The Vanishing Ball Illusion: A new perspective on the perception of dynamic events

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ABSTRACT

Our perceptual experience is largely based on prediction, and as such can be influenced by knowledge of forthcoming events. This susceptibility is commonly exploited by magicians. In the Vanishing Ball Illusion, for example, a magician tosses a ball in the air a few times and then pretends to throw the ball again, whilst secretly concealing it in his hand. Most people claim to see the ball moving upwards and then vanishing, even though it did not leave the magician's hand (Kuhn & Land, 2006; Triplett, 1900). But what exactly can such illusions tell us? We investigated here whether seeing a real action before the pretend one was necessary for the Vanishing Ball Illusion. Participants either saw a real action immediately before the fake one, or only a fake action. Nearly one third of participants experienced the illusion with the fake action alone, while seeing the real action beforehand enhanced this effect even further. Our results therefore suggest that perceptual experience relies both on long-term knowledge of what an action should look like, as well as exemplars from the immediate past. In addition, whilst there was a forward displacement of perceived location in perceptual experience, this was not found for oculomotor responses, consistent with the proposal that two separate systems are involved in visual perception.

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1. Introduction

Our ability to respond rapidly to changes in our surroundings relies on anticipating and predicting future events. This occurs at all levels of visual perception. In its simplest form, prediction is needed to compensate for delays caused by the propagation and processing of neural signals (Cavanagh, 1997). It is also needed for anticipating the movements of various objects in the environment, both animate and inanimate (Hawkins, 2004). And at a higher level yet, social interactions often require us to predict what other people will do (Frith & Frith, 2006). This increased recognition of the importance of prediction in perception coincides with the recent development of models in which high-level knowledge modulates perceptual processing via feedback connections (Clark, 2013; Friston & Kiebel, 2009; Kilner, Friston, & Frith, 2007). In general, then, evidence is converging that much—if not most—of our conscious experience reflects prediction rather than the actual state of the world (Changizi, 2009; Nijhawan, 2008).

The involvement of prediction can be seen in a variety of phenomena involving the perception of dynamic events. For example, *representational momentum* shows that people generally misremember the disappearance point of a moving object along its trajectory (Freyd & Finke, 1984); this bias appears to reflect predictions about how its movement will unfold over time. Although these effects are relatively small, they are nevertheless robust and fairly general in nature; for example, representational momentum has been found for several stimulus dimensions, including rotation, motion trajectory (Hubbard, 1995), and the panning of a camera though a scene (Munger et al., 2006). These biases can be greatly influenced by people's assumptions about how events should behave (for reviews, see Hubbard, 2005, 2010, 2014a)

Another such phenomenon is the *flash-lag effect* (Nijhawan, 1994): if a ball moves at a continuous speed and a point light suddenly flashes just as the ball passes it, observers perceive the point light as lagging behind the ball. One explanation of this phenomenon is that the future location of the ball is easily predicted, so that our visual perception of it can be based upon this; in contrast, such prediction is not possible for the flash, and so our percept of it must be based on its actual (rather than predicted) position. Like representational momentum, the flash-lag effect has been demonstrated in several stimulus dimensions, such as different colours. (For detailed reviews including other proposed explanations, see Hubbard, 2014b; Nijhawan, 2008; Sheth, Nijhawan, & Shimojo, 2000.)

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When predictions of this kind are correct they can be of great value. But when they are wrong they can lead to noticeable errors in our perceptual experience. Magicians have learnt to exploit many of these errors, developing strategies to maximize their impact (Kuhn, Amlani, & Rensink, 2008; Rensink & Kuhn, 2015). A striking example of this is the Vanishing Ball Illusion, in which a magician causes a ball to apparently vanish in mid-air (Kuhn, Kourkoulou, & Leekam, 2010; Kuhn & Land, 2006; Thomas & Didierjean, 2015; Triplett, 1900). Here, the magician tosses a ball up and down in the air a few times, and on the final toss, merely pretends to throw the ball. Interestingly, most audiences experience the ball as moving upwards and suddenly vanishing in thin air. In accord with the idea that perceptual experience can be based on predicted events, this illusion is influenced by top-down expectations, such as the social cues used by the magician to misdirect expectations (e.g. head and gaze direction, see Kuhn & Land, 2006; Thomas & Didierjean, 2015).

