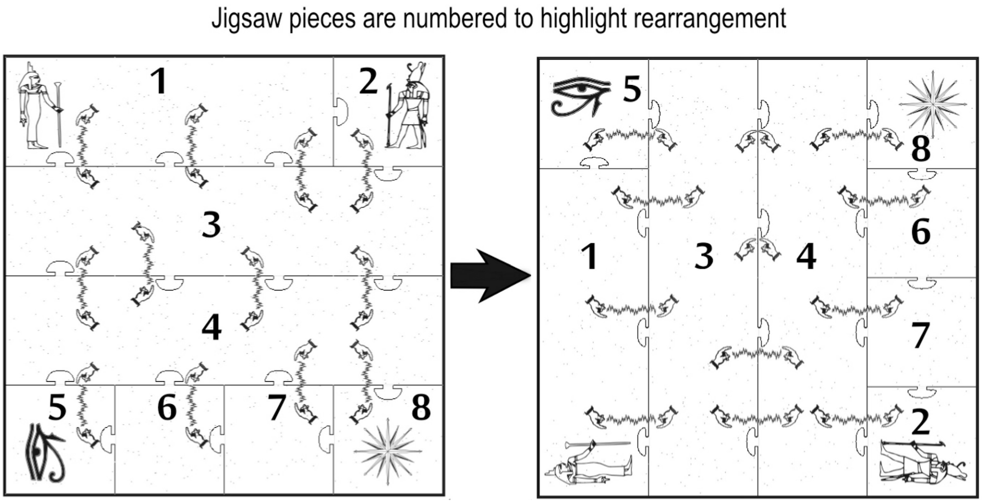

FIGURE 4 | The magic jigsaw. The first configuration, shown on the left, depicts 12 "spells," two of which subsequently seem to vanish in the second configuration, shown on the right. Each "spell" in the second configuration has grown imperceptibly in length. The numbers on the pieces have been added here to help show where each piece starts and ends in each configuration; the real jigsaw as sold is not numbered.

focussed on the relevant links; in this scenario they also report that size increases of over 20% can go unnoticed. This may point to a general psychological effect: that higher thresholds of size change perception may be present where attention is not fully focussed.

The observer of the trick is required to count the number of rectangles on the puzzle; we investigated the amount of cognitive load this produced. Previous studies, see Mandler and Shebo (1982), suggest a response time of 250–350 ms per item counted above the subitizing range (the number of items that are able to be counted in a negligible amount of time without much cognitive effort; generally thought to be up to 4 items). We performed our own online experiment to determine the rate at which subjects ($N = 49$) were able to count rectangles on a screen, see **Figure 5**. During our experiment, it was necessary for the participants to find and press an on-screen button, indicating the numbers of rectangles they had counted, and another button to submit their count. From the data, it is estimated that this process takes approximately 2800 ms. Adjusting our data for this, and calculating a per item response time, it appears that as the number of rectangles increase, the underlying time increase per rectangle also increases slightly; this may be explained by participants being more likely to lose count while viewing more rectangles, and therefore having to restart. Further, for larger numbers, any time taken by a participant to check the count is likely higher. Times were recorded only for correct counts. From our data, counting the rectangles takes between approximately 160 ms per rectangle (for 4 rectangles) to approximately 470 ms per rectangle (for 16 rectangles).

A trick with too many pieces may take the performer too long to assemble, and be prone to error. After a trial study ($N = 5$), it appears that the time taken for subjects to assemble blank jigsaw pieces into a square shape becomes highly variable beyond eight pieces. See **Figure 6**. This gives us another constraint we include in the optimization.

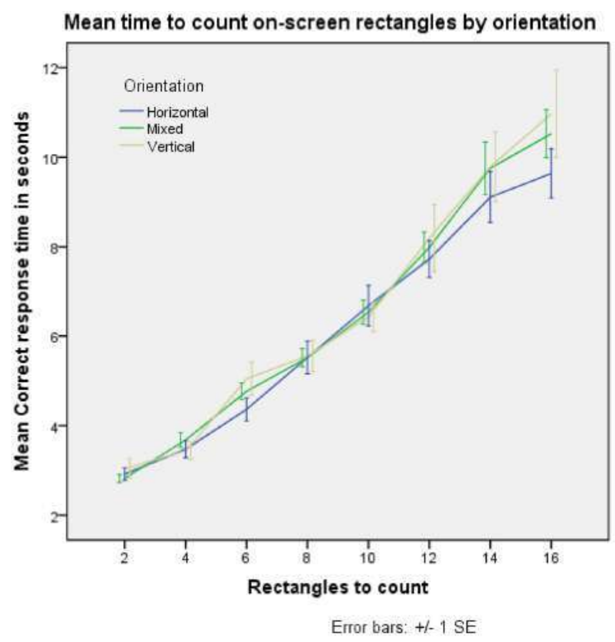

FIGURE 5 | Increasing the number of rectangles on screen for a participant to count linearly increases the time taken to accurately count them.

