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How Magic Changes Our Expectations About Autism

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Abstract

In the vanishing-ball illusion, the magician's social cues misdirect the audience's expectations and attention so that the audience "sees" a ball vanish in the air. Because individuals with autism spectrum disorder (ASD) are less sensitive to social cues and have superior perception for nonsocial details compared with typically developing individuals, we predicted that they would be less susceptible to the illusion. Surprisingly, the opposite result was found, as individuals with ASD were more susceptible to the illusion than a comparison group. Eye-tracking data indicated that subtle temporal delays in allocating attention might explain their heightened susceptibility. Additionally, although individuals with ASD showed typical patterns of looking to the magician's face and eyes, they were slower to launch their first saccade to the face and had difficulty in fixating the fast-moving observable ball. Considered together, the results indicate that individuals with ASD have difficulties in rapidly allocating attention toward both people and moving objects.

Keywords

autism, eye movements, social attention, visual illusion, allocation of attention, top-down modulation

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Illusions lie at the heart of magic tricks, and many of them rely on strategically manipulating people's expectations by stage-managing the context (Kuhn, Amlani, & Rensink, 2008). Although some of these illusions are similar to the types of visual illusions typically investigated by psychologists (e.g., Ponzo, Müller-Lyer), others are more complex and cognitive in nature. The vanishing-ball illusion is a notable example of such a cognitive illusion (Kuhn & Land, 2006; Triplett, 1900). In this illusion, a magician (the experimenter) is seen first throwing a ball up in the air a couple of times and then catching it. However, on the final throw, the magician merely pretends to throw the ball, when in fact it remains secretly concealed in his hand, making it appear as though the ball has disappeared. During this pretend throw, the magician's gaze (i.e., head and eye direction) follows the trajectory of the imaginary ball (see Fig. 1). Although the ball does not leave the magician's hand, research shows that almost 70% of observers watching a video clip of the illusion claim to have seen the ball leave the hand and move to the top of the screen (Kuhn & Land, 2006).

In the vanishing-ball illusion, the magician's social cues of head movement and eye gaze play a crucial role in misdirecting people's attention and expectations (Kuhn & Land, 2006). This has been demonstrated clearly in research: When the magician's gaze is directed toward the hand concealing the ball, and not to the imaginary trajectory of the ball, the effectiveness of the illusion is significantly reduced (from 68% to 32%). Moreover, although most participants subsequently claim that they were looking only at the ball, eye-tracking results reveal that they spend much of their time looking at the face, and often glance at the magician's face prior to moving their eyes toward the expected location of the ball, which suggests that the visual system utilizes the social cues in this illusion.

Research on the perceptual strategies of cricket players may help to explain why people make use of additional contextual information when locating a ball in the air (e.g., Land & McLeod, 2000). A cricket ball is relatively small and continuously moving. People are generally poor at locating and fixating small, fast-moving objects, as this poses a severe oculomotor challenge. People therefore rely on top-down heuristics to plan the likely outcome of a ball throw. They expect to see a ball in the air after it is thrown, and in the case of the magic trick, they rely on the social cues of body, head, and gaze direction to predict its trajectory and destination.

