Errors in visual metacognition using cognitive illusions

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Wisdom lies in understanding our limitations.


We can be blind to the obvious, and we are also blind to our blindness.

*Daniel Kahneman* (2011) *Thinking, fast and slow.*

There is an amiable but misleading tendency of people to exaggerate the wonders of their own conscious experience.


Mistakes are not just opportunities for learning; they are, in an important sense, the only opportunity for learning or making something truly new.

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Summary

The present research comprises five experiments that examine egocentric biases and metacognitive errors in visual metacognition. We used cognitive illusions/magic tricks as stimuli as they exploit counterintuitive limitations in cognition and metacognitive failures. The participants of these experiments were undergraduate students from the National University of Colombia and Goldsmiths, University of London. In Experiment 1, participants answered a general questionnaire about their ability to notice visual stimuli and changes. In Experiments 2-4, subjects watched magic tricks that exploit failures of visual awareness (i.e., inattentional blindness and change blindness) and made metacognitive judgments about themselves and about others. We also examined the level of surprise that participants reported at missing a visual change as surprise might be a tell-tale sign of underlying beliefs. Our findings suggest that participants’ metacognitive judgments about themselves and about others were biased by prior beliefs and by their detection experiences. Specifically, subjects who detected how a magic trick was done made higher metacognitive judgments compared to those who experienced blindness, thus exhibiting an egocentric bias. Moreover, subjects made overestimation and underestimation errors. Interestingly, change blindness prevented participants from overestimating others’ ability to detect a visual change. Overall, these findings indicate that prior beliefs and the availability heuristic play a key role in making visual metacognitive judgments.

Keywords: inattentional blindness; change blindness; visual metacognition; metacognitive judgments; cognitive illusions; prior beliefs; availability heuristic; egocentric biases; metacognitive errors.
Resumen

La presente investigación comprende cinco experimentos que examinan los sesgos egocéntricos y los errores metacognitivos en la metacognición visual. Utilizamos ilusiones cognitivas / trucos de magia como estímulos, ya que explotan limitaciones contraintuitivas en la cognición y fallas metacognitivas. Los participantes de estos experimentos fueron estudiantes universitarios de la Universidad Nacional de Colombia y de Goldsmiths, Universidad de Londres. En el Experimento 1, los participantes respondieron un cuestionario general sobre su capacidad para notar estímulos y cambios visuales. En los Experimentos 2-4, los sujetos observaron trucos de magia que explotan fallas de conciencia visual (i.e., la ceguera por falta de atención y la ceguera del cambio) y realizaron juicios metacognitivos sobre ellos mismos y sobre los demás. También examinamos el nivel de sorpresa que los participantes reportaron al no haber notado un cambio visual, ya que la sorpresa podría ser un signo revelador de las creencias subyacentes. Nuestros hallazgos sugieren que los juicios metacognitivos de los participantes sobre sí mismos y sobre los demás estuvieron sesgados por creencias previas y por sus experiencias de detección. Específicamente, los sujetos que detectaron cómo se hizo un truco de magia realizaron juicios metacognitivos más altos en comparación con aquellos que experimentaron ceguera, demostrando un sesgo egocéntrico. Adicionalmente, los sujetos cometieron errores de sobreestimación y subestimación. Curiosamente, la ceguera al cambio evitó que los participantes sobreestimaran la capacidad de los demás para detectar un cambio visual. En general, estos hallazgos indican que las creencias previas y la heurística de disponibilidad desempeñan un papel clave en la formulación de juicios de metacognición visual.

Palabras clave: ceguera por desatención; ceguera al cambio; metacognición visual; juicios metacognitivos; ilusiones cognitivas; creencias previas; heurístico de disponibilidad; sesgos egocéntricos; errores metacognitivos.
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Introduction

What is metacognition?

The popular Greek aphorism “know thyself” suggests that it is possible for human beings to have access to their minds. However, whether and how this is possible is a matter of scientific and philosophical debate (Carruthers, 2009). Some researchers have posited that it is possible to access one’s own cognitive processes (Reyes & Sackur, 2014; Reyes & Sackur, 2017), whereas others have suggested the counterintuitive idea that we cannot access our own beliefs (Carruthers, 2017; Dennett, 2005). As we develop, we become aware of the powers and limits of our minds, yet much of what happens in our minds is unsuspected by us, including some of our cognitive limitations (Kahneman, 2011).

According to Nelson and Narens (1994), humans do not only process environmental stimuli and build mental representations, but they are also self-reflective organisms. The authors define metacognition as processes that allow people to control and monitor their mental activity. Metacognition does not refer to making judgments about environmental stimuli, but to the processing of internal representations (Metcalf, 2008). However, Comte’s paradox questions how it possible that the mind can observe itself, and at the same time observe the objects outside of it. This is relevant given that there are limited attentional resources available (Proust, 2013). To address this paradox, Metcalfe (2008) proposed that consciousness is not unitary but fragmented, and that it is therefore able to simultaneously process external stimuli and internal representations. For instance, Nelson and Narens (1994) established that cognition is divided into two interrelated levels: the object level and the meta-level. Furthermore, Metcalfe (2008) indicated that another possible solution to Comte’s paradox is that mental activities directed at processing external stimuli and self-observation occur at different times.