It is commonly believed that the success of this illusion relies on a visually similar, non-deceptive action preceding the deceptive one (Fitzkee, 1945; Kuhn, Caffaratti, Teszka, & Rensink, 2014; Lamont & Wiseman, 1999; Sharpe, 1988). Triplett suggested that a "ghost ball" is experienced on the deceptive throw, based on the "perceptual residue" of the previous real throws. But in the flash-lag effect (at least in the form where there is an onset of the point light), there is no such "residue", suggesting that this is not necessary for at least some kinds of perceptual displacement (Khurana & Nijhawan, 1995). More generally, it is unclear what predictions of this kind are based upon: Do they rely entirely on long-term knowledge of what an action should look like? Do they need an exemplar from the immediate past to establish a perceptual context of some kind? The aim of the current study is to answer these questions for the Vanishing Ball Illusion. In particular, it examines the effect of the perceptual priming caused by showing participants a real throw before the deceptive one.

2. Method

2.1. Participants

Fifty undergraduates (35 female, ages 18–25) at the University of Durham participated in exchange for payment (£2). The experiment received ethical clearance from the Durham University Psychology department's ethics committee.

2.2. Material

Participants viewed edited versions of the Vanishing Ball Illusion previously used by Kuhn and Land (2006). A magician (G.K.) is seen throwing a ball up in the air and catching it after each throw (Fig. 1 & Online supplementary material). On the final throw (pretend throw), he only pretends to throw the ball; in reality, it remains concealed in his hand. For the current experiment, this clip was edited to create two test conditions: primed and non-primed. In the primed condition, the magician threw the ball once before executing the pretend throw.[1] In the non-primed condition, the clip contained only the pretend throw (with the magician initially holding the ball in his hand). Only one of these was shown to each participant. Both clips started with a frozen frame displayed for 2 s, and ended with a frame presented for 5 s. The video clip in the primed condition lasted 10.72 s; in the non-primed condition, 9.04 s.

The video clips (25 fps) were presented using Experiment Builder (SR-Research) and displayed on a 21-in. CRT monitor (Samsung SyncMaster 1100 MB) with a refresh rate of 75 Hz. The screen resolution was set to 1024 × 768, whilst the videos measured 720 by 576 pixels. The clips were presented in the centre of the screen, and the remainder of the screen was black.

Eye movements were recorded with a head-mounted, video-based eye tracker (EyeLinkII; SR Research Ltd., Osgoode, Ontario, Canada), and were sampled at 500 Hz. Eye movements were recorded monocularly, and analyzed using Eyelink Data Viewer (SR-Research). The eye tracker was calibrated using a 9-point calibration and validation procedure.

2.3. Procedure

Participants were randomly allocated to the primed or the non-primed condition (between-subject design); they were told they would see a magic trick and that their task was to find out how this was done. Each participant saw only one video clip (primed or non-primed). Immediately after the video clip, participants were presented with an image of the last frame of the video clip, measuring 14.7 cm (horizontal) by 11.7 cm (vertical), and were asked to mark the location where they saw (i.e., experienced) the ball for the last time. The true final location was the last point at which the ball was physically visible; this was a point 4.1 cm from the bottom of the image[2] (white solid line in Fig. 2).

After this, participants were asked to do three additional things: (a) report whether they had seen the ball move up on the pretend throw (yes/no forced choice), (b) describe what they saw, (c) explain the method they thought was used to create this illusion. (For the latter two, they were asked to respond in their own words.) Participants were then debriefed and informed about the true method used.

2.4. Measures

Several measures were used to assess participants' susceptibility towards the illusion: (i) forced-choice verbal reports of whether they had seen the ball move upwards (even though it was not physically present), (ii) verbal estimates of where they last saw it, and (iii) patterns of their eye movements as they watched the videos (see Kuhn & Land, 2006; Kuhn et al., 2010). A written questionnaire then assessed their awareness of what they saw, and how the trick might have been done.