We empirically evaluated the magical effect of the jigsaw ($N = 100$) and compared the ratings from those gathered for the classic magic tricks ($N = 96$). Unfortunately, the idea to record participant's general ratings of magic came only after the classic magic trick experiment had been run, therefore it is only possible to report unadjusted ratings for these tricks (i.e., the ratings are not calibrated by a participant's rating of magic in general).

The participants for the trick evaluations were recruited from university mailing lists, and from disseminating details of the experiment on twitter. To simplify the questionnaire, we did not ask for age, gender or country of origin data from the participants. We showed participants videos of each trick, and asked them to rate their enjoyment of the trick on the scale [Hated (=0) through Loved (=4)]; for the jigsaw trick experiment we also asked the participant how much they enjoyed magic generally, using the same scale.

Different versions of the jigsaw trick were produced, to investigate the effect of narrative. The jigsaw trick videos shown were: (1) The full jigsaw trick, with a narrative describing the events shown, which frames the trick in a mythological story based in ancient Egypt; the vanishing rectangles are "spells." (2) The same trick, but with no narrative describing the events shown; the jigsaw is simply rearranged on screen in a mechanical way, with a finger pointing to the "spells." (3) The jigsaw is rearranged on screen, but no "spells" vanish, therefore nothing magical has occurred; a narrative is supplied, very similar to the Egyptian themed mythological story supplied previously, but with a different ending that does not reference anything vanishing. (4) The jigsaw is rearranged on screen, but no "spells" vanish, therefore nothing magical has occurred; no narrative is supplied.

FIGURE 6 | Increasing the number of pieces of a blank jigsaw to assemble as a task seems to become non-trivial for the participants for jigsaws with greater than 8 pieces.

The classic tricks shown were: (1) A skilled magician showing a cup vanishing, just before being smashed; no sounds or patter. (2) A skilled magician showing a piece of cloth vanishing; no sounds or patter. (3) A skilled magician showing a piece of paper floating in the air; no sounds or patter. (4) A skilled magician showing a cigarette being broken in two, then magically repaired; no sounds or patter. (5) A skilled magician showing a giant coin suddenly appearing; no sounds or patter.

For ratings of each trick, see **Figures 7**, **8**. The jigsaw trick with a full narrative scores comparably with classic tricks (though they are presented without a narrative). The calibrated values emphasize weak ratings. The difference between the general rating and the trick rating, for the full jigsaw trick with a narrative, is 0.24. The difference between the other video ratings and their associated general ratings is much higher: jigsaw, no trick, no narrative (0.9); jigsaw, no trick, with narrative (0.84); jigsaw, with trick, no narrative (0.67).

It is interesting to note the role that introducing a narrative to the jigsaw trick has on its enjoyment rating; the worst score comes from the version where nothing magical occurs, and no narrative is supplied (unsurprisingly). Introducing a narrative to this version improves the enjoyment of the experience; however, the version showing a magical effect, but with no attached narrative, scores better (using the difference metric). The implication is that if the viewer is expecting a magic trick and nothing magical happens, this has a detrimental impact on their enjoyment, even if a

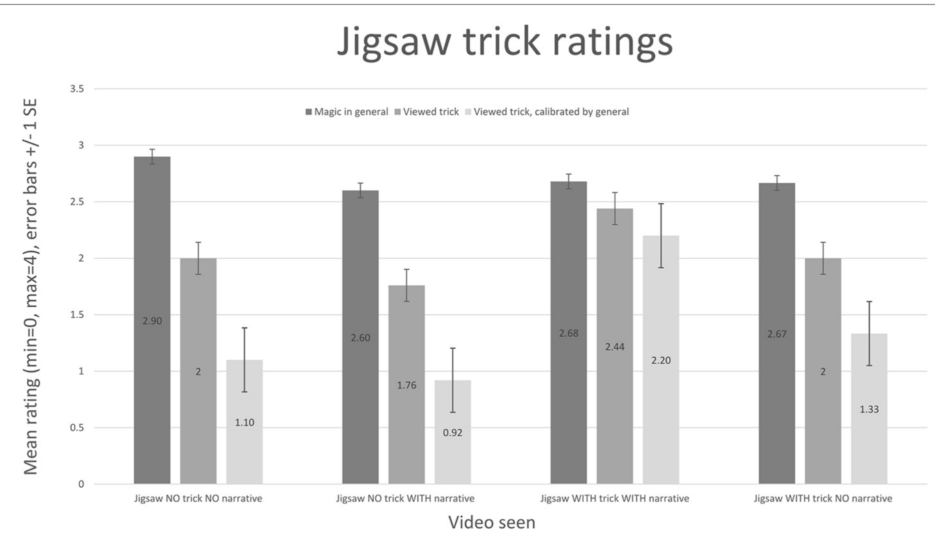

FIGURE 7 | The jigsaw enjoyment ratings are shown, along with the reported enjoyment of magic in general by the viewers of each video. The third rating is a calibrated value, based on the formula $CalibratedRating = TrickRating + (TrickRating - GeneralRating)$. The jigsaw trick with a full narrative scores comparably with classic tricks. The calibrated values emphasize weak ratings. The difference between the general rating and the trick rating, for the full jigsaw trick, is 0.24.