Historically, developmental and cognitive psychologists were interested in the relationship between metacognition and memory performance, although they had different research
goals and strategies (Koriat, 2004). Namely, developmental psychologists were interested in how metacognition changes with age and its contribution to learning and memory performance, while cognitive psychologists were interested in the processes and dynamics that underlie monitoring and control (Koriat, 2004). Currently, cognitive scientists study metacognition mainly from a functional model (Browne, 2004), which encompasses knowledge that people have about their mental abilities (e.g., I have concentration difficulties), and regulation of cognitive activity through processes of evaluation (e.g., how well did I perform on the test?) and control (e.g., I have to spend more time studying this material) (Fernandez-Duque, Baird, & Posner, 2000; Shimamura, 2000).

According to the influential model proposed by Nelson and Narens (1994), the object level corresponds to mind functions, such as attention, perception, and memory, while the meta-level builds an imperfect model of the object level. Information flows between these two levels through the processes of monitoring and control. Through monitoring, the information flows from the object level to the meta-level. The meta-level influences the object level by means of control actions that start, change or end a process. Besides building a model of the object level, the meta-level establishes goals and contains knowledge about possible courses of action, and perceived constraints. These factors can generate and modify the control actions of the meta-level. For instance, the goal of mastering a subject can influence the way students assign their study time (Van Overschelde, 2008).

Proust (2013) explained that one perspective regards metacognition as a task of “monitoring,” while the other regards it as “thinking about thinking” or knowledge about cognition. She pointed out that the first stance implies that metacognition consists of evaluating cognitive outputs and endorsing them, but does not involve beliefs or metaknowledge. It may involve feelings, such as the feelings of knowing and feelings of ability. In the second view, metacognition is based on conceptual knowledge and consists of attributing thoughts to oneself and others in a way influenced by beliefs about how the mind works. Importantly, self- and other-attributions are symmetric, because the self and others share universal properties of cognition. According to Proust (2013), metacognition as knowledge (inclusivist definition) refers to “the capacity to attribute mental states to oneself or to others” (p. 4). On the other hand, metacognition as monitoring (exclusivist definition) implies the evaluation of one’s own abilities without any theoretical knowledge of mind, but possibly based on procedural knowledge. Proust (2013) defended an exclusivist
view which posits that non-human animals have metacognitive abilities. However, Carruthers (2017) criticized Proust’s definition for being too broad, as it applies to processes that would not be considered metacognitive.

The inclusivist definition implies forming representations about representations (Dokic, 2012). Vierkant (2012) posited that metarepresentations are useful because they allow us to distinguish between something we are thinking about, for example a snake, and a real snake. In other words, they allow us to know that our thoughts are not real things. Moreover, recognizing our thoughts as such allows us to consider the possibility that they may be false.

A mental representation is composed of propositional content (e.g., the ice is melting) and a psychological attitude towards the content (e.g. I believe, I think). Mental states such as beliefs, desires, and perceptions, also called intentional states (Crane, 2003), can be represented, and in this case meta-represented. Although not all philosophers use the terms in the same way, here we take Crane’s (2003) idea of intentionality “as directed on something” (p. 31). Being in a first-order intentional state means that the person is thinking about something external (e.g., a tree), whereas being in a higher-order intentional state means that the person is thinking about his own or someone else’s intentional states (Browne, 2004). A metarepresentation has propositional content, a psychological attitude about the content, and a second-order attitude directed at the first-order attitude (Arango-Muñoz, 2010). An important aspect of metacognition as the ability to metarepresent is that only animals that possess mental concepts have metacognition (Arango-Muñoz, 2010).

The following is a paraphrased example of a representation and a metarepresentation by Dokic (2012). Suppose that someone asks me the following question:

(1) Who wrote “Hiroshima”?

I know that John Hersey wrote Hiroshima. The psychological attitude is “I know,” while the content of the representation is “John Hersey wrote Hiroshima.” If I represent my first-order attitude and content at a higher level, then it follows that “I know that I know that John Hersey wrote Hiroshima.” It may seem a truism that if I know something, I thereby know that I know it. But in fact, there are unconscious thoughts and unconscious perceptions that
may have a causal role (Kahneman, 2011). Blindsight patients, for instance, are able to avoid obstacles as they walk or to discriminate visual stimuli, but they are not aware of being able to do so. Pernier (2012) explained that “one reason why we find it difficult to distinguish knowing from the recursive knowing that one knows may be our Cartesian intuition, where our mind is considered to be transparent to itself” (p. 244).

Now, suppose that someone asks me the following question:

(2) Do you know who wrote Hiroshima?

While question (1) was about literature, question (2) refers to my mental state, to whether or not I know who wrote Hiroshima. It may happen that I know the answer but fail to retrieve it (Dokic, 2012). Therefore, I may answer “yes” to question (2) yet be unable to answer question (1). It has been proposed that metacognitive feeling (e.g., feeling of knowing) is what drives me to answer question (2) affirmatively.

Proust (2009) agreed that metacognition may involve self-directed interpretations, but disagrees with Carruthers’ strong claim that there is no introspection of one’s own mental attitudes. She criticized the definition of metacognition as involving metarepresentations, as it leaves out the possibility that it may involve other representational formats.