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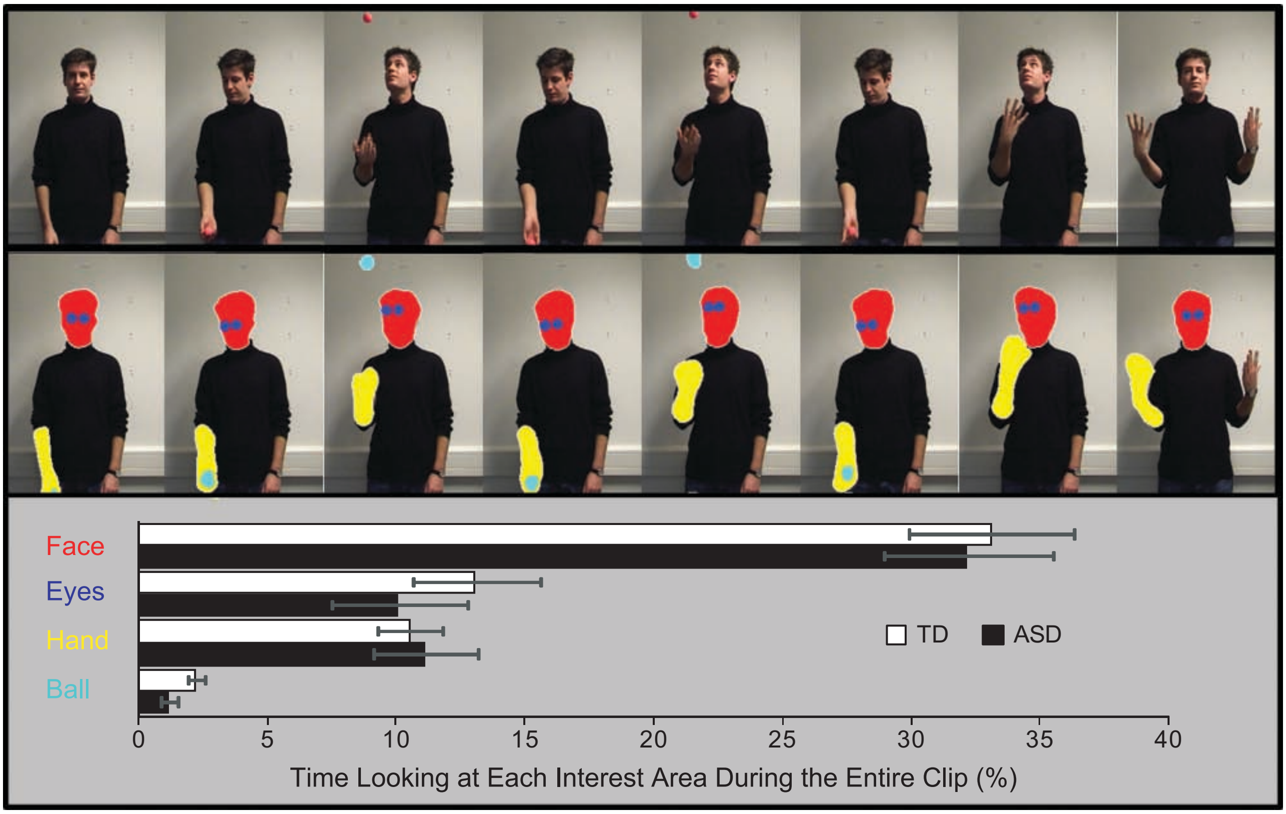

Fig. 1. Frames from a video clip of the vanishing-ball illusion and the percentage of time participants looked at each of the interest areas while watching the clip. The top row shows the sequence of events (from left to right) in the illusion. (The frames are not drawn to scale.) In the first six frames, a magician throws a ball up in the air twice and catches it both times. On the final throw, he merely pretends to throw the ball (seventh frame), when in fact it remains secretly concealed in his hand. The middle row shows the areas of interest: face, eyes, hand, and ball. Because objects in a dynamic scene change in location, size, and shape, and may even totally disappear, the size and location of each area was adjusted for each frame. As a result, each area varied in shape and size over the duration of the video clip. Overall, the head accounted for 1.85%, the eyes for 0.21%, the hand for 1.17%, and the ball for only 0.083% of the total area. The bar graph shows the proportion of time spent looking at each of the areas of interest for the typically developing (TD) and the autism spectrum disorder (ASD) groups. Error bars denote standard errors of the mean.

Although most individuals are deceived by the vanishing-ball illusion, there are several reasons to predict that one group of individuals, those with autism spectrum disorder (ASD), might be less susceptible to the illusion. Autism is a disorder characterized by impairments in social interaction and communication and by restricted and repetitive quality of behavior (American Psychiatric Association, 1994). Individuals with ASD have an uneven profile of abilities; they have intact or superior skills in various nonsocial areas, such as processing of fine details, but also are impaired in other areas, such as attending to the social elements of the environment.

