**Exploiting failures in metacognition through magic: Visual awareness as a source of visual metacognition bias**

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**Abstract**

We used cognitive illusions/magic tricks to study the role of visual awareness as a source of biases in visual metacognitive judgments. We conducted a questionnaire-based study (*n* = 144) and an eye tracking study (*n* = 69) in which participants watched videos of four different magic tricks that capitalize on failures of visual awareness (inattentional blindness and change blindness). We measured participants’ susceptibility to these illusions, their beliefs about other people’s susceptibility, as well as the role that fixating (i.e. eye position) the critical event has on detecting the secret. Participants who detected the method of the tricks believed it was more likely that other people would detect it compared to those participants who failed to notice the method. Moreover, they believed that they moved their eyes to look at it. Eye tracking data show that, contrary to participants’ beliefs, peripheral vision played a significant role in detecting the method. Overall, the findings from these studies suggest that visual awareness may bias visual metacognitive judgments.

*Keywords:* visual metacognition; metacognitive biases; visual awareness; cognitive illusions; eye movements.

**1. Introduction**

Our visual experience supports the belief that we have a rich, uninterrupted visual mental representation of the world (Blackmore, 2002; Cohen, Dennett, & Kanwisher, 2016; Dennett, 2002). Current psychological and neurophysiological data demonstrate that this belief is a compelling illusion; one we rarely challenge. An indication of this erroneous belief can be seen in people’s surprise when they discover failures in visual awareness, such as inattentional blindness (Mack & Rock, 1998) and change blindness (Rensink, O’Regan, & Clark, 1997). For example, people are often astonished to discover they failed to notice the gorilla (Simons & Chabris, 1999), and the fact that this illusion has been viewed more than 50 million times online is a true testimony to how suprising it is. This surprise may be interpreted as resulting from overestimation of perceptual skills combined with erroneous beliefs about mental representations (Cohen, 2002; Dennett, 2002).

We have some insights into our cognitive processes (Nelson & Narens, 1994; Van Overschelde, 2008). For instance, we intuitively know that dividing attention reduces the ability to notice visual stimuli (Finley, Benjamin, & McCarley, 2014). However, we can be oblivious to some of our cognitive limitations (Kahneman, 2011), such as the failure to notice unexpected salient changes in our environment (Beck, Levin, & Angelone, 2007a; Levin, Momen, & Drivdahl, 2000), the inability to faithfully record events that we see and hear (Simons & Chabris, 2011), or the lack of color vision in the periphery of our visual fields (Dennett, 2005). This blindness to our blindness is one of the most striking features of metacognition.

There has been much research investigating metacognition in learning and memory, yet little is known about metacognition of perception (Levin, 2004). Understanding biases and errors in visual metacognition has important implications for the way we judge ourselves and others in real-world scenarios (e.g., eye witness testimonies, road safety litigations, perceptual errors in radiology). Whilst there is a large literature addressing cognitive failures that undermine real-life phenomena, much less is known about the metacognitive failures involved. Levin et al. (2000) have shown that failures in metacognition are particularly prominent in visual short-term memory. In their study, the experimenter described four scenarios after which participants were asked if they would notice the changes that took place. The majority of subjects reported that they would notice the changes, yet previous experiments revealed that most were missed (Levin & Simons, 1997; Simons and Levin, 1998). The discrepancy between what participants believed they would notice and the actual detection rates shows that people overestimate their change-detection ability; the same pattern of results was found when participants were asked about other people’s change detection abilities. Levin et al. (2000) suggest several explanations for why change blindness blindness (CBB) occurs. For example, people may think that salient stimuli will capture their attention automatically, and situations in which they successfully detect changes might lead them to overestimate their change-detection ability.

Beck et al. (2007a) showed that people were less susceptible to change blindness when they were told to look for changes, but they still failed to understand that directing attention intentionally improves their performance. Smilek, Eastwood, Reynolds and Kingstone (2007) criticized this study based on the fact that individuals rarely experience radical changes to stable and unchanging objects. Indeed, they found that people’s predictions are often better when the examples relate to real life situations in which they have personal experience (e.g., driving). However, Beck, Levin, and Angelone (2007b) argued that in real life, objects often change locations (e.g., a saltshaker is replaced with a spoon). In addition, people also exhibit inattentional blindness blindness (IBB). Levin and Angelone (2008) found that 88% of subjects predicted detecting the gorilla as opposed to the 42% that actually detected it in Simons and Chabris (1999).

Other studies on visual metacognition have examined subjects’ meta-attentional errors. The findings from these investigations are relevant because traditionally it has been claimed that attention is necessary for conscious visual awareness (Cohen, Cavanagh, Chun, & Nakayama, 2012). Kawahara (2010) asked participants to look at pictures and use a pen to delineate the shape(s) of their immediate attentional focus (foci). Subjects believed that they could divide their attentional spotlight and that it covered larger areas than those reported in laboratory studies. Moreover, a subsequent experiment revealed that participants were unable to direct their focus of attention to two opposite locations at the same time, which suggests that people have inaccurate intuitions about their ability to distribute attention over space.

Overt attentional processes are determined by where we look, and most of our eye movements are driven by unconsious processes. Consequently, we rarely reflect on where we look. However, there is evidence to suggest that we do have some insights into where we have looked in the past. A question that arises is whether participants’ reports on where they look indicate that they remember their scanpaths. Several studies have addressed this issue (Foulsham & Kingstone, 2013; Marti, Bayet, & Dehaene, 2015; Võ, Aizenman, & Wolfe, 2016). Võ et al. (2016) remark that information about fixations is not useful for most daily life activities, although it might be important for tasks where visual scrutiny is necessary such as scanning a medical image. Foulsham and Kingstone (2013) conducted several experiments to examine whether observers can recognize their own fixations. Participants viewed a series of natural scenes and their fixations were recorded using an eye tracker. They were asked to discriminate their fixation patterns from representations that corresponded to random patterns of fixations, fixations they made while viewing a different scene, and fixations made by another observer. Participants were able to discriminate between their scanpaths and a random pattern with an accuracy better than chance. However, their accuracy dropped when they had to distinguish their scanpaths from fixations they made while viewing a different scene and fixations made by another observer. It is not clear from these findings whether participants remembered where they looked or remembered the objects in the scene and therefore inferred that they looked at them.