Arango-Muñoz (2010) proposed that the apparent conflict between metarepresentational and control theories of metacognition can be resolved if we distinguish two levels of metacognition, “each having a different structure, a different content and a different function within the cognitive architecture” (p. 44). Moreover, Arango-Muñoz (2010) suggested that these two levels of metacognition may be associated with the two cognitive systems (System 1 and System 2) of the dual-process theories. According to Kahneman (2011), System 1 “operates automatically and quickly, with little or no effort and no sense of voluntary control” (p. 20), whereas System 2 “allocates attention to the effortful mental activities that demand it, including complex computations” (p. 21). System 2 may override the outputs of System 1, which can be seen as the control dimension of metacognition. However, its operations are disrupted if attentional resources are drawn away. When does System 2 intervene? Kahneman (2011) indicated that System 2 activates when a conflict arises. For example, in the Stroop task a person will try to inhibit the automatic response of
reading a word (e.g., blue) to instead focus on saying the color of the ink in which the word is written (e.g., red).

Although System 2 is considered to operate consciously and System 1 unconsciously (Kahneman, 2011), Evans (2009) argued that using consciousness to differentiate between these systems in unwarranted. He stated that System 2 can operate unconsciously, but something about it can be introspected because it uses working memory. In this vein, System 1 and System 2 might not be wholly different. Rather, they might differ only in that System 2 “makes use of the domain-general working memory system, whereas System 1 one does not” (Carruthers, 2013a, p. 161). In accordance with this perspective, Shea, Boldt, & Bang (2014) suggested that there are forms of control operated by System 1. For instance, a person can adapt to the difficulty of a task without being aware of mental effort. They propose a dual systems framework of metacognition in which System 1 operates implicitly and can exert intrapersonal control, whereas System 2 is engaged in a supra-personal cognitive control that allows humans to share and discuss their representations, thus establishing novel forms of social adaptation.

Based on the operation of these two systems, it has been proposed that metacognitive judgments might be information based or experience based (Koriat, Nussinson, Bless, & Shaked, 2008). Unlike the direct access perspective, which posits that people can directly access their memory traces to form metacognitive judgments, the dual-process framework posits that metacognitive judgments are formed inferentially from cues (Koriat, 1997). Intrinsic cues are those that characterize the material that is used (e.g., strength of association between paired words); extrinsic cues are those related to the context (e.g., encoding operations, levels of processing); and mnemonic cues are internal signals that may provide a heuristic for making judgments (e.g., accessibility, familiarity, ease of processing). Intrinsic and extrinsic cues might be utilized for analytic processing, and mnemonic cues might operate through nonanalytic processing (Koriat, 1997).

**Metacognition about one’s self and about others**

Some theorists believe that metacognition about one’s self and metacognition about others share some characteristics. In accordance to this view, Jost, Kruglanski, and Narens (1998) posited an expansionist definition of metacognition which includes “(a) beliefs about one’s own mental states and processes as well as beliefs about those of other people, (b)
momentary sensations as well as enduring folk theories, and (c) descriptive beliefs about how the mind works and normative beliefs about how it ought to work” (p. 137).

Several theories have been advanced to account for the attribution of mental states to others: the theory-theory, the simulation theory and the rationality theory. However, it is important to remark that defenders of each view might differ in some aspects. Some theorists even support a hybrid account (e.g., Goldman, 2000). Carruthers (2004) noted that “almost all theory-theorists accept that simulation plays an important part in enabling us to explain and predict the mental lives of others” (p. 241), and that “most simulationists actually accept that we gradually build up a body of theoretical beliefs about the operations of the mind, as a result of engaging in the process of simulation” (p. 262).

The theory-theory holds that people have theoretical knowledge about the functioning of the mind which depends on having mental concepts (Carruthers, 2004). Subjects engage in mindreading to attribute mental states to others. Mindreading refers to the ability to represent other people’s mental states (Carruthers, 2009). The theory-theory in its purest form assumes that mindreading is based on theoretical reasoning that is guided by principles of folk psychology (Goldman, 2006). Carruthers (2009) summarized four accounts of the relationship between metacognition and mindreading. The first claims that metacognition and mindreading are independent capacities and can be doubly dissociated, such that a person could introspect her mental states and not be able to interpret other people’s mental states, or could not access her mental states but be able to mindread. The second account is that there is a single metarepresentational capacity with two types of access to mental states: the introspective mode allows people to represent their own mental states, while the perception mode allows them to interpret other people. The third account argues that metacognition occurs prior to mindreading, and predicts that there should be cases where mindreading is disrupted and metacognition is preserved. Finally, the fourth account maintains that metacognition results from turning our mindreading ability upon ourselves. Dissociations should not occur because mindreading and metacognition are a single faculty, but it should be possible to induce people to confabulate regarding their mental states. This view generally denies introspection concerning mental attitudes (i.e., beliefs, judgments, decisions, intentions), unlike the first three. Carruthers (2009) endorsed this account.
The theory-theory assumes that people’s understanding of their minds and others’ is theoretical, and if so, how do they acquire this theory? The theorizing-theory view posits that children are like scientists who elaborate theories based on the data that they have available. This acquisition process relies on learning mechanisms (Goldman, 2006). Children’s mindreading skills will improve as a function of changes in their understanding of mental concepts. Generally, 3-year-old children fail in false-belief tasks. In a typical example, a child and another person observe the experimenter to place a ball in a blue box. When the person leaves the room, the experimenter changes the location of the ball by placing it in a yellow box. To the question of where will the person look for the ball when she returns the child answers that she will look into the yellow box. In contrast, older children answer that she will look into the blue box. This difference has been taken to imply that young children fail to understand the mental concept of belief and they cannot represent that another person may have a false belief. However, failure in this task might stem from performance or information-processing difficulties given that simple versions of the task are passed by 3-year-olds (Goldman, 2006). On the other hand, the nativist view proposes that theory of mind is an isolable module that is genetically channeled to make its appearance at a certain stage, but it is also influenced by experience. Autism seems to provide evidence in favor of this account because this condition, which has a genetic basis, impairs mindreading in children although they may have normal intelligence. In contrast, children with Down’s syndrome have impaired intelligent although they appear to have good mindreading abilities. On this view, theorizing occurs below awareness which explains why it might be difficult for people to articulate the source of their knowledge, they simply intuitively know others’ minds (Carruthers, 2004).