These impairments in social attention suggest that people with ASD are less likely than others to be misdirected by the magician's social cues. A number of studies have shown that individuals with autism have social-attention difficulties, spending less time looking at face and eye regions of a visual scene (Dalton et al., 2005; Pelphrey et al., 2002; Riby & Hancock, 2008; Sasson et al., 2007) and more time looking at objects (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). However, the level of these social-attention difficulties depends on several factors, such as the participant's age, the complexity of the task, and the severity of the disorder (Bar-Haim, Shulman, Lamy, & Reuveni, 2006; Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; Kuhn et al., 2010; Nation & Penny, 2008; Speer, Cook, McMahon, & Clark, 2007).

The superior processing of local detail that is associated with ASD suggests that people with ASD would be more efficient at detecting the ball than individuals without ASD, and might also be less inclined to use top-down strategies in interpreting what they see. Indeed, it has previously been proposed that people with ASD have a reduced susceptibility to illusions involving visual distortions because of a bias for local processing (Bölte, Holtmann, Poustka, Scheurich, & Schmidt, 2007; Happé, 1996) and a possible accompanying failure to integrate information into context. Although this claim has been challenged (López & Leekam, 2003; Mottron & Belleville, 1993; Ropar & Mitchell, 1999), the weight of the evidence supports the claim that people with autism have a bias for local, detail processing (e.g., Iarocci, Burack, Shore, Mottron, & Enns, 2006).

In the study presented in this article, we evaluated susceptibility to the vanishing-ball illusion among individuals with ASD and those with typical development. Theoretical accounts emphasizing the local-processing bias (e.g., Happé & Frith, 2006; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006) and "social brain"–based accounts of autism (for reviews, see Schultz, 2005; Senju & Johnson, 2009) both predict that individuals with ASD should be less susceptible to the vanishing-ball illusion.

Method

In this study, we used the same procedures and analysis as those established in nonclinical populations (Kuhn & Land, 2006).

Participants

Fifteen individuals with ASD (12 males and 3 females; ages 17–22 years) were recruited from a special college for autism. All had been diagnosed with high-functioning autism or Asperger's syndrome by experienced clinicians using the Autism Diagnostic Observation Schedule (Lord, Rutter, DiLavore, & Risi, 1999) or the Autism Diagnostic Interview-Revised (Lord, Rutter, & Le-Couteur, 1994). A comparison group of 18 typically developing (TD) individuals (16 males and 2 females; ages 18–34 years) was recruited from mainstream colleges. Participants' mental age was assessed using the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), and all participants obtained Full Scale IQ scores above the average range (IQ > 80). All participants had normal or corrected-to-normal visual acuity and took part in this study as paid volunteers. None of the participants were familiar with the magic trick used. The groups were well matched for chronological age, $t(31) = 1.35$, $p = .19$; verbal IQ, $t(31) = 0.16$, $p = .87$; nonverbal IQ, $t(31) = 0.72$, $p = .48$; and full-scale IQ, $t(31) = 0.36$, $p = .72$ (see Table 1).

Materials

The magic trick was presented using the video clip of the vanishing-ball illusion previously used by Kuhn and Land (2006). This clip shows a person throwing a ball up in the air and catching it twice before pretending to throw it up in the air. On this fake throw, he merely pretends to throw the ball, and in fact it remains secretly concealed in his hand. The entire magic trick lasts 6.44 s. We added 125 still frames (5 s) to the beginning of the clip and 75 frames (3 s) to the end.

The video clip was presented using SR-Research Experiment Builder software (Kanata, Ontario, Canada), which guaranteed accurate timing of the frames (25 frames per second). The movies were displayed on a 21-in. CRT monitor (75 Hz). Screen resolution was set to 600 × 800 pixels so that the video clip filled most of the screen. Eye movements were recorded using an SR-Research Eyelink2 eye tracker (Kanata, Ontario, Canada; 500 Hz). Viewing distance was 63 cm, and the head's location was fixed using a chin rest.