Marti et al. (2015) examined whether subjects could report the fixations they made during a serial search task. Participants were asked to report the sequence of their eye fixations using mouse clicks and their reports were compared to recorded eye movements. The results suggested that they could introspect about their eye fixations to some extent. However, some of the actual fixations were not reported, and participants reported fixations that never occured. Marti et al. (2015) hypothesize that false reports indicate introspection of covert attentional shifts. Võ et al. (2016) ran two experiments using natural and artificial scenes. Participants were instructed to indicate where they looked and to guess where someone else would look by clicking on the scenes. To discourage participants from deliberately trying to encode their fixations, they were instructed to indicate where they looked by clicking on the scenes in only 25% of the trials. To measure memory for fixations, Võ et al. (2016) calculated the overlap between participants’ actual fixations and their clicks. They compared this measure with the overlap that would be produced by an ideal observer who has a perfect memory for fixations. Participants’ estimates of their own and someone else’s fixations were better than chance but far from an ideal observer’s estimate, and their performance was worse using artificial scenes. These studies suggest that observers have intuitions about where they look, although there is no compelling evidence that they can actually remember their scanpaths.

Overall, studies on CBB, IBB and meta-attention reveal counterintuitive limitations in cognition. Another example of a counterintuitive experimental finding is that people can fail to perceive a salient unexpected stimulus, even when they look at it (Beanland & Pammer, 2010; Memmert, 2006). The reason why this finding is counterintuitive is because we typically make voluntary eye movements towards a stimulus that is relevant to us, and in doing so we get a more detailed image of the area. Therefore, our intuition tells us that we should be able to consciously perceive an object that we are looking at. In many tasks, such as reading, it is essential to fixate the appropiate position in the word, to ensure that each letter can be perceived. In many everyday tasks, such as making a cup of tea (Land, Mennie, & Rusted, 1999) or a sandwich (Hayhoe, Shrivastava, Mruczek, & Pelz, 2003), our eyes fixate the objects that are central to the task. Our visual acuity drops sharply with eccentricity, as cones are sparser in the periphery (Holmqvist et al., 2011), and consequently our peripheral vision is poor. However, a common misconception is that peripheral vision contributes very little or nothing at all to object recognition. For example, observers can perform recognition tasks without executing multiple fixations which indicates that object recognition “involves significant peripheral processing” (Rosenholtz, 2016, p. 442).

The popular phrase “keep your eyes on the road” illustrates the common-sense idea that looking means seeing[[2]](#footnote-2). However, numerous studies have shown that fixations alone cannot account for conscious visual perception. For example, Mack and Rock (1998) have shown that people are equally (if not more) attentionally blind to stimuli that appear at fixation compared to those in the periphery (see Most, Simons, Scholl, & Chabris, 2000, for similar results using a dynamic display). Similarly, using the gorilla illusion (Simons & Chabris, 1999), Memmert (2006) showed that detection of the gorilla was independent of whether it was looked at or not.

Using static scenes Henderson and Hollingworth (1999) have shown a clear relationship between visual eccentricity and change detection. However, studies using dynamic displays have found no significant relationship. For example, Smith, Lamont and Henderson (2012) found that people fail to detect a change even if they fixate the object that changes. This study used a magic trick that depicted a pair of hands passing a coin and then dropping it on the table. In the critical trial, the coin was secretly replaced for another one. Participants watched a series of videos and had to guess whether the coin would land with heads or tails facing up. Most of them failed to detect the change after the first presentation despite the fact that they had fixated the coin before and after the change.

In recent years there has been much interest in using magic to study a range of cognitive processes and failures of visual awareness (Kuhn, Amlani, & Rensink, 2008; Rensink & Kuhn, 2015; Thomas, Didierjean, Maquestiaux, & Gygax, 2015). Most previous research on IB and CB that have used magic tricks simply asked people to report whether they detected the method or not. Whilst misdirection exploits meta-cognitive errors in perception, none of these previous studies have investigated people’s beliefs about whether they or others are able to detect the secret. As such, our study is the first to empirically investigate people’s meta-cognitive biases in perception.

Magic tricks create a conflict between our beliefs and our experience, and magicians use misdirection to create these effects (Kuhn, Caffaratti, Teszka, & Rensink, 2014). Misdirection involves exploiting counterintuitive limitations in cognition, and as such it provides the ideal tool to investigate failures in metacogntion. Misdirection provides effective ways to control spectators’ overt attention (Barnhart & Goldinger, 2014, Kuhn & Findlay, 2009; Kuhn & Tatler, 2005; Kuhn, Tatler, Findlay, & Cole, 2008; Kuhn & Teszka, 2017) and consequently it has been useful to explore the relationship between eye movements and failures of visual awareness.

In 1893 Max Dessoir noted how misdirection can be used to induce a “state of mental blindness” and more importantly that our perception can be independent of where we look. He stated that “success lies in the *ars artem celandi,* the art of so influencing the observer that one can do everything before his nose without his noticing it”. Much of the recent work on misdirection supports Dessoir’s idea.

In the experiment conducted by Kuhn et al. (2008), participants watched a magic trick consisting of the vanishing of a cigarette. To accomplish this trick, the magician simply dropped the cigarette into his lap, whilst misdirecting the spectator’s attention. Eye movement data revealed that the distance between participants’ fixations and the dropping cigarette was not predictive of inattentional blindness (see also Kuhn & Findlay, 2009). Barnhart and Goldinger (2014) used a trick in which a coin vanishes from a starting location and reappears in a different location. The method used to accomplish this illusion spans a longer period of time than previous studies (Kuhn et al., 2008; Kuhn & Findlay, 2009), thereby allowing more time for participants to make fixations on the critical stimulus. Their results showed that fixations predict inattentional blindness under conditions of low perceptual load and longer exposure to the critical stimulus. However, on the whole, most of the research on inattentional blindness suggests that awareness of an unexpected stimulus is largely independent of where people look.