According to Caruthers (2011), knowledge about the self and knowledge about others share similar behavioral cues, cognitive mechanisms, and conceptual resources. From this viewpoint, mindreading is the source of both types of knowledge. He claimed that metacognition consists of turning our mindreading abilities upon ourselves, and involves metarepresentations of first-order cognitive processes. The mindreading system only receives sensory inputs. This implies that people are unable to access their mental attitudes but can have introspective access to their perceptual states and quasi-perceptual states (e.g., inner speech, imagery). Carruthers (2011) called this theory the “interpretive sensory-access” (ISA) theory of self-knowledge. To attribute thoughts to oneself, the mindreading system has to interpret those sensory inputs. Meanwhile, underlying attitudes remain
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inaccessible and compete with one another to gain access to consciousness. In order words, people do not know their own beliefs, but construct them through interpretation. If this is correct, how is then possible that I can swiftly answer a question about what I believe in the absence of inputs for self-interpretation? Paraphrasing Carruthers’ example (2009), let’s say that some asks me for the date on which the first man landed on the moon and I instantly reply “July 20, 1969”. In this case, I may not have behavioral or imagery inputs that serve for self-interpretation. Carruthers (2009) explained the verbal expression of this belief does not require metacognitive access to it. Instead, the executive system searches for the answer, retrieves it and then is formulated as a belief in collaboration with language.

Occasionally, self-interpretation gives rise to false beliefs. Carruthers claimed that confabulation data is an important strand of support for the interpretive sensory-access theory (Carruthers, 2013b). An interesting example of confabulation was provided by Johansson, Hall, Sikström and Olsson (2005). In their choice experiment, they showed picture pairs of female faces to participants and asked them to choose which face they found most attractive. On some trials, participants had to explain the reason behind their choice. Unknown to subjects, one face was exchanged for the other in certain trials after the choice was made. Therefore, their choice became the opposite of what they intended. Manipulated pictures were detected only in 13% of the trials. Surprisingly, participants provided reasons for choices they did not make with the same confidence as for the choices they actually made. Johansson et al., (2005) coined the term “choice blindness” for this phenomenon. Choice blindness suggests that in some cases people do not have introspective access to their beliefs. Further support for this notion comes from experiments with split-brain patients. When information is presented to their right hemisphere and they execute an action according to that information, they often confabulate the reason for their action. Carruthers (2009) stated that they do this with the same sense of immediacy and obviousness that people without brain damage show when they give introspective reports. Regarding this evidence, he argues that normal people and split-brain patients are simply interpreting rather than introspecting. However, Zinck, Lodahl, and Frith (2009) pointed out that confabulations do not prove that a person is unable to access her beliefs and know whether they are true. At most, they show that introspection is limited. This view is supported by the simulationist theorist Goldman (2000), who claimed that “to say that a characteristic of consciousness is introspectively accessible or discriminable is only to say that it can potentially be identified or discriminated, not that it is or will be identified on every (or any) occasion that it occurs” (p. 179). In other words, introspective access does not
necessarily mean that the mind is fully transparent (the Cartesian intuition). Moreover, Fiala and Nichols (2009) indicated that confabulations of split-brain patients are often tinted by uncertainty, unlike introspective reports. They asserted that “there are systematic differences in confidence levels between confabulation and apparent introspection, which in turn suggests a difference in underlying mechanism” (p. 25). Carruthers (2009) responded to this comment by noting that there are also cases in which split-brain patients confabulate without hesitation.

According to Lombardo, Chakrabarti, and Baron-Cohen (2009), neuroimaging evidence shows that mindreading and metacognition share the same underlying neural mechanisms. This finding is compatible with Carruthers’ view that “mindreading is prior.” However, metacognition and mindreading recruit brain regions in a different way. For instance, the ventromedial prefrontal cortex (vMPFC) is recruited more for metacognition than mindreading, while the posterior cingulate/precuneus (PCC) is recruited more for mindreading than metacognition. Carruthers (2009) responded that differences in activation do not undermine the validity of his hypothesis because mindreading and metacognition use different information inputs. For example, metacognition uses information about internal states (e.g., visceral and somaesthetic sensations) that we could not access in other people through mindreading.

Another view about the attribution of mental states to others is the simulation theory. According to this perspective, people represent themselves and others as having mental states (Goldman, 2000). Subjects run mental simulations of others’ mental states using imagination, perspective taking and mental pretense (Goldman, 2000; Shanton & Goldman, 2010). For example, an individual will use information from a person’s preferences in order to predict which smartphone she might buy and then feed this information into a decision-making mechanism. Goldman (2000) has made the assumption that mindreaders have introspective access to their mental states. Introspection allows mindreaders to access the state generated during the simulation before attributing it to the target. He has supported a hybrid account which supports a role for theory-driven mindreading (Shanton & Goldman, 2010).