3. Results

3.1. Forced-choice reports

Participants were classified as having experienced the illusion if the forced-choice report indicated they experienced the ball moving towards the top of the screen during the pretend throw. Participants in the primed condition were twice as likely to have experienced the illusion (64%) as participants in the non-primed condition (32%), (χ^2 = 5.13, p = .024). Importantly, the rate of reporting the illusion in the non-primed condition was also significantly different from zero (Binomial test, p < .0001).

3.2. Location estimates

Perceptual displacement was calculated as the difference between the ball's final physically-visible position (solid white line in Fig. 2) and its final experienced position (as given by conscious verbal estimate); positive numbers indicate a forward (upwards)

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[1] In the original clip, the magician throws the ball *twice* before executing the pretend throw.

[2] After this point the hand continued to move upwards, and thus the ball is occluded for 3 frames before it fails to appear on the expected motion path.
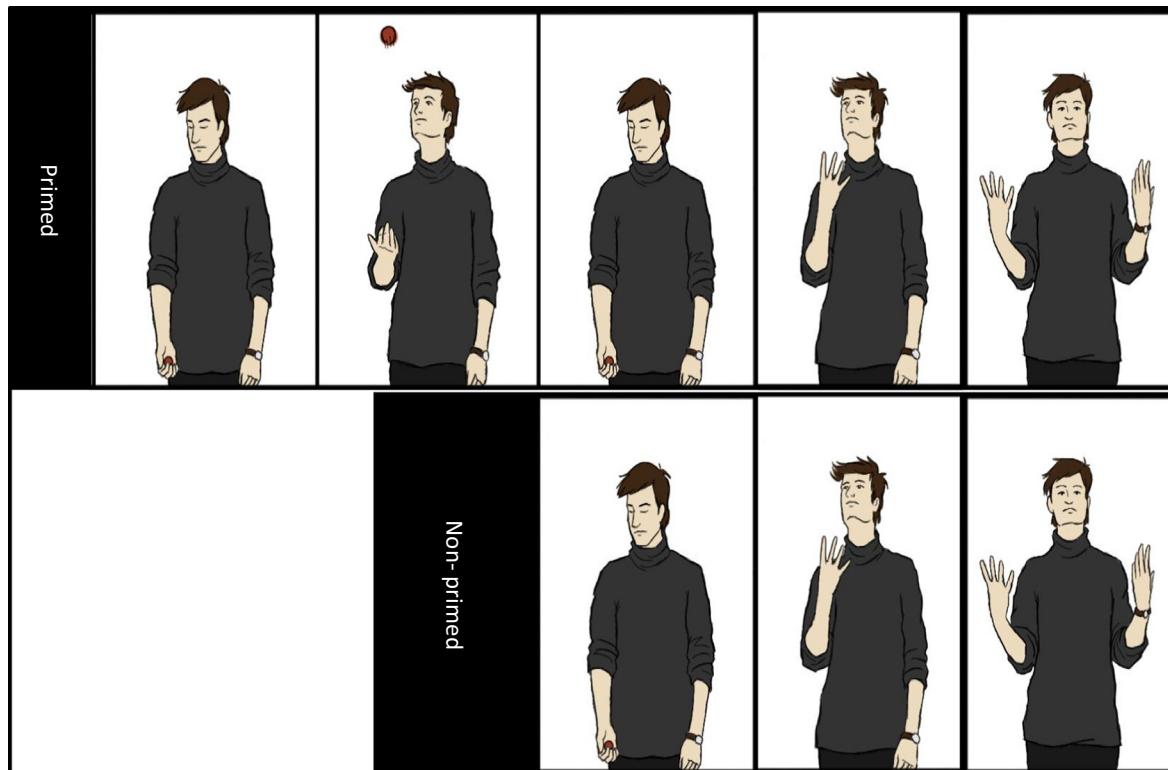
Fig. 1. Schematic of the two test conditions. In the primed condition, the magician throws the ball once before executing the pretend throw. In the non-primed condition, only the pretend throw is shown. The ball is clearly visible on the first frame of each. See Supplementary material for video clips.