The aim of the present investigation was to study the role of visual awareness as a source of biases in visual metacognitive judgments. We used four different types of magic tricks that exploit four different cognitive failures. The first two tricks relied on inattentional blindness in which participants typically fail to perceive a brief (Kuhn & Findlay, 2009) or sustained event (Barnhart & Goldinger, 2014). Two further tricks were used that rely on change blindness in that observers typically fail to notice the difference between two mental representations (see Jensen, Yao, Street, & Simons, 2011). In the color-change trick (Smith, Lamont, & Henderson, 2013), the change takes place in full view, whilst in the princess card trick (Kuhn, Teszka, Tenaw, & Kingstone, 2016) the change is hidden.We used these cognitive illusions/magic tricks to examine two types of metacognitive biases. Firstly, we evaluated participants’ beliefs about other people’s susceptibility to the cognitive illusions and the extent to which these beliefs were modulated by their own susceptibility towards the illusions. Secondly, we examined participants’ beliefs about the relationship between looking and seeing and the extent to which their visual awareness influenced their beliefs about where they were looking at the time the event took place.

**2. Study 1**

Participants were asked to watch four different short magic tricks that all employed different forms of misdirection to prevent them from noticing a highly salient critical event (i.e., the method). The color-change trick exploits change blindness while spatial attention is misdirected, the lighter trick and the coin trick exploit inattentional blindness, and the princess card trick exploits change blindness. We measured participants’ susceptibility to these illusions, their beliefs about other people’s susceptibility, as well as the role that fixating the critical event has on detecting the secret.

*2.1. Method*

*2.1.1. Participants*

One hundred forty-four undergraduate students at Goldsmiths, University of London participated in the study in exchange for class credit (mean age: 28.8; 120 females). All participants were naïve about the aim of the study. The actual number of participants included for the analysis of each trick was between 122 and 136 due to incomplete questionnaires[[3]](#footnote-3).

*2.1.2. Materials and procedure*

The following four cognitive illusions were used:

***The color-change trick.*** This is a card trick in which explicit misdirection is used to prevent participants from noticing a salient color change. We used a modified version of the trick by Smith et al. (2013). The magician (first author) shuffles a deck of blue-backed cards and asks the participant to count the number of red cards (i.e., numbers and figures) that are dealt face up on the table. Once complete, she shows that the backs of the cards have changed from blue to red. To accomplish this effect, the magician used a set of blue and red cards. Only the red-backed cards are shown in the reveal. The magic trick was filmed at 29 fps using a Nikon COOLPIX L830 digital camera. The video was edited in MAGIX Movie Edit Pro 2014 Plus and has a duration of 64 seconds. The period when the color change takes place and the red cards remain visible lasts for 7.3 seconds (supplementary video S1).

***The lighter trick.*** Here the magician uses misdirection to prevent participants from noticing that he drops a lighter from his hand, a trick previously used by Kuhn and Findlay (2009). The magician picks up a lighter with his left hand and lights it. He pretends to take the flame with his hand and moves it away. He then shows that the flame is gone. He turns his attention to the other hand, snaps his fingers and shows that the lighter has vanished. To accomplish this trick, the magician drops the lighter into his lap. This method happens in full view. In Kuhn and Findlay (2009), 13 participants (65%) saw the lighter drop. The trick lasts 13.7 seconds, and the dropping of the lighter is visible for 120 milliseconds (supplementary video S2).

***The princess card trick.*** Here misdirection is used to prevent participants from noticing that the values of the playing cards have changed. This version was based on the trick used by Kuhn et al. (2016). Five cards are displayed in a fan, and the spectator is asked to think of one. The magician (first author) pretends to make the thought-of card vanish, and fans the cards in hand to show that it is gone. The method consists of secretly changing the value of all of the cards, thus ensuring that any thought-of card is no longer present. Whilst this trick involved two effects (i.e. a card disappears, and the magician knows the card’s identity), participants were only asked about whether they discovered why their chosen card, rather than any of the other cards disappeared. The magic trick was filmed at 29 fps using a Nikon COOLPIX L830 digital camera. The video was edited in MAGIX Movie Edit Pro 2014 Plus and has a duration of 47 seconds (supplementary video S3).

***The coin trick.*** Here misdirection is used to prevent spectators from noticing that a coin moves visibly from one location to another. We used the trick by Barnhart and Goldinger (2014). The effect is the disappearance of a coin placed under a napkin, and its reappearance under a different napkin. The method used to accomplish this effect was to make the coin slide across the placemat from one location to another. The video clip lasted 32 seconds, and the moving coin is visible for 550 milliseconds. In Barnhart and Goldinger (2014) 15 participants (45.4%) noticed the moving coin (supplementary video S4).

The study was conducted in a classroom and the data were collected on-line in a single session. Participants were asked to watch a series of video clips that were displayed on a large screen (approx. 8 m by 6 m). At the end of each video clip, they were asked to answer a questionnaire (for wordings see Appendix). On the first page, they had to report whether they had seen the video clip before and whether they noticed how the trick was done. If they answered yes to the latter question, they had to describe the method used to create the illusion. It might be argued that observers’ responses indicate that they found out the secret after a reasoning process and not because they have perceptually noticed it (Kuhn et al., 2008). However, Kuhn and Findlay (2009) showed that participants’ reports for the lighter trick reflected what they saw, and not how they thought the trick was done. Barnhart and Goldinger (2014) addressed the problem of inference by implementing a method in the coin trick which disallows inference. Similarly, it is very difficult to figure out how the princess card trick or the color-change trick work without noticing the change. We are therefore confident that their reports of the method reflect perceptual experiences.