Low-level mindreading allows subjects to attribute mental states to others without introspecting their propositional contents. For instance, attribution of emotional states on the basis of facial expression seems to rely on mirror neurons. These neurons activate
when the mindreader observers another person performing an action. This has been interpreted as evidence that the mindreader is reexperiencing the target’s state. Shanton and Goldman (2010) reviewed neuropsychological and neuroimaging data that support this interpretation. However, this account is open to dispute. One objection is that activation of mirror neurons could simply indicate mimicry rather than attribution. On the other hand, high-level mindreading involves propositional contents and the use of imagination to take someone’s perspective. The mindreader uses information about the target (e.g., desires, beliefs) and then creates pretend desires and beliefs that are fed into a decision-making mechanism. The output of this process is a pretend decision that is attributed to the target (Goldman, 2006). This simulation is run off-line, which means that the mindreader must not use his own preferences during the simulation. But occasionally, the simulation might be contaminated by the mindreader’s own mental states (quarantine failure) leading to egocentric biases (Shanton & Goldman, 2010). Biases understood in a neutral sense as “a tendency to slant in one way rather than another” (Keren & Teigen, 2004, p. 91) do not necessarily indicate the presence of errors. Saxe (2005) argued that the simulation theory cannot explain some errors that children and adults make when reasoning about other people’s minds. In some cases, mindreaders’ predictions are congruent with their beliefs about how the mind works. Therefore, Saxe (2005) claimed that a pure form of the simulation theory fails to account for some attribution errors, whereas a hybrid form that incorporates theories would lose its parsimony. Mitchell (2005) commented that Saxe’s (2005) argument from error posits a false dichotomy between simulation and theory-theory. Instead, mindreading could be characterized as a dual system that uses simulation and theories in a flexible manner.

The rationality view challenges the idea that we need theories to read other people’s minds. All we need to do is to make the assumption that people behave rationally (Carruthers, 2004). Dennett (2015), one of the defendants of this account, has used the term “folk psychology” to refer to a less theoretical explanation according to which people have the ability to interpret people, animals and machines as agents that have beliefs and desires and will select the most rational course of action to achieve their goals. For instance, to predict the behavior of a computer chess player we assume that it “knows” the rules, it “knows how” to play and it “wants” to win. In doing this, we are adopting the intentional stance, which works to make predictions regardless of whether or not people have minds (Dennett, 2015). People adopt the intentional stance so naturally and effortlessly that
Dennett (2015) suggested that it might have a genetic basis. Carruthers (2004) has pointed out that rationality, which lies at the heart of this account, has been very hard to define and it is not clear which theory of rationality people are committed to. Moreover, individuals often behave irrationally, in which case they should be uninterpretable. However, if we see a man yelling at his computer and hitting it, we infer that he’s angry because the computer has malfunctioned. We don’t attribute a state of anger to the man on the basis that it is rational to behave in this way when a computer malfunctions. Goldman (2006) highlighted some apparent difficulties for the rationality theory. For instance, the rationality view deals with the attribution of propositional attitudes and does not encompass an elaborated explanation for the attribution of other mental states such as desires. When we see a person screaming, do we ascribe pain to him on the basis of rationality? In this and other cases, rationality does not seem to be the guiding mechanism (Goldman, 2006).

Occasionally, people make mistakes when ascribing mental states to others. For instance, sometimes they erroneously believe that other individuals know what they know. This phenomenon is known as the curse of knowledge (Camerer, Loewenstein, & Weber, 1989). Two types of egocentric bias might occur when attributing mental states to others (Wallin, 2011). Egocentric matching occurs when the mindreader attributes his mental state to the target and the attribution is false. In egocentric distortion, the mindreader’s mental states gets mixed with the target’s mental states and therefore the attribution is false. According to Wallin (2011), egocentric distortion can be explained by quarantine failure during the simulation. However, egocentric matching can only be explained by severe quarantine failure, which poses a threat to the reliability of simulation. Instead, egocentric matching might be best explained by directly assigning one’s own state to someone else. Goldman (2006) explained that in this case the mindreader skips the simulation and rather projects a genuine state of her own onto a target. Wallin (2011) argued that this form of egocentric matching might be best explained by a principle of folk psychology that assumes that people share identical mental states.

In sum, the theory-theory posits that we ascribe mental states to people according to theories that we elaborate or through an implicit theory of mind that is genetically channeled. In contrast, the rationality account rejects that people have theories. Instead, they have an innate ability to interpret others by simply assuming that they are rational agents. Finally, the simulation theory holds that attributing mental states to others involves
imagination, perspective taking and mental pretense. The mindreader runs an off-line simulation that creates pretense mental states and then feed these states into a cognitive mechanism that generates a new output (e.g., a decision).

**Assessment of metacognition**

It is difficult to measure metacognition because it is not an explicit behavior. However, it can be assessed behaviorally through self-reports (i.e., judgments), think aloud protocols, and systemic observations (Akturk & Sahin, 2011).

In self-reports, metacognitive judgments refer to probabilistic estimations of one’s performance before, during, or after a task (Schraw, 2009a). Prospective judgments (predictions) occur prior to the performance of a task (e.g., “I will learn six items”). Concurrent judgments occur while performing the task. In this case, the individual makes a judgment after each item. Finally, retrospective judgments occur after task completion (e.g., “I am sure that I was right”) and the subject evaluates performance on the whole test (Schraw, 2009b). In Nelson and Narens’ model (1994), the object level refers to task performance (e.g., how many words did the person learn?), and the meta-level refers to monitoring and controlling the object level (Fleming & Dolan, 2012).