direction. Fig. 2 shows each location estimate plotted on the frame in which the ball appeared to vanish (see Table 1 for means). In the primed condition, the average reported location for all participants was significantly higher (M = 4.97 cm, SD = 2.66) than for the non-primed condition (M = 2.11 cm, SD = 3.62; $t(48)$ = 3.18, p = .003). Interestingly, the vast majority of primed participants indicated that they saw the ball leave via the top of the image; only two saw it disappear before it left the screen. Even in the non-primed condition, however, estimates of the ball's final location were significantly greater than zero ($t(24)$ = 3.06, p < .005).

An ANOVA showed that participants who experienced the illusion (as determined via forced-choice reports) had significantly larger perceptual displacements (M = 6.68; SD = 1.44) than those who did not (M = 0.64; SD = 1.83, $F(1,49)$ = 156, p < .0001, η^2 = .77), suggesting a close connection between these two measures. A significant connection was also found between experiencing the illusion and priming ($F(1,49)$ = 4.62, p = .037, η^2 = .091). For participants who experienced the illusion, however, the magnitude of perceptual displacement was essentially the same whether the condition was primed or not ($|t(22)|$ < 1), with the majority in both conditions (primed = 94%, non-primed = 72%) seeing the ball leave at the top of the image. Interestingly, a displacement of the size found here (at least 6.69 cm) translates into an interval of at least 230 ms during which participants had a visual experience of the ball, even though it was not present physically.[3]

Meanwhile, a different pattern was found for participants who did not experience the illusion. To begin with, the average perceptual displacement for this group did not significantly differ from zero ($t(25)$ = 1.80, p = .083). Displacement in the primed condition (1.93 cm) was significantly greater than in the non-primed condition (−0.05 cm), ($t(24)$ = 3.00, p = .006), but not as large as for those who had experienced the illusion ($t(24)$ = 8.51, p < .0005). The displacement in the non-primed condition did not significantly differ from zero ($|t(16)|$ < 1).

3.3. Eye movements

Fig. 2 shows participants' fixations at the time the ball appeared to vanish (generally when it appeared to leave the top of the screen); this is given for both the primed and non-primed conditions, and as a function of whether they experienced the illusion or not. In contrast to the location estimates, there was little difference in eye-movement patterns between those who experienced the illusion and those who did not, at least until the ball appeared to vanish (as measured by the final fixation point along its trajectory). There was a somewhat greater variability in the primed condition (Levene's test of equality of variance for oculomotor displacement: $F(1,49)$ = 7.75, p = .008), but this is not very surprising: these participants had viewed an additional toss, thereby allowing for more variations in viewing behaviour. We also measured oculomotor displacement, defined as the vertical distance between participants' final fixation on the apparent ball and the last physically-visible position (solid white line in Fig. 2). Results are shown in Table 1. An ANOVA with priming and illusion as between-subjects variables found no significant main effect of priming $F(1,49)$ = 0.032, p = .86, η^2 = .001, illusion $F(1,49)$ = 1.35, p = .25, η^2 = .028, or priming by illusion interaction $F(1,49)$ = 2.55, p = .12, η^2 = .053. Oculomotor displacement therefore appeared to be completely independent of visual experience.