Procedure

Participants were informed that they were about to see a video clip of a magic trick and that their task was to discover how it was done. No other instructions were provided. The eye tracker was then calibrated using a nine-point calibration procedure, which was immediately followed by a validation procedure. Calibrations were accepted if the mean error was less than 0.5°. Each trial started with a black fixation point on a gray background. The fixation point was 8° from the center of where the magician's face was going to appear. Once participants held fixation, the trial was initiated by the experimenter, and the fixation display was replaced with the first frame of the video clip.

Immediately after the presentation of the magic trick, participants were given a short questionnaire (based on the one used by Kuhn & Land, 2006), which assessed their susceptibility to the illusion. First, they were presented with an image of the final frame of the video clip and asked to mark the location at which they saw the ball for the last time. The last time the ball was fully visible was when it was held in the hand prior to the fake throw. Any indication of having seen it above that point (6.5 cm from the bottom of the image) implies that participants saw an illusory ball. It has previously been shown that participants who claim to have seen the illusory ball mark the location at which they saw the ball for the last time at a point much higher than participants who were not fooled by the illusion (Kuhn & Land, 2006). The advantage of this distance measure is that it is entirely objective and largely independent of verbal ability. Second, after marking the location

Table 1. Participants' Mean Age and IQ

		IQ		
Group	Age (years)	Verbal	Nonverbal	Full Scale
Autism spectrum disorder	19 (1.6)	98.3 (15.5)	104.2 (12.9)	101.3 (12.4)
Typically developing	21 (4.1)	97.6 (9.8)	107.1 (10.3)	102.7 (9.5)

Note: Standard deviations are given in parentheses. IQ was measured with the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999).

where they last saw the ball, participants were asked for suggestions about possible explanations of how the illusion was created. Answers implying that the ball was removed from the top of the screen indicated that they saw an illusory ball, whereas solutions involving the ball being held in the hand or dropped implied that participants were not taken in by the illusion.

Results

Level of susceptibility

Markings of the location where the ball was last seen were significantly higher for the ASD group (M = 8.52 cm, SD = 2.32) than for the TD group (M = 6.91 cm, SD = 2.00), $t(31)$ = 2.14, p = .04, Cohen's d = 0.74. This result suggests that individuals with ASD were more susceptible to the illusion. The higher level of susceptibility was also reflected in the types of answers participants gave for how they thought the illusion was created. Each participant's explanation was rated by five independent coders, who were blind to the participant's diagnostic status. Each statement was rated according to whether it implied the ball left the top of the screen, the bottom of the screen, or whether it was ambiguous. The most frequent answer was used. Five of the TD group's and two of the ASD group's statements were considered ambiguous. Of the remaining statements, 53% from the ASD group implied that the ball left the hand, but only 15% from the TD group implied this, $\chi^2(1, N = 33) = 4.3$, p = .039. Participants who implied that the ball left the hand gave significantly higher distance ratings (M = 9.8 cm, SD = 1.73) than those who implied that it did not (M = 6.39 cm, SD = 1.36), $t(24)$ = 5.72, $p < .0005$, Cohen's d = 2.19.

Two types of evidence suggest that level of susceptibility is independent of verbal and nonverbal ability. First, there was no evidence of an association between level of susceptibility (i.e., the distance measure) and IQ, whether Full Scale IQ, verbal IQ, or nonverbal IQ (all r^2s < .01, all ps > .05). Second, the ASD group's statements explaining how they thought the trick worked were very similar to the TD group's statements in terms of comprehensibility and complexity.

Eye-tracking measures

Because of calibration difficulties, eye movements were not recorded for 2 participants in the ASD group. Data from 1 participant in the TD group and 1 in the ASD group were excluded because of tracking difficulties. Eye movement data (tracked at 500 Hz) were analyzed using Data Viewer (SR-Research) and custom-written software.