There are several types of metacognitive judgments. For instance, ease of learning is a type of prospective metacognitive judgment that occurs prior to acquisition in a learning task. The individual has to predict which items will be easy or difficult to learn, or which strategies will improve learning. The judgments of learning occur during or soon after acquisition, where the individual has to make predictions about future performances on recently studied items. In a word-list learning task, the evaluator asks the subject to predict how many words he will be able to learn. A prediction that exceeds actual performance reveals a low metacognitive accuracy (e.g., the subject predicted that he would learn ten words, but only learned four). These variables allow metacognitive accuracy to be measured by comparing the judgment of the individual with his real performance (Fleming & Dolan, 2012). The feeling of knowing refers to judgments about whether an item that has not been retrieved is known and/or will be remembered on a subsequent test (Nelson & Narens, 1994).
Besides evaluating metacognitive judgments through self-reports, individuals rate their level of confidence in their answers. For performance confidence, the most common approach is to make judgments on a continuous scale (e.g., 1-100 units) or on an ordinal scale with 10-point intervals (e.g., from 10% to 100%). The second approach is to make a dichotomous judgment (e.g., successful or unsuccessful). The data generated by the latter type is analyzed using non-parametric techniques (Schraw, 2009a).

There are several outcome scores to measure the accuracy of metacognitive judgments: absolute accuracy (or calibration) refers to the precision of a confidence judgment compared to performance on a task. For instance, if a subject is 50% confident and he answered an item correctly, his judgment is moderately accurate. The following formula can be used to obtain the average absolute accuracy when data is continuous:

\[
\text{Absolute accuracy index} = \frac{1}{n} \sum_{i=1}^{n} (c_i - p_i)^2
\]  

where \(n\) is the number of confidence judgments, \(c_i\) is the confidence rating for each item and \(p_i\) is the performance score for the same item (Schraw, 2009b). Deviation scores are squared to place them on the positive scale being employed. Scores close to zero and large scores indicate high accuracy and low accuracy, respectively (Schraw, 2009b).

The bias index is another measure of absolute accuracy that indicates the magnitude and the direction of the deviation. To obtain the bias index, the same formula of absolute accuracy is used, but the difference between confidence and performance is not squared. Large negative scores indicate underconfidence and large positive scores indicate overconfidence (Schraw, 2009b).

Relative accuracy (or resolution) refers to the relationship between several confidence judgments and their corresponding outcome scores on a task. It focuses on consistency rather than precision. It can be assessed using Pearson’s \(r\) or the gamma coefficient (Schraw, 2009b):

\[
\text{Pearson correlation coefficient} = \sum z_x z_y / (n - 1)
\]
where $Z_x = \sum (X_i - \bar{X}) / s$. Consistent confidence judgments lead to high relative accuracy without necessarily leading to high absolute accuracy. Therefore, the use of either an absolute measure, a relative measure, or both will depend on the research questions (Schraw, 2009b).

Although in healthy subjects the association between confidence and accuracy can be taken as a measure of metacognition, it should be noted that measures based on statistical correlation are sensitive to bias and their reliability could be questioned when incentives are absent (Fleming & Dolan, 2012). For instance, some subjects tend to give high confident ratings and others give low confidence rating because of personality traits, maybe they are shy or humble (Fleming & Lau, 2014). On the other hand, measures based on signal detection theory and receiver operating characteristics are bias free. For instance, in a visual discrimination task, participants will have correct and incorrect answers, and they will rate their confidence on their response as high or low. Using this information, researchers can eliminate biases by estimating $d'$ as follows:

$$Type \ 2 \ d' = z(H2) - z(FA2)$$

Where H2 is the proportion of trials in which participants’ confidence ratings were high and their answers were correct, FA2 is the proportion of trials in which participants’ confidence ratings were high, but their answers were incorrect and $z$ is the inverse of the cumulative normal distribution function (Fleming & Lau, 2014). The problem with this measure is that, while distributions in metacognitive accuracy measures are non-Gaussian and have different variance, type 2 $d'$ assumes a Gaussian distribution and equal variances for the signals of correct and incorrect answers (Fleming & Lau, 2014). The alternative measure is a non-parametric analysis via receiver operating characteristics in which multiple confidence ratings are use. To separate low from high confidence, we treat each confidence level as a criterion. For a liberal criterion, low confidence = 1 and high confidence = 2-4. For a higher criterion, low confidence = 1 and 2 and high confidence = 3 and 4, and so on. In the ROC plot, the hit rate is plotted on the vertical axis and the false rate is plotted on the horizontal axis. As a result of using multiple criteria, we have multiple points and we can calculate the area between the curve passing through these points and the diagonal of the
plot. If the curve coincides with the diagonal, then performance is at chance. The closer the ROC curve is to the upper left corner the higher the sensitivity (Fleming & Lau, 2014).

**Visual metacognition and magic**

An illusion is something that is not what it appears to be (Blackmore, 2002). In the present experiments, I used cognitive illusions that involve psychological factors (Kuhn, Amlani, & Rensink, 2008a), such as the control of visual attention, which influences observer’s conscious perception (Rensink & Kuhn, 2015). An example of this type of illusion is the vanishing coin trick: the spectator perceives that the magician transfers a coin from one hand to the other and makes it disappear using a pen as a magic wand. In reality, the magician never transfers the coin. He keeps it concealed in the hand that is also holding the pen (Lamont & Wiseman, 1999). By exploiting limitations in cognition as well as the spectator's incorrect assumptions about the mind, the magician creates the illusion of the impossible.