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[3] A rough estimation can be obtained using the formula for displacement $d = v_0 t - gt^2/2$, where v_0 is the initial speed of the ball, and g is the acceleration due to gravity (e.g., Kleppner & Kolenkow, 2013). Recasting gravity in terms of image coordinates (a factor of approximately 10), and measuring v_0 as approximately 40 cm/s in the image, a displacement of 6.69 cm is first attained at around 230 ms. This is necessarily a lower bound for the time that the ball was experienced, since observed displacement d might have been higher had the trajectory of the apparent ball not been truncated by the top of the image.
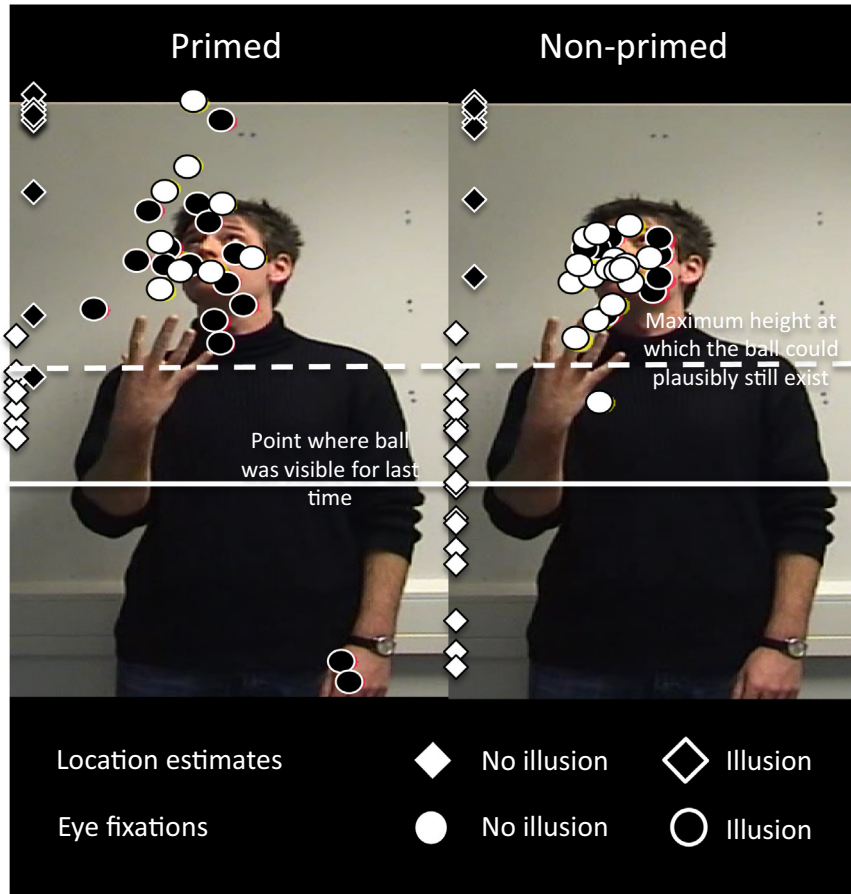
Fig. 2. Location estimates (diamonds) and eye fixations (circles) at the time that the ball appeared to vanish (or leave the top of the screen), as a function of priming and subjective experience of the illusion. Location estimates refer to the reported height, and are simply plotted on the left of the image. The left frame shows participants in the primed condition; the right, participants in the non-primed condition. The solid white line marks the height at which the ball was physically visible for the last time. The figure width is not proportional to that used in the experiments, as the frames were horizontally cropped to save space.

Table 1
Perceptual and oculomotor displacement as a function of priming and subjective experience of the illusion. These are taken from the last *physically visible* point; this is 2.4 cm below the last point at which the ball could plausibly still have existed (Fig. 2). Parentheses contain standard deviations.

	Perceptual Displacement		Oculomotor Displacement	
	Primed	Non-primed	Primed	Non-primed
Illusion	6.68 cm (±1.58)	6.69 cm (±1.21)	3.38 cm (±3.15)	4.43 cm (±0.52)
No Illusion	1.93 cm (±0.59)	−0.035 cm (±1.90)	5.01 cm (±1.47)	4.17 cm (±0.84)