For each of the tricks, participants were shown different figures that described the method, and they were asked to answer other questions. In the figures for the color-change trick, the lighter trick, and the coin trick (Figure 1), a green circle indicated the location where the method of the trick occurred (method area) and a yellow circle indicated the location where an action to control participants’ attention took place (misdirection area). In the figure for the princess card trick, there were two images. The image to the left showed the five cards presented at the beginning of the trick, and the image to the right showed four different cards that were presented at the end of the trick (Figure 2).

|  |  |  |
| --- | --- | --- |
| a. | b. | c. |
|  |  |  |
| **Fig. 1.** In the color-change trick figure (a), the green circle indicates the area where the color change took place and the yellow circle indicates the location of the cards that participants had to count. In the lighter trick figure (b), the green circle indicates the location of the dropping lighter and the yellow circle indicates the face of the magician. In the coin trick figure (c), the green circle indicates the space where the coin moved and the yellow circle indicates the location of the empty cup shown by the magician. | | |

|  |  |
| --- | --- |
| a. | b. |
|  |  |
| **Fig. 2.** The cards presented at the beginning of the trick (a) were different from the cards presented at the end of the trick (b). | |

For the magic tricks that involved controlling overt attention (i.e., the color-change trick, the lighter trick and the coin trick), participants were asked to estimate the likelihood of someone else noticing the method of the trick and the likelihood of having moved their eyes to the area indicated by the green circle at the time where the secret method took place. Then, they had to indicate the likelihood of noticing the method when looking at the green circle (i.e., foveal vision judgment), compared to when looking at the yellow circle (i.e., peripheral vision judgment).

For the princess card trick, participants were asked to estimate the likelihood of someone else to notice that the cards changed, the likelihood that they looked only at the selected card, and the likelihood of noticing the method when looking only at the selected card and when looking at all the cards.

The likelihood judgments were done on a scale ranging from 1 (“very unlikely”) to 10 (“very likely”). No other variables were measured.

*2.2. Results*

Participants were classified as having detected the method if they answered yes to whether they noticed how the trick was done and described it accurately. The method was noticed by 41.4% of participants in the color-change trick, 15% of participants in the lighter trick, 75% of participants in the coin trick, and 43.4% of participants in the princess card trick.

*2.2.1. Influence of visual awareness on the metacognitive judgment about whether someone else would notice a salient stimulus*

We explored the relationship between people’s own ability in detecting the method and their judgments of others. Table 1 shows the likelihood estimates of detecting the method as a function of whether they detected the method themselves or not. Two things become apparent when looking at Table 1. Firstly, participants generally overestimated other people’s ability to detect the method. Whilst an average of 44% of participants detected the method across all four tricks, they judged that people would be rather likely to notice it. Secondly, participants’ judgments about other people’s perceptual abilities are related to their immediate perceptual experience. Noticing the method significantly increased participants’ estimates that others would notice it too.

**Table 1**

Likelihood judgment of whether someone else would notice the method as a function of detection

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trick | Detection | *n* | *%* | *Mdn* | *U* | *p* | *r* |
|  |  |  |  |  |  |  |  |
| Color-change trick | No | 75 | 59% | 5 | 2862 | < .001 | .38 |
|  | Yes | 53 | 41% | 7 |  |  |  |
|  |  |  |  |  |  |  |  |
| Lighter trick | No | 113 | 85% | 5 | 1590 | .003 | .25 |
|  | Yes | 20 | 15% | 6 |  |  |  |
|  |  |  |  |  |  |  |  |
| Coin trick | No | 34 | 25% | 5 | 2820 | < .001 | .47 |
|  | Yes | 102 | 75% | 8 |  |  |  |
|  |  |  |  |  |  |  |  |
| Princess card trick | No | 69 | 57% | 3 | 2736 | < .001 | .43 |
|  | Yes | 53 | 43% | 6 |  |  |  |

*2.2.2. Influence of visual awareness on the metacognitive judgment about the deployment of overt attention*

Next, we looked at participants’ reports on where they believed to be looking at the time of the method, as a function of whether they saw how the trick was done or not. Table 2 shows that participants who detected the method were significantly more likely to believe that they had moved their eyes to the method area compared to those who failed to notice it.

**Table 2**

Likelihood judgment of having deployed overt attention to the method area as a function of detection

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trick | Detection | *n* | *Mdn* | *U* | *p* | *r* |
|  |  |  |  |  |  |  |
| Color-change trick | No | 75 | 4 | 3116 | < .001 | .49 |
|  | Yes | 53 | 7 |  |  |  |
|  |  |  |  |  |  |  |
| Lighter trick | No | 113 | 4 | 1660 | .001 | .29 |
|  | Yes | 20 | 7 |  |  |  |
|  |  |  |  |  |  |  |
| Coin trick | No | 34 | 4 | 2924 | < .001 | .52 |
|  | Yes | 102 | 8 |  |  |  |

**The princess card trick**. There is no physical method area for the princess card trick, and so we used a different analysis. We examined whether participants believed that noticing the change was related to the number of cards they fixated before the change. A significantly higher number of participants (69%) estimated that it is more likely to notice that the cards changed if they looked at all the cards than if they looked only at the selected card χ*2* (1, *n* = 122) = 17.3, *p* < .001. However, the estimated likelihood of having looked only at the selected card was not significantly different between those who noticed that the cards changed and those who failed to notice it *U* = 1.474, *z* = -1.84, *p* = .065.

*2.2.3. Looking and seeing*

In this analysis we explored participants’ beliefs about why people would fail to detect the method. We obtained one score by dividing the estimate of detecting the method when foveated (i.e., foveal judgment) by the estimate of detecting the method when people looked elsewhere (i.e., peripheral judgment). We calculated the percentage of participants who scored higher than one, indicating that they believed it is more likely to detect the method using foveal vision than using peripheral vision, whereas scores less than or equal to one indicated that they believed it is more (or equally) likely to detect the method using peripheral vision than using foveal vision.

For all three effects, a significantly higher number of participants indicated that it is more likely to detect the critical event when fixating the method area than when fixating the misdirection area: Color-change trick (69.5%), lighter trick (75.9%), coin trick (75.7%) (Table 3).