There are several interesting implications of illusions. Seth (in press) stated that “a common intuition is that the function of perception is to recover an accurate – veridical – representation of some external state of affairs, of, for instance, a world full of objects of different shapes, sizes, and colours” (p. 1). Much to our dismay, we cannot perceive reality as it is (Hoffman, 2015) and occasionally we are not even aware of what happens at our own spatial scales (Eagleman, 2011). Illusions defy our intuitions and instead suggest that perception is an inferential process that builds a model of the world. Second, they reveal cognitive limitations that are counterintuitive. Both implications seem to tell us that we have false beliefs about perception and what our visual experience is like which might render us vulnerable to illusions. These two aspects are discussed in the present section.

**The inferential and the ecological views about perception.** One of the most interesting questions about perception is whether it is an inferential process (Gregory, 2002), or whether we can perceive the world directly (Gibson, 1950). There is no scientific consensus about this issue, although some attempts have been made to reconcile divergent views (Norman, 2002). Advocates of the constructivist approach to visual perception regard illusions as evidence that perception is inferential (Carbon, 2014; Kuhn, Tatler, Findlay, & Cole, 2008b). However, there is also the view that illusions are proof that the perceptual
system is doing what it is supposed to do and that they are ecological failures instead (Warren, 2005).

According to the constructivist theory of perception, we do not have full perceptual access to distal stimuli (i.e., external objects), and we can therefore only perceive the environment indirectly (Gregory, 2002). We only have direct access to the proximal stimuli or sensations. Nevertheless, sensations are ambiguous and insufficient to specify the objects and their properties (Warren, 2005). Gordon (2004) offered the following metaphor: a perceiver is like the captain of a submarine. He has knowledge of the surrounding medium, but he is not able to experience it directly; he uses instruments that show the presence of other submerged objects, the distance from the ocean floor, etc. As he gains more experience, he becomes better at evaluating the evidence. Moreover, our drives, mindsets, and expectations can significantly influence our perceptions. Because the observer does not have direct access to the environmental stimuli, the mind has to make unconscious inferences about what is out there (Gordon, 2004). Presumably, illusions occur when this inferential process fails (Warren, 2005). Gregory (2002) explained perception in three stages: energy patterns are detected by sense organs and converted to neural signals (stage one), which are represented as data according to a code (stage two). The codes are not based on the laws of physics, but are rather arbitrary. Finally, the data are used to form perceptual hypotheses that have predictive power (stage three).

Constructivists take visual illusions as examples to support their assumptions. For instance, we are surprised to learn that the lines in the Müller-Lyer illusion are of the same size (Appendix A, Figure 1). We are shocked when we realize that the Ames room (Appendix A, Figure 2) is not what it seems. These and other illusions persist even after we have found out the truth about the stimuli. This persistence has been referred to as “cognitive impenetrability” (Newen & Vettter, 2017). From the viewing position, the Ames room looks like any other ordinary room with four rectangular walls. In reality, it is an irregular shape with a receding wall. It is the decoration that produces the illusion of it being a normally proportioned room. When a person walks from one of the two far corners of the room to the other, the place continues to look rectangular, but the person appears to change in size (Gordon, 2004). Why is the observer unable to perceive the room’s true shape, even after learning that it is not an ordinary room? This seems to contradict the notion that perception is a direct response to patterns of stimulation. Instead, it suggests that perceptions are
constructions. The constructivist stance proposes that sensory organs receive signals that trigger neural events, which interact with our knowledge to create psychological data. This data is in turn used to create hypotheses that serve to make sense of the world. This chain of events is what constitutes perception (Gordon, 2004).

Another example is the Necker cube (Appendix A, Figure 3). It is an interesting illusion that shows how a single pattern of stimulation can give rise to different percepts. This seems to suggest that there is not a one-to-one relationship between stimulation and perception, but that perhaps other processes are intermediate links in the perceptual chain. For instance, Kuhn et al. (2008a) explained that perception implies making assumptions, and this approach “can sometimes lead to errors, which take the form of illusions” (p. 351). Consider the example of the vanishing ball illusion. In this trick, the magician throws a ball into the air several times as he follows its motion trajectory with his eyes and his head. In the final throw, the magician retains the ball in the hand and pretends to throw it again. In a study on this illusion, eye tracking data revealed that participants observed the magician’s face before watching the ball, which suggests that the visual system relies on social cues to make predictions. However, the oculomotor system is not fooled: in the final throw, the eyes did not move to where the participants saw the ball disappear (Kuhn & Land, 2006). Interestingly, participants did not report that they never saw the ball leaving the magician’s hand, and instead reported that they saw it disappear in the air. This evidence is congruent with the idea that other processes participate in perception. However, the constructivist theory is not without difficulties.

Among these difficulties is the question of how perceivers can find out whether their internal representations truly match distal stimuli if they do not have access to the latter. A way to circumvent this issue is to rely on the assumption that observers have previous knowledge about the structure of the world (Warren, 2005). However, such an assumption begs the question of how this knowledge was attained (De Wit, van der Kamp, & Witthagen, 2015). Furthermore, how is it possible that people share common visual experiences if perception is essentially indirect and constructivist? A possible answer to this question, from a functionalist perspective, is that species share a common environment that regularizes perception (Gordon, 2004). Moreover, it is not clear what type of hypotheses are formulated by perceivers, how they test them, or how they modify them. Given that perceptual
hypotheses are not represented in language, it is difficult to determine whether they can really be tested (Gordon, 2004).