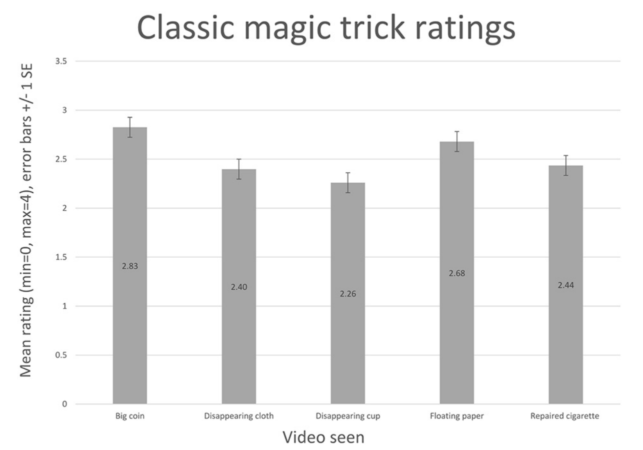

FIGURE 8 | The enjoyment ratings for classic magic tricks are shown.

story is told. Narrative, however, does play a large role: the highest scoring video supplies both a narrative and a magical effect. While it might be expected that the version that shows a magical effect but has no narrative would score similarly to the classic effects (also presented without narrative), it should be noted that the jigsaw trick arguably relies more heavily on the narrative to explain what is occurring than the other tricks—crucially to highlight that something has vanished—the classic effects are all easy to understand without an accompanying narrative.

Participants who viewed the jigsaw tricks were also asked to select a word to describe their reaction to the tricks they had witnessed. This evaluation was performed with a longer list of words than the distilled list we use for our, later developed, standard evaluation; the longer list was selected from words describing the classic magic tricks. Not all participants (from $N = 100$) chose to select a word to describe their reaction. What follows is a breakdown of the number of times a word was reported by a participant after viewing the full jigsaw trick (with vanishing "spells" and a narrative). Most responses are positive, or express a sense of something unexplainable having occurred: Bored (1), Clever (5), Clumsy (1), Confused (3), Cool (4), Disappointed (2), Dull (5), Easy (1), How? (6), Interested (5), Predictable (2), Puzzled (5), Rubbish (1), Skeptical (3), Simple (4), Slick (2), Surprised (1), Unexpected (2), Wonder (1).

In a final qualitative study ($N = 7$), when asked to describe how the trick worked, or any suspicious moments arising, four participants reported having no idea how the trick worked, two made accurate guesses but were hesitant, while the remaining participant explained the trick as an optical illusion.

A physical version of the jigsaw was productized as a wooden puzzle, laser cut and printed, and packaged with instructions for sale. The jigsaw was included as part of the inventory in a reputable and well established magic shop in London, and the two runs of the product sold out (30 units). The cost for the jigsaw was set in conjunction with the shop owner, an experienced salesman of magic tricks, who was able to provide what, in his professional opinion was a competitive price compared to other similar tricks. This is direct evidence of the efficacy of the methods presented in this paper to create novel, practical, and saleable magic effects. These sales are considered as evaluation metrics in a research project rather than as a commercial product, but it is worth noting the shop requested further stocks.

2.6. COMBINATORIAL CARDS

We then applied our framework to the creation of a mind reading card trick. Using the conceptual framework outlined, we created a flexible automated system capable of searching for user specified combinatorial structures in decks of regular playing cards that can be used for magic tricks, taking into account cards that would be most likely selected by an observer.

The use by magicians of cyclical combinatorial structures in mind reading effects, for example De Bruijn sequences—cyclical sequences of objects in which each unique subsequence of a given length appears once—have been extensively investigated by Chung et al. (1992) and Diaconis and Graham (2012). There are well known computational algorithms capable of generating particular types of sequences, detailed in Knuth (1997), Fredricksen (1982) and Stein (1961); here we build on these to devise an algorithm able to produce cyclically ordered decks of cards to flexible specifications, for use in magic tricks.

Finding cyclical structures can be a difficult task for a human trick designer: the number of permutations of a deck of 52 standard playing cards is a huge 52 factorial (8×10^{67}). A cyclic sequence of cards is of benefit to a magician during performance, as cutting a deck of cards allows a false sense that the cards have been shuffled (see Hugard and Braue, 1974 for extensive discussion of card shuffling techniques), without disrupting the cyclical sequence.

The cognitive characteristics of playing cards have been previously studied by Fisher (1928). Recent work by Olson et al. (2012) shows that certain cards tend to be liked in preference to others. For example, the picture cards (Jack, Queen, King) and Aces are preferred, along with the Heart and Spade suits.

To encode the card characteristics in a form suitable for our framework we allocated individual playing cards as belonging to a number of categories depending on their features—for example the King of Hearts belongs to the categories: Heart, Red, Picture Card, High Value. We define the Liked (and Not Liked) category by using the Likeability index, an ordered ranking of how well liked each playing card in a standard deck is when compared to other cards, described by Olson et al. (2012).