**Table 3**

Differences between the foveal and the peripheral judgment

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trick | Type of judgment | *Mdn* | *z* | *p* | *r* |
|  |  |  |  |  |  |
| Color-change trick | Foveal | 8 | -8.24 | < .001 | -.51 |
|  | Peripheral | 4 |  |  |  |
|  |  |  |  |  |  |
| Lighter trick | Foveal | 8 | -8.42 | < .001 | -.52 |
|  | Peripheral | 3 |  |  |  |
|  |  |  |  |  |  |
| Coin trick | Foveal | 9 | -8.63 | < .001 | -.52 |
|  | Peripheral | 5 |  |  |  |

These results suggest that participants believed that failure to detect the method resulted from looking at the wrong spatial location.

*2.2.4. Peripheral vision judgment*

To get a sense of how likely participants believed it to be to notice the method peripherally, we calculated the percentage of subjects who claimed that they would be likely to notice the method without fixating it (scores 6 and higher) in the color-change trick (25%), the lighter trick (14.3%), and the coin trick (49.3%). These values comport with the previous results. Participants clearly believed that detection of the method was contingent upon fixating the method area.

*2.3. Discussion*

Our results show that participants generally overestimated other people’s ability to notice the method, and that visual awareness influences visual metacognitive judgments. Participants who detected the trick’s method believed that it was more likely that others would do so compared to those who missed it. Moreover, they believed it was more likely that they moved their eyes to the method area compared to those who failed to notice the method. While this might be the case, other studies show that misdirection is effective to control where people look as well as their covert attention (Barnhart & Goldinger, 2014; Kuhn & Findlay, 2009; Kuhn & Tatler, 2005; Kuhn et al., 2008), and thus it is likely that they looked elsewhere. Although visual awareness modulated participants’ judgment about the deployment of their visual attention, we did not directly measure their eye movements to test for differences between actual and perceived gaze.

Interestingly, even though participants’ spatial attention was directed explicitly to the misdirection area in the color-change trick, those who noticed the method were very confident that they looked at the method area. Their overt attention could have been automatically directed to the color change. However, we believe that this is unlikely, as looking at the misdirection area was task-relevant. In Smith et al. (2013) all participants fixated the faces of the cards while they were counting. Additionally, subjects believed that it is more likely to notice the method if they foveate it. Although the relationship between fixation and detection was not examined in this study, past research suggests that performing highly demanding tasks may render people blind to salient stimuli even if they fixate them (Beanland & Pammer, 2010; Memmert, 2006), and this blindness might occur when performing a less demanding task (Smith et al., 2012). Finally, few participants believed that detection under peripheral vision was likely. However, previous studies using the misdirection paradigm show that the number of peripheral detectors was significant (Kuhn & Findlay, 2009; Kuhn & Tatler, 2005; Kuhn et al., 2008). Because magic tricks were presented in a classroom, it was not possible to counterbalance the order of the clips nor to control the viewing distance. These factors could have affected the overall detection rates, but it is unlikely that they would have systematically affected people’s metacognitive judgments.

**3. Study 2**

The first study provided evidence that metacognitive judgments differed between participants who detected the method and those who missed it. We conducted an eye tracking study to examine whether participants’ judgment about where they looked would be driven by their visual awareness rather than eye movements, and to gain additional insights into the relationship beween looking and seeing, and in particular people’s beliefs about this relationship.

*3.1. Method*

*3.1.1. Participants*

Sixty-nine undergraduate students at National University of Colombia participated in the study in exchange for partial fulfillment of a class requirement (mean age: 21.2; 32 females). All participants had normal or corrected-to-normal vision and were naïve about the aim of the study. The actual number of participants included for the analysis of each trick was between 58 and 65 due to poor eye tracking recording (i.e., missing samples during period of interest), or incomplete questionnaires[[4]](#footnote-4).

*3.1.2. Materials and procedure*

Participants were tested individually in the Cognitive Neuroscience and Communication Laboratory. We used the video clips from Study 1 which were displayed on a 23 in. TFT screen (Tobii Technology) at a viewing distance of 60 cm via Tobii Studio 3.4.0 software. Eye movements were monitored using a Tobii TX300 eye tracker, binocularly, at a sampling rate of 300Hz. Eye movements were calibrated using a nine-point calibration procedure, and the order of the clips was counterbalanced. We asked participants to watch a series of video clips and answer a questionnaire at the end of each. We used the questionnaires of the first study.

*3.1.3. Data preparation*

A velocity-based algorithm was used to convert raw data into fixations when the eyes moved slower than 30 degrees/second for a period of at least 100 milliseconds. For the magic tricks that involved misdirecting spatial attention, we created dynamic areas of interest (AOIs) that were active during the period when the method of the trick occurred. Participants were categorized as having fixated the method area when they made one or more fixations on this location that lasted for at least 100 milliseconds during the critical period.

***Color-change trick.*** We defined two AOIs during the period when the color change occurred and the red-backed cards remained visible (7.3 seconds): 1. The location of the cards that were face-down in the magician’s hand (method area), and 2. The location of the cards that were dealt face-up on the table (misdirection area) (supplementary video S5).

***Lighter trick.***We defined three AOIs during the period when the lighter dropped (120 milliseconds): 1. The magician’s left hand that drops the lighter (method area), 2. The magician’s face (misdirection area), and 3. The magician’s right arm (supplementary video S6).

***Coin trick.*** We defined five AOIs during the period when the coin slid on the placemat (550 milliseconds): 1. The napkin under which the coin was hidden, 2. The napkin under which it was discovered, 3. The space between the napkins (method area), 4. The cup that was displayed to the camera (misdirection area), and 5. The magician’s face (supplementary video S7).

***Princess card trick.*** We drew the AOIs around the indexes which convey the information about the identity of the cards (supplementary video S8).

*3.2. Results*

Participants were classified as having detected the method if they answered yes to whether they noticed how the trick was done and described it accurately. The method was noticed by 39.7% of participants in the color-change trick, 54.1% of participants in the lighter trick, 78.5% of participants in the coin trick, and 50% of participants in the princess card trick.