Attention to social cues. Four interest areas were defined: head, eyes, hand, and ball (see the middle row of Fig. 1). We calculated the average time participants spent looking at each of the interest areas during the entire clip (see Fig. 1 for mean percentages). For three of the interest areas, the average viewing times did not differ between the ASD group and the TD group. There was no evidence to suggest that participants in the ASD group, compared with those in the TD group, spent less time looking at the head, $t(27)$ = 0.64, p = .85; the eyes, $t(27)$ = 0.82, p = .43; or the hand, $t(27)$ = 0.24, p = .81. However, participants in the TD group spent significantly more time looking at the ball than participants in the ASD group did, $t(27)$ = 2.32, p = .028 Cohen's d = 0.90.

To examine whether participants avoided looking immediately at the face, we examined their first fixations. All but 1 participant (from the ASD group) fixated the face immediately (within one or two saccades; M = 1.2). Of the participants who took two saccades to fixate the face, the first saccade was always in the direction of the face. These results clearly demonstrate that participants in the ASD group did not avoid looking at the face, even though the magician's gaze was directed toward them. However, participants in the ASD group were significantly slower to fixate the face (M = 267 ms, SD = 73.7) than participants in the TD group (M = 201 ms, SD = 43.5), $t(27)$ = 3.01, p = .006, Cohen's d = 1.16. Moreover, participants in the ASD group had higher latencies in generating the first saccade (M = 190 ms, SD = 48.0) than participants in the TD group did (M = 152 ms, SD = 40.2), $t(27)$ = 2.3, p = .03, Cohen's d = 0.89, regardless of whether the face was fixated immediately or on the following fixation. These results suggest that individuals with ASD may be generally slower at initiating saccades than are TD individuals.

Looking at the ball. In order to quantify participants' fixations, we recorded the y-axis coordinates (in degrees of visual angle) at the time when fixation reached its highest point. A value of 25° implies that participants fixated the top of the screen, whereas 0° implies they fixated the bottom of the screen. The group difference in looking at the ball was particularly apparent on the two occasions when the magician visibly threw the ball in the air. Figure 2 shows a snapshot of fixations at the times when the ball reached its zenith and during the final, fake throw. The probability that participants fixated the ball when it was at the top of the screen (first and second throws) was .33 for the TD group, compared with only .13 for the ASD group. Moreover, when the ball was actually thrown, the maximum height of the fixation was significantly higher for the TD group than for the ASD group, $t(27)$ = 2.2, p = .037, Cohen's d = 0.85. Thus, the participants with ASD were less likely to fixate the ball once it reached the zenith. Altogether, these results demonstrate that when the ball was thrown for real, participants in the ASD group were less likely to look at it than were participants in the TD group.

Conclusion

Contrary to our prediction, individuals with ASD were more, not less, susceptible to the vanishing-ball illusion than TD control participants. These results challenge existing