In many mind reading effects involving playing cards a magician will dispense cards from a pre-ordered deck and subsequently ask a number of vague innocuous sounding questions to covertly recover the information needed to reveal the card identity, for example: "are you thinking of a red card?". This process is referred to by magicians as fishing (discussed in detail in Aronson, 1990), magically arriving at a specific, supposedly secret, card while not making it look like they are asking too specific a set of questions. To elicit a magical effect the questions must be perceived as vague and almost inconsequential. The varied approaches to the bank of fishing questions often differentiate the quality and impact of these effects. A classic example is Larson and Wright's Suitability, described in Diaconis and Graham (2012):

a 52 card deck is ordered in such a way that dealing three consecutive cards from any position in the deck yields a unique set of three Suits. Other orderings can be found such that consecutive cards may be differentiated by multiple categories; for example, Suits, Color, and Picture Cards. A suitable set of fishing questions then need to be deployed to recover the actual identity.

These kinds of orderings of cards characteristics may be represented as a computational tree structure, defined in Knuth (1997), a category at each level determining which tuples (sequences) of cards are placed at which node (branching points), ending in leaf nodes that contain only one tuple of cards of the requisite length. The trick Suitability's tree has only one level beyond the root (the start node), thus requiring only one fishing question per card (which suit it belongs to).

Generally, the shorter the fishing trip of questions is, the more magical the effect. Simon Aronson's trick Simon-Eyes, described in Aronson (1990), can also be analyzed as a tree structure; Simon-Eyes' tree has multiple levels. The pay off is that only two cards need be dispensed, and the questions are never met with two negative responses—for example, if the route through the tree leads to an enquiry suggesting one of the cards is low valued, then at least one of the two cards will be low valued. This is a powerful technique for a magician to deploy, as it builds confidence for the observer that the magician is performing something other than simple question and answer sessions.

In the context of our framework we wish to encode a tree based structure representing a cyclically ordered set of playing cards that deconstructs at each level of the tree into a set of cards distinguished by category. Additionally at each leaf node there must be only one set of cards of a given length and all cards in the deck must be in at least one leaf node. See **Figure 9** for a simple example of this type of structure as used in a magic trick.

Different orderings of cards result in different tree structures of variable quality, depending on their maximum and average depths (related directly to the number of questions required to traverse from the root to a leaf node). The magical potential of an ordering that also relies on the Likeability of certain cards introduces an interesting probabilistic perspective—people are more likely to choose well liked cards in a presented set, but this choice is not guaranteed. However, having those Liked cards in otherwise standard tuples should bias the likelihood of their selection, which can lead to a reduction in fishing questions needed. Therefore, the positioning of Liked cards throughout the cyclic deck becomes an additional constraint to optimize.

Finding and evaluating appropriate cyclic orderings is an extremely time consuming process for a human; a task arguably better handled by the search and optimization engine component of our framework. We chose Simulated Annealing (SA), a probabilistic search technique based on the metallurgical process of annealing, as the most appropriate technique available, as it has been shown to perform well in related search tasks such as the 8-Queens problem described in Russell and Norvig (2009). In computing, SA algorithms combine hill climbing and random walks to effectively traverse discrete search spaces in search of optimal solutions, and prove suitable for the discovery of cycles and Liked cards distributions. The categories that differentiate

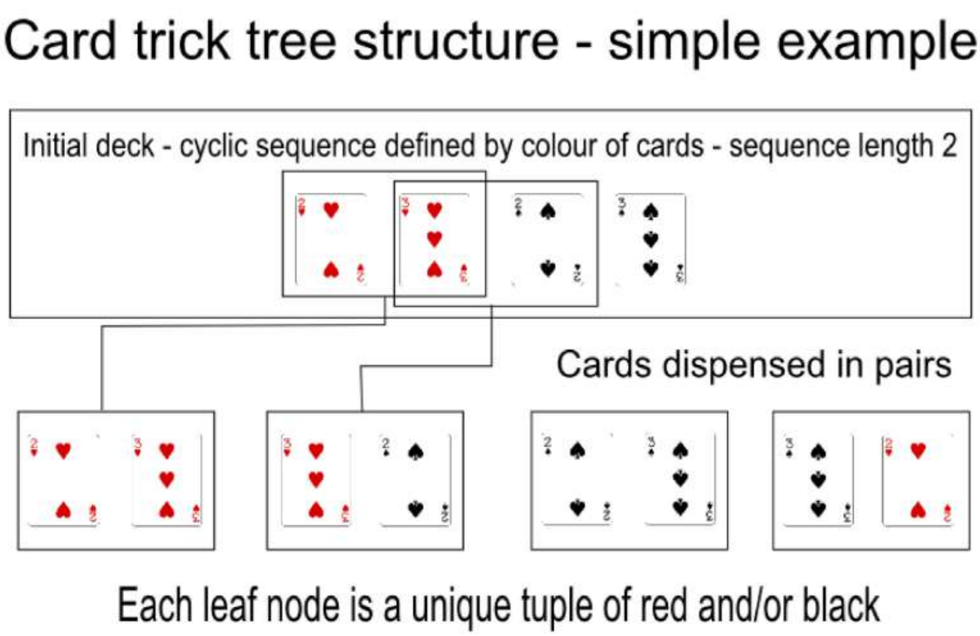

FIGURE 9 | A simple example of how a deck can be cyclically ordered, breaking down into tuples of length two, within a four card deck. This is a very simple tree with only one level below the root. Each pair of cards dealt from the deck will be a unique sequence of red and black cards. A magician can dispense two consecutive cards from the deck to a spectator, for example the 3♡ and the 2♠, then fish from the spectator the color of each card (in this case Red then Black). Finally, the magician can ask the spectator to select one of the cards. If the spectator selects the first card, the magician knows that it must be the 3♡.