*3.2.1. Influence of participants’ visual awareness on their judgment on whether someone else would notice a salient stimulus*

We examined whether participants’ own experience influenced their beliefs about other people’s perceptual abilities (Table 4). For the color-change trick, and the coin trick, participants who detected the method were more confident in others spotting the tricks than those who missed it. Whilst the medians for the lighter trick and the princess card trick went in the predicted direction, the differences were not significant.

**Table 4**

Likelihood judgment of whether someone else would notice the method of the magic trick

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Trick | Detection | *n* | *%* | *Mdn* | *U* | *p* | *r* |
|  |  |  |  |  |  |  |  |
| Color-change trick | No | 35 | 60% | 4 | 658 | < .001 | .54 |
|  | Yes | 23 | 40% | 7 |  |  |  |
|  |  |  |  |  |  |  |  |
| Lighter trick | No | 28 | 46% | 5 | 586 | .07 | .23 |
|  | Yes | 33 | 54% | 6 |  |  |  |
|  |  |  |  |  |  |  |  |
| Coin trick | No | 14 | 22% | 4 | 586 | < .001 | .46 |
|  | Yes | 51 | 78% | 7 |  |  |  |
|  |  |  |  |  |  |  |  |
| Princess card trick | No | 30 | 50% | 4 | 566 | .08 | .22 |
|  | Yes | 30 | 50% | 6 |  |  |  |

*3.2.2. Relationship between detection and fixation*

We examined whether method detection was related to fixating the critical event. Table 5 shows the number of participants who detected the method as a function of whether or not they fixated the method area.

**Table 5**

Number of participants as a function of detection and fixated area

|  |  |  |  |
| --- | --- | --- | --- |
| Trick | Detection | Fixated the method area | Did not fixate the method area |
|  |  |  |  |
| Color-change trick | No | 0 | 35 |
|  | Yes | 5 | 18 |
|  |  |  |  |
| Lighter trick | No | 0 | 28 |
|  | Yes | 10 | 23 |
|  |  |  |  |
| Coin trick | No | 2 | 12 |
|  | Yes | 14 | 37 |

***Color-change trick.*** Participants who fixated the method area were more likely to detect the method than those who fixated elsewhere (*p* = .007, two-tailed Fisher’s exact test). The odds ratio indicates that the odds of detecting the color change were 21.1 higher if they were fixating the method area than the odds of detecting the color change if they were fixating elsewhere. However, the majority of participants who detected the method (78.3%) did not look at the method area.

***Lighter trick.*** Participants who fixated the method area were more likely to detect the method than those who fixated elsewhere (*p* = .001, two-tailed Fisher’s exact test). The odds ratio indicates that the odds of detecting the dropping lighter were 25.4 higher if they were fixating the method area than the odds of detecting the dropping lighter if they were fixating elsewhere. However, the majority of participants who detected the method (69.7%) did not look at the method area.

***Coin trick.*** There was no significant relationship between fixating the method and detection (*p* = .487, two-tailed Fisher’s exact test). The majority of participants who detected the method (72.5%) did not look at the method area.

*3.2.3. Influence of participants’ visual awareness on their judgment about their deployment of overt attention*

Next, we explored the relationship between whether participants detected the method and their belief about where they were looking. Participants who detected the method peripherally were significantly more confident in having moved their eyes to the method area compared to those who missed it (Table 6).

**Table 6**

Likelihood judgment of having deployed overt attention to the method area as a function of detection (only peripheral detectors are included)

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Trick | Detection | *n* | *Mdn* | *U* | *p* | *r* |
|  |  |  |  |  |  |  |
| Color-change trick | No | 35 | 3 | 556 | < .001 | .62 |
|  | Yes | 18 | 8 |  |  |  |
|  |  |  |  |  |  |  |
| Lighter trick | No | 28 | 3 | 524 | < .001 | .54 |
|  | Yes | 23 | 8 |  |  |  |
|  |  |  |  |  |  |  |
| Coin trick | No | 12 | 2.5 | 408 | < .001 | .62 |
|  | Yes | 37 | 8 |  |  |  |

***The princess card trick.*** Thirty participants (50%) detected that the cards changed. Those who failed to notice that the cards changed were more confident in their belief that they looked at only one card (*Mdn* = 9), compared to those who detected the change (*Mdn* = 4) *U* = 191 *z* = -3.88, *p* < .001. Using eye tracking data, we identified that, on average, participants looked at four out of the five cards. The recordings indicated that both groups fixated the same proportion of cards (*Mdn* = 0.8). Furthermore, most participants (95%) estimated that it is more likely to notice that the cards changed if they look at all the cards than if they look only at the selected card. Results from the princess card trick provide further evidence that participants’ awareness of where they look is driven by their experience of detection rather than eye movements.

*3.2.4. Looking and seeing*

We performed the same analysis as in Study 1 to examine participants’ belief about the relationship between seeing the method and fixating the critical event. As in Study 1, for all three effects, most participants indicated that it is more likely to detect the critical event when fixating the method area than when fixating the misdirection area: Color-change trick (97%), lighter trick (95%), coin trick (93%) (Table 7). Once again, this suggests that people assume a strong relationship between eye movements and awareness.

**Table 7**

Differences between the foveal and the peripheral judgment

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Trick | Type of judgment | *Mdn* | *z* | *p* | *r* |
|  |  |  |  |  |  |
| Color-change trick | Foveal | 9 | -6.53 | < .001 | -.61 |
|  | Peripheral | 3 |  |  |  |
|  |  |  |  |  |  |
| Lighter trick | Foveal | 9 | -6.31 | < .001 | -.58 |
|  | Peripheral | 3.5 |  |  |  |
|  |  |  |  |  |  |
| Coin trick | Foveal | 9 | -6.54 | < .001 | -.57 |
|  | Peripheral | 3 |  |  |  |

*3.2.5. Peripheral vision judgment*

As we did in Study 1, we calculated the percentage of subjects who claimed that they would be likely to notice the method without fixating it (scores 6 and higher) in the color-change trick (21%), the lighter trick (23.3%), and the coin trick (20%). Although few participants believed that detection under peripheral vision was likely, most of them were peripheral detectors (Figure 3). This result indicates that participants underestimated the role of peripheral vision in visual awareness.