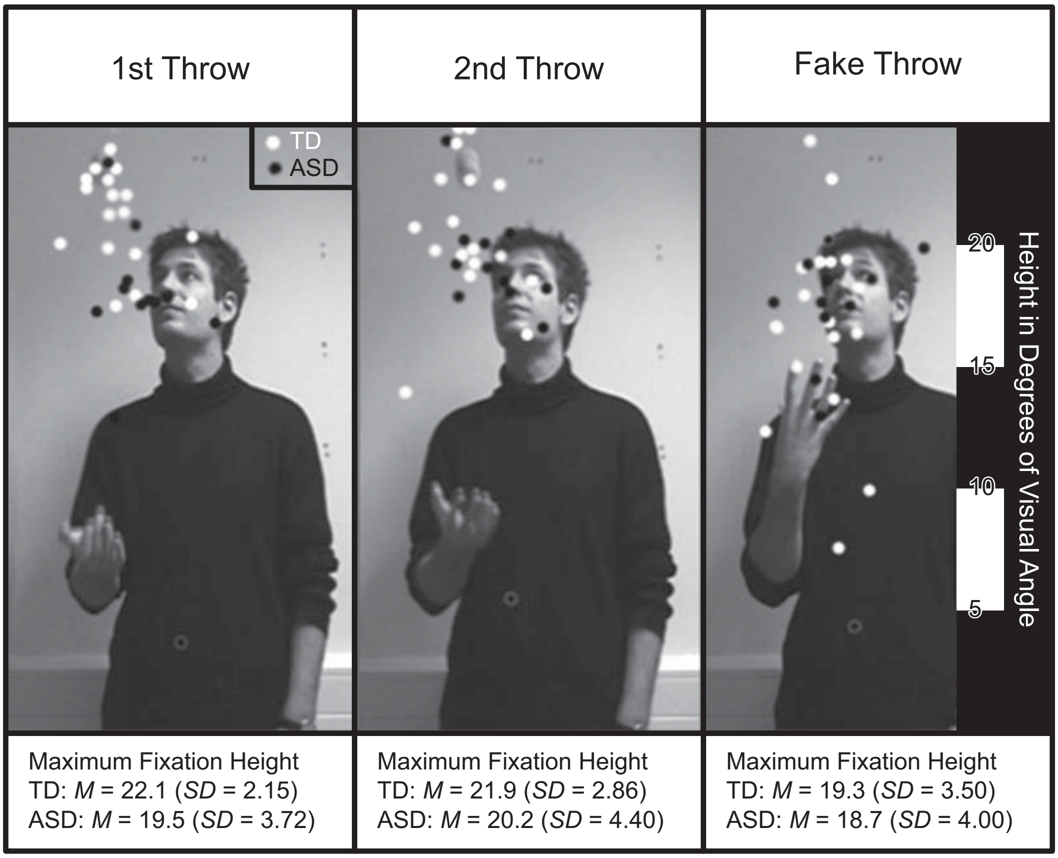

Fig. 2. Participants' fixation points when the ball reached its zenith on the first and the second throws, as well as during the fake throw. Fixation points are denoted by black and white dots. Below each illustration, the figure shows the mean maximum fixation height (in degrees of visual angle) for that frame in the autism spectrum disorder (ASD) group and the typically developing (TD) group.

explanations of social-attention difficulties and enhanced visual processing of details in ASD, and provide new evidence about the temporal allocation of attention.

Because of previously reported evidence of social-attention difficulties in ASD, we expected that individuals with ASD would pay less attention to the misdirecting social cues of the magician, and in particular to the face and eyes (e.g., Klin et al., 2002). Our results clearly do not support this prediction. Individuals with ASD spent the same amount of time fixating the eyes and the face as did TD participants. Contrary to the findings from Klin et al., there was no evidence to suggest that individuals with ASD avoid direct gaze, at least not when presented with a video clip. Thus, our results contradict a general pattern of gaze-avoidance among individuals with ASD.

Not all research has shown social-attention impairments in adults with autism, however (see Nation & Penny, 2008), and one explanation for these divergent research results is that social-attention difficulties become reduced with development because over time people with ASD learn to use social cues. For example, Fletcher-Watson et al. (2009) monitored the spontaneous eye movements of adults with ASD who were simultaneously presented with two photographic images, one in which a person was present and one with no person. Participants with ASD who were asked to look at the pictures and given no other instructions showed a strong bias to look at the person-present scene, and did not differ from TD participants in the time spent fixating the person and his or her face and eyes. However, the participants with ASD exhibited a subtle difference from the TD participants in that they were less likely to look to the person in the image within the first saccade. We also found subtle differences in that participants in the ASD group were significantly slower to fixate the face and to launch their first saccade than participants in the TD group (see Goldberg et al., 2002, for similar findings using memory-guided saccades). From these results, we conclude that individuals with ASD do make use of social cues. Their attention was misdirected by the magician toward his head and face and away from the location of the ball in the same way as it was for the comparison group. However, there were subtle divergences between participants in the ASD and TD groups in the initial temporal allocation of attention. These initial saccades were generally initiated very rapidly, suggesting that the group difference was probably driven by a bottom-up process.