playing cards may be combined within a single deck, at different levels of the tree. Our approach allows for the flexible creation of decks to specification, allowing a performer to concentrate on designing an effective presentation, the importance of which is emphasized in Ortiz (1994).

The basic function of the SA procedure is to operate on a list of playing cards, swapping card positions to re-order the deck over many iterations, in order to maximize the longest consecutive sequence of cards that contains non-repeating subsequences of a specified length that uniquely identify themselves in the deck by the order of their categories (in the context of which level in the tree structure they are). A fifty two card cycle is the theoretical maximum for a fifty two card deck. As there may be more than one valid cycle for each set of categories selected, additional heuristics may be used to guide specific (not categorical) card placements, depending on the type of deck sought.

We employed our system, see **Figure 10**, to create and test a number of different decks, each with their own set of properties (categories, number of cards dispensed, etc).

Once a particular ordering of cards has been specified and found by the system, it must be deployed in performance (see **Figure 11**). Tricks featuring ordered decks of cards generally require memorization, and are usually limited by the mnemonic properties of the sequence. Cue cards as memory aids are common in commercial card tricks, for example the Simon-Eyes effect described in Aronson (1990). Human assistants or confederates can be deployed during such tricks, particularly if the method relies on some mathematical principle that requires information to be covertly available to the performer in some way; see Kleber and Vakil (2002), Simonson and Holm (2002) and Lee (1950b) for examples. The constraint on memorable orders can be lifted by using a digital assistant: in our case a mobile phone application that serves as both a cognitive aid for the performer of the type