**Fig 3.** Fewer than 30% of participants said it was likely to detect the method under peripheral vision. However, eye tracking data showed that a significant number of subjects (over 60%) detected the method using peripheral vision rather than foveal vision.

*4. Discussion*

As in Study 1, participants who detected the method of the tricks judged as more likely that others would also notice it. Additionally, they believed that they moved their eyes to the method area. However, eye tracking data revealed that most of them were peripheral detectors. Failure to detect the change in cards in the princess card trick (Study 2), led participants to believe that they only looked at one card when in fact they looked at a similar number of cards as those who noticed the change. Again, this suggests that their visual awareness biased their belief about where they looked. We found a significant relationship between detection and fixation in the color-change trick and the lighter trick, which is compatible with participants’ intuition that they are more likely to notice the method when looking at the critical event. However, the number of peripheral detectors was significant, which stands in disagreement with their underestimation of peripheral vision and disproves their belief that they made eye movements to the method area.

These results show that relying on experience can result in biased metacognitive judgments, such as thinking that other people would be more or less likely to notice a salient event, reporting false fixations, and underestimating the role of peripheral vision in visual awareness.

**5. General discussion**

Previous studies have shown that we are often blind to salient stimuli and changes that we don’t attend to (Mack & Rock, 1998; Rensink et al., 1997; Simons & Chabris, 1999). However, we don’t just fail to notice things; we are typically surprised that we failed to notice them, and surprise is a compelling sign that we have false beliefs about cognition. We expanded the scientific knowledge about visual metacognition by studying visual awareness as a source of some of these false beliefs.

We used magic tricks to study biases in visual metacognition, as they naturally exploit counterintuitive limitations in cognition (Kuhn et al., 2014). We found that participants were biased by their visual experience when making metacognitive judgments. Our results showed that participants’ who detected the secret method were more likely to judge that others would do so, than those who missed it. Our four magic tricks relied on four different types of cognitive failures; IB for sustained and brief events, CB for changes that occur in full view or occluded, and yet the same pattern of results was found for all illusions in Study 1 and two illusions in Study 2. These magic tricks provide a natural way of studying cognitive failures, and our results demonstrate that judgments about other people’s susceptibility to IB and CB in different contexts are driven by their experience of having detected the method or not.

Why do these biases in metacognition occur? A dual-process perspective (Koriat, Nussinson, Bless, & Shaked, 2008) presumes that metacognitive judgments are based on two types of processing: System 1 and System 2 (Stanovich and West, 2000). System 1 is an unconcious, fast and automatic processing whilst System 2 is a deliberate, slow and effortful processing (Kahneman, 2011). System 1 processing may lead to biased metacognitive judgments because it’s based on implicit inputs (Thompson, 2009) and therefore people do not have control over the factors that determine these judgments (Kelley & Jacoby, 1996). In contrast, System 2 processing may lead to more accurate metacognitive judgments because people will gain more control over the factors that come into play by applying rules and theories systematically (Kelley & Jacoby, 1996).

Kelley and Jacoby (1996) provided evidence in a non-perceptual domain that illustrates how subjective experience biases judgments about other people’s capabilites. They showed that the ease by which participants solved anagrams influenced their judgment about how difficult it would be for other people to solve them. Consistent with the dual-process perspective, they found that blocking subjective experience by giving participants the anagrams along with the solution words resulted in a more effortful approach to the task in that they made the difficulty ratings more slowly compared to those who had to solve the anagrams.

Stanovich and West (2000) explain that one of the main differences between System 1 and System 2 is that the former leads to highly contextualized and personalized construals whereas the latter is useful to decontextualize and depersonalize problems. System 1 recruits prior knowledge and beliefs and sometimes leads to biases (Thompson, 2009). Kahneman (2011, p. 80) explains that “when uncertain, System 1 bets on an answer, and the bets are guided by experience. The rules of betting are intelligent: recent events and current context have the most weight in determining an interpretation”. The availability heuristic may account for participants’ belief that others would be very likely to detect a salient event when they themselves have detected it. Future experiments could address this interesting issue and examine whether observers generalize from their visual awareness to make metacognitive judgments instead of using an analytic approach based on theories and rules.

In the current experiment, participants’ judgments about where they looked were driven by the experience of having detected the method or not, rather than their actual eye movements. Other experiments have shown that people report fixations that they never made (Marti et al., 2015; Võ et al., 2016), but they did not assess how confident subjects were about their responses, which could have revealed more about their meta-attention. In Study 1, participants who noticed the method of a trick were very confident that they fixated the method area compared to those who missed it, thus revealing their intuition that failure to spot the trick results from not looking at the critical event. However, in Study 2 we found that the majority of participants who detected the method used peripheral vision. We suggest that people’s beliefs about where they are looking are driven by their visual awareness, rather than the oculomotor system itself. Conversely, it is possible that people who detected the method (perhaps by peripheral vision in the case of motion) may have a demand characteristic to infer they looked there. People’s beliefs about their fixations may have been influenced not only by their subjective memory of the locations fixated, but also by knowledge of their detection performance.

Our results also suggest that people underestimated the role of peripheral vision. Scientific evidence has shown that peripheral vision plays an important role in object recognition (Rosenholtz, 2016). In a study comparing eye movements of pathologists, students, and residents, Krupinski et al. (2006) found that pathologists used peripheral vision more frequently than the other participants to select areas of interest for further inspection. Both pathologists and inexperienced observers selected common locations, but pathologists made fewer fixations. Overall, these results suggest that pathologists were more efficient at scanning the images. Several visual tasks that use a brief exposure suggest that we can extract a lot of information from a scene through a single glance, thus relying significantly on peripheral vision (Greene & Oliva, 2009; Rousselet, Joubert, & Thorpe, 2005; Thorpe, Fize, & Marlot, 1996). This kind of evidence has been taken to support the notion that the visual system represents ensembles and not just individual items (Cohen et al., 2016), and peripheral vision makes an important contribution to creating these ensembles.