We had also expected that people with ASD, given their superior processing of local detail, would be more efficient than people without ASD at detecting the ball and less inclined to use top-down strategies. On the contrary, we found that individuals with ASD used top-down expectations, anticipating that a ball that had previously been thrown should be in the air again, and relied on the social cues of body, head, and gaze direction to infer its trajectory. This finding conflicts with previous work suggesting that individuals with ASD make judgments about the world on the basis of the physical properties of a stimulus, rather than the context in which the stimulus is presented (Happé, 1996; Happé & Frith, 2006). Our results clearly demonstrate that individuals with ASD process contextual information and that their judgments may in fact be less, rather than more, veridical.

An unexpected and striking result, however, was that individuals with ASD simply failed to fixate the ball when it was actually thrown. Once the ball reached its zenith, it remained relatively stationary for approximately 100 ms, so there was a very short opportunity to fixate it. Although fixating the ball was a general oculomotor challenge for all participants, on 33% of the real throws participants in the TD group did fixate the ball during this time window. In contrast, participants in the ASD group fixated it rarely (13%), which suggests that they experienced a greater visuo-oculomotor challenge. In addition, participants in the ASD group spent less time looking at the ball and had a lower maximum height of fixation than participants in the TD group. Individuals with ASD may have particular problems in timing the allocation of attention. Indeed, our results suggest that participants in the ASD group had severe difficulties in fixating the moving ball, and this failure in looking at the ball may account for the higher level of deception in this group. The experience of seeing an illusory ball implies a failure in distinguishing between the real throws and the fake throw. Unpublished work from our lab has shown that if the ball is less visible on the first couple of real throws, participants are more susceptible to the illusion (see also Triplett, 1900). The ball is relatively small, and in order for it to be properly perceived it must be fixated. There is some tentative evidence for the importance of fixation in our TD group. For example, participants who did not fixate the ball on the final real throw rated the height of the illusory ball numerically higher (M = 7.2 cm, SD = 2.0 cm) than those who did fixate it (M = 5.9 cm, SD = 2.1 cm).

Why did individuals with ASD fail to fixate the ball? In complex dynamic situations, such as the one presented in our experiment, it is difficult to deploy attention to the relevant location at the right time. Although eye movements are often driven by bottom-up visual saliency, people frequently use top-down heuristics to plan the likely outcome of an event, which enables rapid deployment of attention to the desired location (Land & McLeod, 2000). In a complex task of fixating a moving ball against a background of social cues, including the magician's head and body motion, the timing of attention allocation may be particularly challenging and participants with ASD may have had difficulty executing an eye movement within the limited time window. In sum, people with autism may not be able to deploy attention rapidly enough to fixate a small moving ball even though in principle top-down strategies based on prior expectations and social cues are available to them.

Our results demonstrate that individuals with ASD were more susceptible to the vanishing-ball illusion than TD control participants. They were misdirected by the magician's social cues and looked immediately to the face, and they were similar to the TD group in terms of overall time spent looking at the face and the eyes. However, the speed of launching the first saccade to the face was slower in the ASD group than in the TD group. Moreover, participants with ASD had difficulties fixating the ball. Recently, it has been argued that movement perception is intact in people with ASD except in cases of high complexity (Bertone, Mottron, Jelenic, & Faubert, 2005). Our results suggest that individuals with ASD have problems in rapidly allocating attention both to people and to moving objects, a difficulty which in complex situations may result in serious perceptual challenges. The extent to which the temporal delays in allocating attention that we observed should be attributed to the social context of the test situation remains to be determined, as the vanishing-ball illusion relies on social as well as nonsocial cues. If individuals with ASD have a general problem in rapidly allocating attention, we would expect this to affect performance in all contexts—even those that do not involve people.

In conclusion, our evidence challenges the idea that adults with ASD have general social-attention difficulties (i.e., gaze avoidance). Apart from exhibiting a subtle delay in launching their first eye movement to the face, participants with ASD showed typical attention to social cues. However, they did not perform like TD individuals in response to the vanishing-ball illusion. Instead, they had problems allocating attention to the ball. Therefore, they performed differently from the TD group and were more susceptible to the illusion. Our findings therefore show that magic can change expectations about autism, and autism can also change expectations about magic.

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The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

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