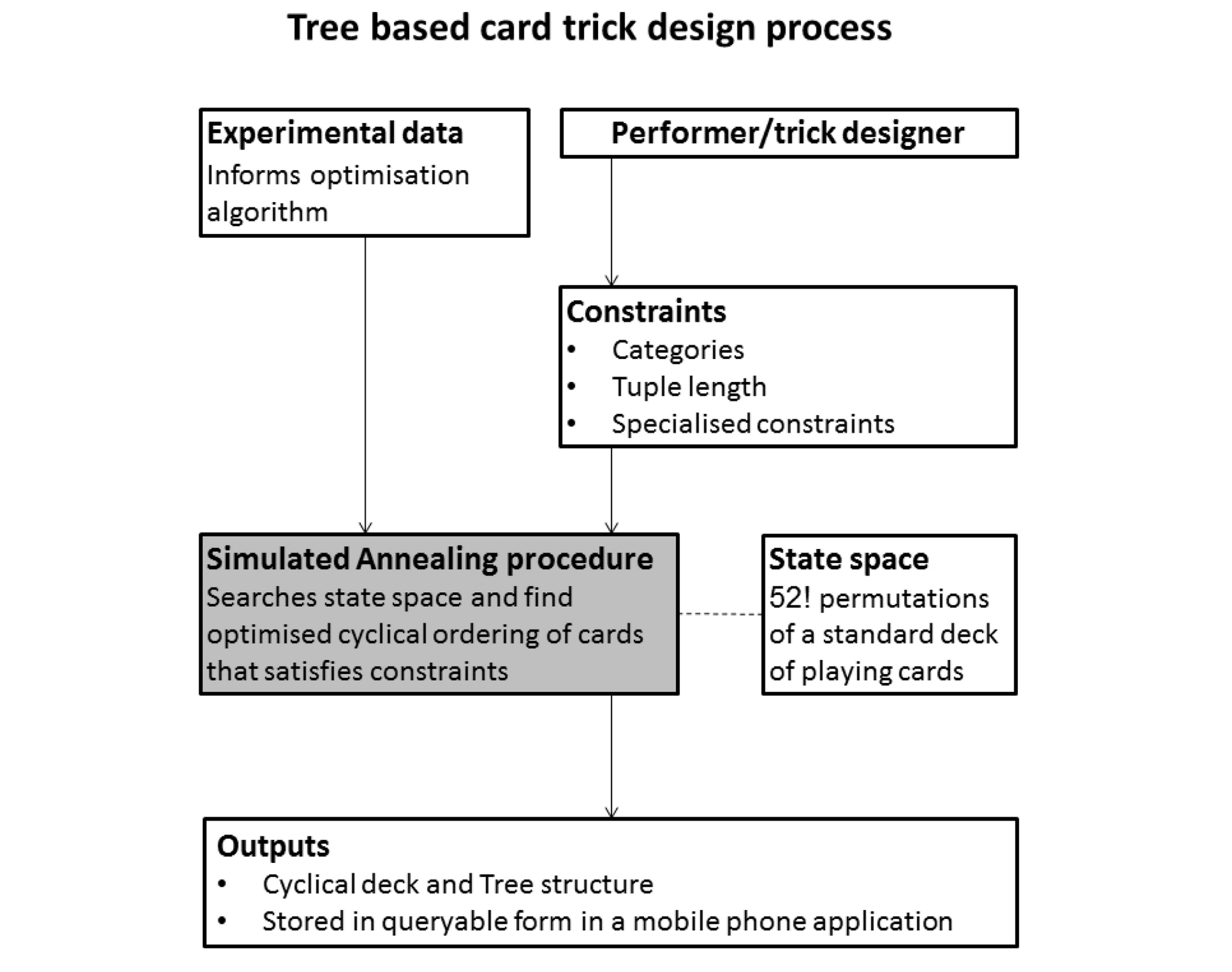

FIGURE 10 | The Simulated Annealing driven card trick design process. Mathematical constraints about cyclical orderings of cards are combined with empirically derived psychological constraints about the likeability of certain playing cards by a SA algorithm that outputs an optimal deck according to operator specified psychological heuristics.

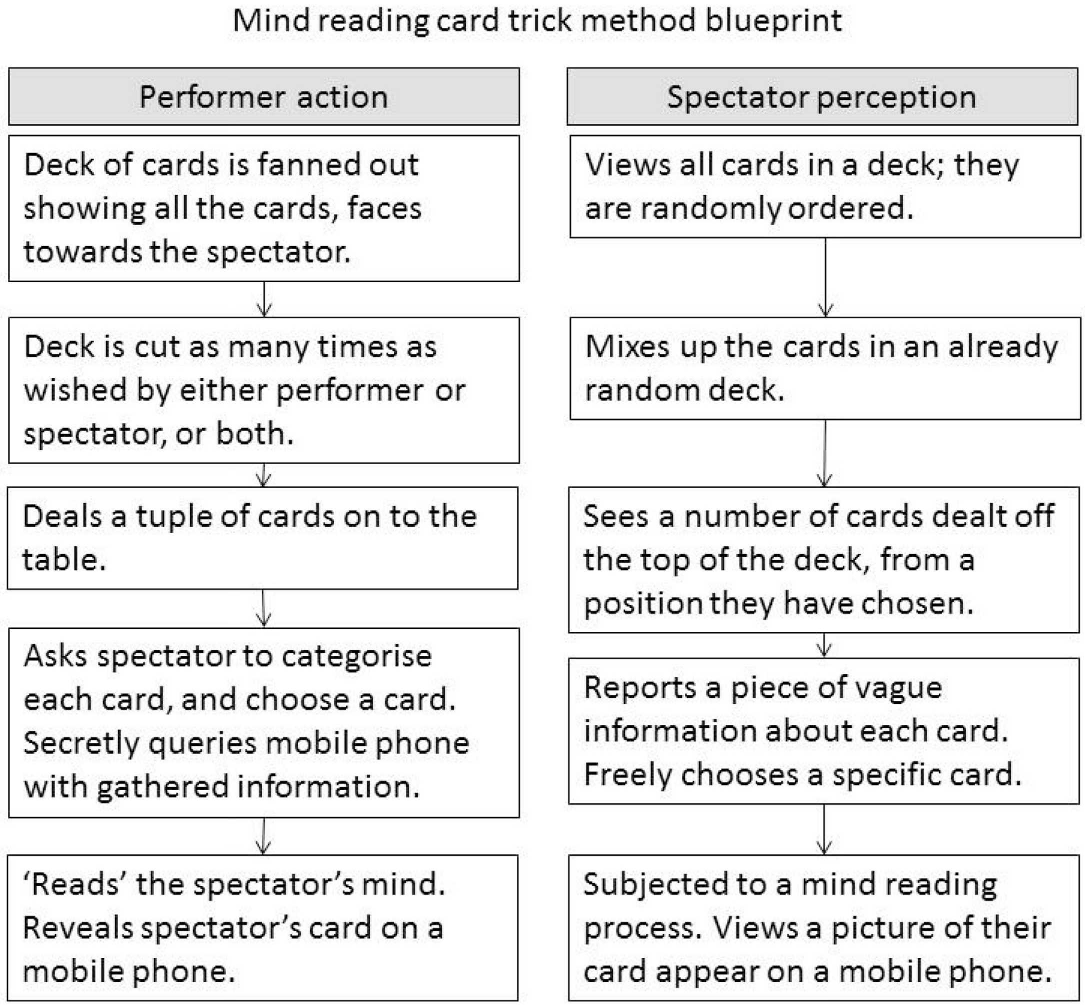

FIGURE 11 | This shows how the card trick can be performed, showing at each stage what the magician is doing, and what the audience is experiencing.

discussed in Dror and Harnad (2008); a queryable memory bank gimmick; and as a display to reveal the selected playing cards. The presence of the mobile phone in the trick could arouse suspicions in a spectator, specifically (and correctly) that the phone was being used as a queryable memory into which the results of the fishing questions were being fed to recover the card selection identity. To help disguise this process we implemented a faked passcode screen, which enables the magician to pass information to the app under the guise of unlocking the phone.