After the apparent vanish, however, eye movements varied dramatically. We used a dynamic interest area analysis (DataViewer, SR-Research) to define interest areas around the magician's right hand (the one palming the ball) and his left hand (empty hand), and then measured the time it took participants to fixate either of these areas after the ball appeared to have left the top of the screen (frame depicted in Fig. 2). Participants who experienced the illusion did not show a significant preference as to which hand to fixate first: 42% fixated the magician's right hand, and 58% his left hand. This differs considerably from participants who did not experience the illusion, of whom 96% fixated the right hand first ($\chi^2 = 17.6$, $p < .0005$); this was true for both the primed ($\chi^2 = 6.17$, $p = .013$) and non-primed conditions ($\chi^2 = 10.1$, $p = .001$). In addition, participants who experienced the illusion but fixated on the right hand first[4] ($n = 18$) took on average

927 ms (SD = 1014) to do so, whereas participants who did not experience the illusion ($n = 23$) took only 254 ms (SD = 234), a reliably shorter time ($t(18.3) = 1.78$, $p = .013$).

3.4. Questionnaire responses

After carrying out the main part of the experiment, participants were asked to (i) freely describe what they saw and then (ii) come up with possible explanations about how the illusion was created. None of the participants were debriefed until after they completed the questionnaire, but all realized that they had seen a magic trick in which a ball disappeared. Those participants who did not experience the illusion realized that the magician merely pretended to throw the ball, whilst those who experienced the illusion all claimed that they saw the ball thrown up, but that it just did not come down again. All members of the latter group realized that something strange was going on, since balls that go up should come down. Responses were rated independently by five researchers on

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[4] Data from two participants (one in each condition) were excluded as their means were more than 2SD from the mean

whether the statements implied that the ball had left the top of the screen, was held in the hand (or dropped off the bottom of the screen), or whether the statement was ambiguous. We used the mode of the five judgements as the response for each participant. Only 3 participants provided statements rated as ambiguous about what they saw; these were omitted from subsequent analysis.

Of the participants who experienced the illusion (as determined via forced-choice verbal reports), 88% indicated that the ball left the top of the screen, as opposed to 0% of those who did not experience the illusion (χ^2 – Fisher's Exact test = 42.5, $p < .0005$). With regards to proposed explanations, 5 of the statements were rated as being ambiguous. Of the remaining 45 participants, 95.9% of those who experienced the illusion suggested that the ball left the top of the screen, as compared to only 16.7% of those who did not experience it (χ^2 – Fisher's Exact test = 35.8, $p < .0005$). These results again reveal a close and consistent relationship between the different verbal measures.

4. Discussion

This study examined the conditions needed for the Vanishing Ball Illusion. Participants primed with a real throw before the deceptive one were twice as likely to experience the illusion as those not primed this way. However, the illusion could also be induced to some extent even without priming: 32% of the participants who were never shown a ball being tossed in the air still experienced such an event.

As in previous studies (Kuhn & Land, 2006; Kuhn et al., 2010) there was a high degree of consistency between all measures based on conscious report. Participants who experienced the illusion (as measured by forced-choice verbal report) reported almost exactly the same perceptual displacement regardless of whether they were primed or not (Table 1). Thus, although priming participants with a non-deceptive action increases the likelihood of experiencing the illusion, it seems to have little effect on the distance apparently travelled, supporting the proposal that the estimation of this quantity draws largely upon long-term knowledge. (Priming can increase the magnitude of perceptual displacement when no illusory ball is reported, which is presumably due to some other mechanism.) In any event, participants who experienced the illusion were also far more likely to suggest methods behind the trick that involved some kind of disappearance of the ball at the top of the visual field, as opposed to any other form of manipulation.

Measures based on eye movements, in contrast, followed a rather different pattern: oculomotor displacement was independent of whether the illusion was experienced, and whether there had been priming beforehand. This is consistent with the relatively automatic nature of eye movements, which tend to respond reflexively to the spatial features in a scene within a window of a few seconds of viewing, while perception tends to accumulate information over time (Lisi & Cavanagh, 2015; Mannan, Kennard, & Husain, 2009; Mannan, Ruddock, & Wooding, 1995). More generally, our results are consistent with the proposal of separate processes underlying conscious visual experience and motor actions (Milner & Goodale, 1995). Previous studies, for example, have demonstrated that grasping actions are unaffected by manipulations that can cause illusions in conscious experience (Aglioti, Desouza, & Goodale, 1995; Kroliczak, Heard, Goodale, & Gregory, 2006). We find a similar dissociation here: eye movements are unaffected by priming, even though this has a strong effect on the likelihood of consciously experiencing an illusion. Moreover, given that various manipulations can affect eye movements but not conscious perception (see e.g., Spering & Carrasco, 2015), the result is a *double* dissociation between the oculomotor and perceptual systems. Such a result has several interesting implications for