Finally, participants in the current experiments believed that observers will be more likely to notice a salient stimulus if they fixate it. The results from the eye tracking study agree with this intuition, but also indicate that fixations are not necessary for visual awareness. Other studies that used tasks exploiting the limits of central attention have found that IB occurred even when the unexpected stimulus appeared at fixation (Beanland & Pammer, 2010; Memmert, 2006; Most et al., 2000). Furthemore, studies using the misdirection paradigm report a dissociation between where people look and what they see (Kuhn & Findlay, 2009; Kuhn & Tatler, 2005; Kuhn et al., 2008). Together, these findings indicate that fixations alone cannot account for conscious visual perception.

The findings from the present research do not support the widely held notion that observers believe that their experience of the world is uniformly rich from the centre out to the periphery of their visual fields (Dennett, 2005). Noë (2002), termed this notion “the snapshot conception of experience”. On the contrary, it provides evidence that in some instances observers believe that noticing salient stimuli is less likely when they are located in the periphery and that eye movements play an important role in visual awareness. The experience of surprise when confronted with failures of visual awareness may not necessarily indicate that observers have a snapshot conception of experience. Noë (2002) points out that surprise could be explained in different ways. For instance, individuals might be surprised simply because they believe that they are better noticers than they actually are. We think that participants’ metacognitive judgments are at odds with the snapshot conception of experience. In contrast, these judgments are congruent with the notion that perception is a process of actively extracting information from the environment through eye movements.

**Supplementary material**

Supplementary material associated with this article can be found in the online version.

**Acknowledgements**

This research was supported by the Administrative Department of Science, Technology and Innovation (COLCIENCIAS), Bogotá D.C., Colombia. We are grateful to Maria Fernanda Lara Ph.D., for providing access to the eye tracker at the Cognitive Neuroscience and Communication Laboratory (National University of Colombia). We thank Marisol Lamprea Ph.D., for inviting her students to participate in the studies. We also thank everyone who participated in this research.

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**Appendix**

Questionnaires used in study 1 and 2

**Color-change trick**

1. How many red cards did you count?
2. Have you watched this video clip before? (Yes/No)
3. Did you notice when the cards changed color? (Yes/No)

If yes, please describe when you saw it:

1. Did you notice the cards change from blue to red during the dealing? (Yes/No)

(Participants have to rate the following on a scale from 1 – “very unlikely” – to 10 – “very likely”.)

1. How likely is it for someone else to notice the back of the cards changed color?
2. How likely is it that you moved your eyes to look at the area indicated by the green circle, after the back of the cards changed from blue to red?
3. If you look at the area indicated by the green circle, how likely is it that you will notice that the back of the cards changed color?
4. If you look at the area indicated by the yellow circle, how likely is it that you will notice that the back of the cards changed color?

**Lighter trick**

1. Have you watched this video clip before? (Yes/No)
2. Did you notice how the magician made the lighter disappear? (Yes/No)

If yes, please describe how:

1. Did you notice the magician drop the lighter? (Yes/No)

(Participants have to rate on a scale from 1 – “very unlikely” – to 10 – “very likely”.)

1. How likely is it for someone else to notice the magician dropped the lighter?
2. How likely is it that you moved your eyes to look at the area indicated by the green circle, just when the magician dropped the lighter?
3. If you look at the area indicated by the green circle, how likely is it that you will notice that the magician dropped the lighter?
4. If you look at the area indicated by the yellow circle, how likely is it that you will notice that the magician dropped the lighter?

**Coin trick**

1. Have you watched this video clip before? (Yes/No)
2. Did you notice how the coin disappeared from one location and reappeared in another spot? (Yes/No)

If yes, then please describe how:

1. Did you notice that the coin slid across the placemat? (Yes/No)

(Participants have to rate on a scale from 1 – “very unlikely” – to 10 – “very likely”.)

1. How likely is it for someone else to notice that the coin slid across the placemat?
2. How likely is it that you moved your eyes to look at the area indicated by the green circle, just when the coin slid across the placemat?
3. If you look at the area indicated by the green circle, how likely is it that you will notice that the coin slid across the placemat?
4. If you look at the area indicated by the yellow circle, how likely is it that you will notice that the coin slid across the placemat?

**Princess card trick**

1. Have you watched this video clip before? (Yes/No)
2. Do you know why your card did not appear among the cards displayed at the end? (Yes/No)

If yes, then please describe:

If you noticed any other details about the trick, please describe them:

1. Did you notice that the cards shown at the end (Fig. B) are different from the cards displayed at the beginning (Fig. A)? (Yes/No)

(Participants have to rate on a scale from 1 – “very unlikely” – to 10 – “very likely”.)

1. How likely is it for someone else to notice that the cards shown at the end are different from the cards displayed at the beginning?
2. How likely is it that you only looked at the selected card at the beginning of the trick and not the others?
3. If you look at all the cards at the beginning of the trick, how likely is it that you will notice that the cards shown at the end are (Fig. B) different from the cards displayed at the beginning (Fig. A)?
4. If you look only at the selected card at the beginning of the trick, how likely is it that you will notice that the cards shown at the end (Fig. B) are different from the cards displayed at the beginning (Fig. A)?

1. E-mail address: jeortegama@unal.edu.co [↑](#footnote-ref-1)
2. The ubiquity of this belief is exemplified by one of our proofreaders who made the following comment: “If one is looking at the car, they would by default notice it. Please provide clarification to avoid any confusion.” [↑](#footnote-ref-2)
3. We excluded participants who claimed to have noticed the method used in a trick but did not provide a description of how it was done (Color-change trick = 11.1%; Lighter trick = 7.6%; Coin trick = 5.6%; Princess card trick = 15.3%). [↑](#footnote-ref-3)
4. We excluded participants who claimed to have noticed the method used in a trick but did not provide a description of how it was done (Color-change trick = 13%; Lighter trick = 7.2%; Coin trick = 4.3%; Princess card trick = 13%), and participants who had a poor eye tracking recording quality (Color-change trick = 2.9%; Lighter trick = 4.3%; Coin trick = 1.4%; Princess card trick = 0%). [↑](#footnote-ref-4)