Further, we undertook experiments to gather data about which cards are most liked when presented in groups of four. Using this data as constraints in the SA search system, we also optimized a cyclical deck consisting of sequences of four cards arranged such that one and only one Liked card would appear in each tuple. During the trick, having identified the color of the four dealt cards, a spectator is asked to select their most liked card. Their card is revealed to them in the usual manner; however, it may take the performer up to four attempts to find the correct card, with an increasing probability of success at each stage but with clearly reducing magical impact. This principled probabilistic extension to the standard cyclic deck, which can reveal the selected card with minimal fishing but carries quantifiable risk, represents a novel element in the design of such tricks.

2.7. CARD TRICK TREE TRAVERSAL RESULTS

To test the optimized decks produced by our system, we tasked it with finding a deck that could be used in an existing trick. We used Simon Aronson's Simon-Eyes effect, in Aronson (1990), for comparison. On average, in Aronson's trick, 4.04 questions will need to be asked before the magician knows the suit and value of the two dispensed cards. Using our SA procedure, a deck with a different set of categories has been found that, on average, will require 3.85 questions. Our deck will more frequently require one fewer question to arrive at the final two cards revealed by the magician. Both decks require a minimum of three questions, and a maximum of five. Aronson's ingenious deck was designed by him to be easily memorable, though Aronson does recommend the use of a cue card. In our effect we use a gimmicked prop, a mobile phone app, to traverse the tree structure.

2.8. THE PROBABILISTIC DECK; MAGIC AND PROBABILITY

To test and optimize the various properties of our proposed probabilistic trick, based on the Liked category, we initially used the algorithm to construct a deck that had two categories, and a tuple length of four (i.e., four cards are dispensed). The categories used were Red, and Liked. Cards are described using the following key:

[*A* : *Ace*, *K* : *King*, *Q* : *Queen*, *J* : *Jack*, ♣ : *Club*, ◇ : *Diamond*, ♡ : *Heart*, ♠ : *Spade*]

Any four cards dealt from the deck will result in just one Liked card being dispensed. This should be the most likely card within that tuple for a spectator to pick (if carefully cued by the performer to select the card they like the most).

Olson et al. (2012) performed experiments showing people two cards at a time to determine the most liked card in each pair; we instead ran tests showing people four cards at a time, to match the setup of the trick; we ranked the cards based on our results, along with Olson's general results about most liked cards (Olson's conclusions are drawn from a much larger data set than ours, so we believe a combination of the results is a balanced approach to deriving something meaningful that can be used in a trick): "People like: Hearts, Spades, Aces, Face cards" Olson et al. (2012).

The 13 cards that made up our Liked category were, in rank order:

A♡, *A*♠, *K*♡, *Q*♡, *J*♡, *K*♠, 10♡, *Q*♠, *J*♠, *A*◇, *K*◇, *A*♣, *K*♣

We configured the optimization engine heuristic rule set to maximize the likelihood of a spectator selecting the predicted liked card in a given tuple of cards. See **Table 2**.

The search process found the following optimized deck:

3♡, *Q*♡, *J*♣, 2♠, 6♡, *A*♣, 4♣, 5♠, 7♣, 10♡, 3♠, 2♣, 9♣, *K*♠, 4♠, 6◇, *Q*♣, *K*♡, 10◇, 5◇, 8♣, *Q*♠, 2♡, 3◇, 5♣, *A*◇, 8♠, *J*◇, 10♣, *K*♣, 6♠, 3♣, 2◇, *J*♡, 7♡, 4♡, 8◇, *A*♡, 8♡, 10♠, 9♡, *A*♠, *Q*◇, 7♠, 4◇, *K*◇, 6♣, 7◇, 9◇, *J*♠, 9♠, 5♡

We performed an online experiment with this deck sequence ($N = 69$), asking participants to select their most liked card in each tuple of four from the fifty two tuples in the cyclical deck. The participant group featured 23 males and 46 females. 35 respondents were from America, 26 from the UK, 2 from Canada, and 1 each from Australia, China, Finland, Libya, Lithuania, and Poland. Ages were approximately evenly distributed from 18 to 72, with a disproportionate number reporting 18 as their age (also the minimum age required for participation in the study). There was a good match between the predicted Liked card in any given tuple and the actual most liked card. The most liked card did not match the predicted most liked card for only one tuple: Eight of spades, Jack of diamonds (actual most liked card), Ten of clubs, King of clubs (predicted most liked). There is no obvious explanation for this, though the most likely is that the Jack of Diamonds is a relatively high ranking card appearing in the middle of the four cards, while the King of Clubs, in this tuple, appears at the edge.

Table 2 | Heuristics specified for the SA procedure, designed to maximize the likelihood of a spectator selecting the predicted liked card in a given tuple of cards.