our understanding of perception. For example, given that conscious visual experience requires visual attention of some kind (see e.g., Rensink, 2013, 2015), this dissociation strongly supports the view that eye fixation and visual attention can be decoupled in free viewing (e.g., Pollatsek & Rayner, 1999). It also suggests that the locations of items in the representations underlying conscious experience are not necessarily updated via the contents of oculomotor representations, but can be—at least in part—derived independently, likely by mechanisms which include high-level prediction.

Why exactly do people experience the Vanishing Ball Illusion? Whilst the influence of priming supports Triplett's "residue" hypothesis to some extent, the fact that 32% of our participants experienced a full-strength illusion without having seen a ball tossed into the air beforehand rules this out as a major factor. And the lack of significant differences in eye fixations (up to the time of the vanish) between participants who did or did not experience the illusion suggests that it is not due to differences in general encoding strategies.

Indications as to what *is* responsible can be gleaned from the eye movements that occur *after* the ball appears to vanish (see also Barnhart & Goldinger, 2014; Kuhn & Findlay, 2010; Kuhn & Tatler, 2005; Kuhn, Tatler, Findlay, & Cole, 2008). Participants who experienced the illusion were almost equally likely to look next at either hand (42% looked at the right hand first; 58% at the left). In contrast, nearly all of those who did not experience the illusion looked immediately at the hand thought to conceal the ball; moreover, they did this within 254 ms on average, far less than the 927 ms taken by those who did experience the illusion. This suggests that participants who continued to see the ball had no reason to immediately check the image, and so were slower (as well as more likely to check either hand). More generally, the finding of differences in eye movements immediately after the apparent vanish supports the proposal that the Vanishing Ball Illusion is not due to introspective errors at the time the participants are questioned about the illusion, but instead results from perceptual and cognitive processes in effect at the time the illusion appeared to occur.

Which processes could these be? Kuhn and Land (2006) speculated that the Vanishing Ball Illusion might result from representational momentum, with participants misremembering the final location of the ball. Hubbard (2005, 2006) suggested that representational momentum involves both top-down memory as well as bottom-up perceptual components, and our results are compatible with this view. (For further discussion of momentum effects, see Hubbard, 2014a.) Nagai and Saiki (2005) report that representational momentum is influenced by illusory motion, or at least, the observer's anticipation of motion direction (Hubbard, Ruppel, & Courtney, 2005; Taya & Miura, 2010; Verfaillie & d'Ydewalle, 1991). This is also consistent with our results, which clearly show that an implied action alone leads to an illusory motion percept.

However, there are also indications that the Vanishing Ball Illusion may *not* be due to representational momentum. Kerzel (2000) suggested that representational momentum is the result of small eye movements that occur after the target object has disappeared, leading to a persisting image in the direction of motion. If so, representational momentum cannot explain the results found here: We did not observe any smooth eye movements in the direction of motion, and the magnitude of our perceptual displacements (often several degrees of visual angle) could in no way be accounted for by small retinal displacements. In addition, Kuhn et al. (2010) showed that individuals with autism are more likely to experience the Vanishing Ball Illusion, in stark contrast to results showing that individuals with autism have reduced representational momentum for facial expressions (Uono, Sato, & Toichi, 2014). Whilst faces and balls are different kinds of stimuli (e.g., the former is social/intentional, and the latter isn't), it does

appear likely that the mechanisms underlying the Vanishing Ball Illusion are not the same as those underlying representational momentum. However, more research is needed to settle this issue definitively.