Heuristic	Purpose
Maximize the distance between the rank in the Likeability index of the Liked card in the tuple, and the highest rank from the other cards	High cards are strongly Liked. Two high cards in a set would make it less likely that one or the other would be selected as a Liked card. The predicted Liked card should be the highest ranking card in the set. The next highest ranking card should be as lowly ranked as possible.
Minimize the number of hearts in any one tuple	Hearts are strongly Liked. A predicted Liked card may not always be a Heart. Minimizing the number of Hearts in a tuple makes clashes with predicted Liked cards that are not Hearts less likely.
For Liked Clubs (i.e., the Ace of Clubs and the King of Clubs) minimize the number of red cards in the same tuple	Red cards are more likely to be Liked than black cards. To maximize the chances of a predicted Liked Club being selected by a spectator, there should ideally only be other black cards in the tuple.

2.9. THE PROBABILITY DECK AND INVISIBLE TECHNOLOGY

We evaluated the magical impact of the probability deck and the feasibility of using a mobile phone gimmick for this trick by performing an experiment at a public event; the trick was performed for random spectators at a science festival ($N = 116$).

The average (mean) rating given to the trick was 3.28 (out of 4). The average (mean) rating given to participant's general view of magic was 3.53. The calibrated average (mean) was 3.04. It is interesting to note that this trick scored higher than both the magic jigsaw and the classic tricks discussed earlier. However, the participant's general rating of magic was also higher. This can possibly be attributed to the fact that the card trick was performed in a live setting, rather than in an online experiment, and that people choosing to sit down to see a trick were more likely to enjoy magic. The online participants may have been a more varied group (in terms of enjoying magic). The difference between the general rating and the card trick rating is 0.25 (this is similar to the jigsaw's difference rating of 0.24).

The words chosen by the participants, from our distilled list, to describe the card trick were overwhelmingly favorable. Participants were asked to circle at least one word from the list; some circled more. Of 164 words reported, 36 were "Surprised," 47 "Amazed," and 61 "Impressed."

The free writing component of the evaluation allows participants to describe how the trick works, and to report any suspicious moments during performance. No participants were able to fully describe the operation of the trick. Around 10%

guessed that the method relied on the ratio of red and black cards on the table. During the performance of the trick, the magician passes the information gleaned from the spectator (about the color of the cards dispensed from the deck, and their most liked card) to the app using a faked passcode screen into which a sequence of numbers representing the information is passed. Perhaps surprisingly, no participants mentioned the faked passcode screen as a possible medium of interaction between magician and phone.

During this probabilistic version of the trick it is inevitable that sometimes the wrong card will appear on the phone initially; it may take up to four attempts to reveal the correct card. Surprisingly, this had little effect on the enjoyment rating of the trick, though on the odd occasion that the full four attempts were taken, there was a reduction in the rating of enjoyment score reported. Otherwise, it is relatively easy for the performer to explain away the failures. For example, the magician might explain away a failure by saying that very advanced mind reading technology is being used, therefore naturally sometimes there are errors, and that they should try again, but this time the spectator must make a more concerted effort to visualize their card in their mind.

The mobile phone app we created that enables the presentation of the trick using various different decks with differing properties was successfully sold to magicians via a reputable magic shop in London, UK, at a price comparable to other apps. The app has recently been released on the Google Play store, and at the time of writing has sold a small number of copies, without yet being widely publicized. Two reviews have been posted, both awarding five stars out of five, along with a review comment from a magician: "Absolutely Brilliant."

3. DISCUSSION

We have introduced a general framework approach to designing and evaluating new magic tricks. The framework describes a method to integrate empirical data about human perception and cognition with artificial intelligence algorithms to create effects previously challenging for a human trick designer to produce, and allowing the inclusion of appropriate probabilistic techniques to enhance impact. The framework also provides a practical, principled way to objectively evaluate the output of the creation process. We note the success with which the tricks were accepted for inclusion in the inventory and sold to magicians in a reputable London magic shop. A copy of the jigsaw product is also archived in the library of the Magic Circle in London. We have shown two case studies that adapted the framework to specific types of trick, and successfully produced novel effects that were proven to be effective in real life scenarios. We believe this general approach to trick design is highly flexible and applicable to many different types of trick. There are many obvious avenues of further investigation, notably stage magic where the perpetual effects of shading or unusual body position may be included, large scale tricks on social media platforms, and close up magic that relies on particular attributes of the human visual system, for example through the modeling of misdirection or sensory illusions. There would appear to be a body of future research that could be fruitfully pursued investigating the human brain's apparent expectations of events, and coupling these observations with recent advances in probabilistic graphical methods in computer science, for example Bayesian Networks, to both produce tricks but also to test our understanding of the psychological processes. Applying these types of methods to the card trick presented here, or similar, could lead to new ways to create effective magic, and explore the cognitive mechanisms underpinning the spectator's experience. We have also shown that effects with significant magical impact can be implemented on computing devices; it might be expected that sophisticated technology would be incapable of producing a magical effect, as any seemingly impossible events could be easily attributable to the computer. Our investigations with the mobile phone card trick have shown that this is not necessarily the case; on the contrary, a new and wide range of possible effects intertwining the real and the virtual may be available to the modern magician with the right tools.

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