Another possible explanation involves perceptual completion. Ekroll, Sayim, and Wagemans (2013) suggest that some magic tricks depend upon a form of amodal completion, and Beth and Ekroll (2015) argue that such mechanisms can extend to the spatiotemporal domain. If so, the Vanishing Ball Illusion may involve the equivalent mechanisms for modal completion (Beth & Ekroll, 2015); moreover, completion of a different kind (possibly amodal) might explain the displacement reported for the primed condition when no illusion was experienced. Given that different grades of visual experience are possible—e.g., a coherent object vs. an undifferentiated patch of colour (Rensink, 2013, 2015)—an interesting topic for future work would be the kind of "seeing" that occurs under these conditions.

A related topic is the duration over which the illusion can exist. Our estimate of 230 ms is an approximate lower bound; more work needs to be done to obtain a better estimate. It may be worth noting, however, that the relatively long duration found here is not far from 175 ms temporal advance found for the flash-lag effect when no transients exist to signal a disappearing object (Maus & Nijhawan, 2006). This duration is also similar to the length of time over which representational momentum is believed to build up before forward displacement begins declining (e.g., Freyd & Johnson, 1987; for review, see Hubbard, 2005).

In any event, perceptual mechanisms alone are unlikely to account for all the effects found here. Instead, many of these are likely due to the invocation of long-term knowledge, either by exposure to the preceding real throws or via the kinematics of the pretend one. Interestingly, Cui, Otero-Millan, Macknik, King, and Martinez-Conde (2011) found that a pretend coin toss often appeared to be real even when it was not preceded by a real toss; similar mechanisms are likely to be involved here. And consistent with the involvement of high-level factors, the Vanishing Ball Illusion—as is true of many other magic tricks—generally relies on just a single trial being used; indeed, unpublished data from our lab has shown that the illusion is far less effective if repeated. Pretend coin tosses can still produce the illusion of a coin being thrown from one hand to the other, even after being repeated several times (Cui et al., 2011), indicating that such repetition does not strongly affect perceptual mechanisms in general. However, the perceptual displacements found in this "coin toss" illusion were substantially smaller than those reported here, suggesting that different mechanisms are involved. It would appear that an important factor in the Vanishing Ball Illusion (but not the "coin toss" illusion) is the element of surprise, which may act by influencing the strength of high-level expectations in later trials. This issue is worth investigating further.

In regards to the influence of such high-level factors, it is worth mentioning that in the Vanishing Ball Illusion, the observer's expectation of a ball going up is violated when the ball does not appear on the expected motion path. Our results suggest that this counterevidence (i.e., the absence of the ball) is weighted less than the evidence that produced the initial expectation. This weighting likely has its origins in the fact that perceiving the ball's upwards trajectory is difficult: no participant managed to track it using smooth pursuit. However, Triplett (1900) showed that the illusion is more powerful when experienced under low levels of illumination, suggesting that sensory counterevidence still has at least some role to play.

In summary, then, our results indicate that people's perceptions can involve predictions driven by long-term knowledge as well as perceptual inputs from the immediate past. Whilst we can only speculate about the particular mechanisms responsible for the Vanishing Ball Illusion, our results indirectly support general models of perception based on predictive feedback (e.g., Clark, 2013; Di Lollo, Enns, & Rensink, 2002; Friston & Kiebel, 2009; Kilner et al., 2007). Interestingly, the forward perceptual displacements observed here were substantially larger than those typically found in other perceptual phenomena ascribed to prediction, such as representational momentum (Hubbard, 2005, 2014a) and the flash-lag effect (Nijhawan, 1994, 2008). As such, our results also support the general proposal that magic tricks can often be harnessed to yield effects much stronger than those obtained by more traditional means (Kuhn, Amlani, et al., 2008; Rensink & Kuhn, 2015; Thomas, Didierjean, Maquestiaux, & Gygax, 2015). In this case, the advantages of the magic trick likely arise because of more effective control of high-level expectations, as well as a better understanding of how these expectations can affect our perception of the world around us.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2015.12.003.

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