The predictive coding model explains inferential perception at a neural level. It challenges the classical view that perception consists of a bottom-up process of receiving signals and extracting increasingly complex information as it moves up in the sensory hierarchy. In the bottom-up model, the information moves in a feedforward direction from the retina to the thalamus, then it moves up through the layers of the visual cortex and as it moves deeper inside the brain it represents more features about the external world. The predictive coding model tells a different story. The brain is a “black box” that has no direct access to the world and therefore it has to discover what’s out there by engaging in a process of prediction (Clark, 2013). The sensory system represents the predictions and the discrepancy between these predictions and the inputs (Kok & de Lange, 2015). In other words, perception is a top-down process in which the brain interprets the sensory signals based on expectations (Seth, in press). The Kanizsa’s triangle may illustrate this idea (Appendix A, Figure 4). We perceive an illusory triangle because of the way that the Pac-Man figures are arranged. Presumably, what is happening here is that, based on previous experience of the world, the brain infers that the most likely cause of the input is a white triangle overlaying three black circles. The role of expectations might be illustrated with Mooney images. These images are black and white blobs that are usually meaningless for people. However, a verbal hint helps them to see the object that was not perceived before (Lupyan, 2017). According to the predictive coding architecture, each cortical sensory region has two population of neurons: prediction units represent the hypothesis about the input received by the cortical sensory region and the prediction error units represent the part of the input that is not explained by the hypothesis. Both population of neurons interact in a multilevel cascade of feedforward and backward communication to find the best representation that matches the sensory inputs of the prediction units. If the prediction is successful the activity of the prediction error units is reduced. On the other hand, a mismatch will trigger activity in the prediction error units and the activity will propagate to a higher level (Clark, 2013; Kok & de Lange, 2015).

Gibson’s (1950) ecological theory of perception denies constructivists’ assumptions. He posited that perception is direct rather than inferential, which enables the perceiver to act effectively in the environment, and it occurs without the influence of memory or any other
mental process. The constructivist theory holds that perception occurs in the brain. In contrast, Gibson (2002) claimed that it arises in the retino-neuro-muscular system. In this process, the photoreceptors are stimulated by ambient light. Light itself contains information (optic-array information) which does not have to be interpreted by the brain, only attended to. According to this view, the environment gives shape to the sensory apparatus, and the two are therefore intimately related in such a way that the proximal stimulus is equivalent to the distal stimulus. There is no need for mental representations, because perception is direct. In turn, the direct perception of stimuli enables the individual to adapt to her environment. Another important aspect of this theory is that the visual system is not only composed of the structures typically related to vision, such as the retina, the optic tract, and the visual cortex, but also includes moving eyes in a moving head on a kinetic body, the musculature, and attentional capacities. In other words, the visual system and the motor system are both responsible for perception. This integration means that perception is not a passive process of receiving information. Instead, it is about actively extracting information from the environment (Warren, 2005). This conception leads to a different interpretation of perceptual illusions. Namely, the ecological theory explains that visual illusions are not failures of the perceptual system, but stem from restrictions imposed on this system (Warren, 2005; Zavagno, Daneyko, & Actis-Grosso, 2015). Consider again the Ames room (Appendix A, Figure 2). People look into the room with monocular vision from a special viewing position. In everyday situations, people use binocular vision and move around freely. If they could do this in the Ames room, the illusion would shatter. In their review about Gibson’s account for visual illusions, De Wit et al., (2015) explained that observers select the wrong information to perceive line length when looking at the Müller-Lyer illusion. Apparently, visual illusions can contain two different optical variables and the observer falls prey when he uses the information that fails to specify the length of the lines.

In some cognitive illusions, magicians use misdirection to control people’s attention. Misdirection encompasses a wide variety of techniques that fundamentally direct spectators towards the effect and away from the secret (Lamont & Wiseman, 1999). Misdirection can influence the way a person perceives a magic trick. For instance, in the paradigm developed by Kuhn and Tatler (2005) to study the mechanisms underlying inattentional blindness, the participants saw a lighter and a cigarette vanishing. Several studies show that this illusion stems from controlling participants’ covert attention (Kuhn & Findlay, 2009; Kuhn et al., 2008b). From the ecological theory perspective, attentional capacities are a fundamental
piece of the visual system (Warren, 2005). Consequently, the illusion is the result of imposing an attentional restriction on the system, and is not a consequence of failed inferences. Furthermore, some illusions derive from taking the perceiver outside of his normal ecological context, having insufficient information, or receiving stimulation that mimics the information present under ecological conditions (Warren, 2005).

All in all, constructivists argue that illusions do not match physical reality, and that what we perceive is therefore a non-normal object or mental representation. Illusions are subjectively indistinguishable from veridical objects. From these premises, it follows that both illusions and environmental objects are mental representations. On the other hand, ecologists point out that illusions can be dispelled when subjects engage in perceptual exploration (Warren, 2005) or when their attention is focused in a special manner (De Wit et al., 2015). The constructivist and ecological perspectives might seem incompatible, but studies in neuropsychology, neurophysiology, and psychophysics suggest that they can be reconciled (Norman, 2002). Norman (2002) explained that the visual system comprises characteristics that are compatible with both theories of perception: the ventral system and the dorsal system process incoming information from the area V1, but they are structurally and functionally different.

The ventral system works with information coming from the center of the retina through the parvocellular pathway and the magnocellular pathway. Information from area V1 projects to the inferior temporal cortex and the adjacent areas. The parvocellular pathway is more sensitive to high spatial frequency, which allows the identification of object properties, such as shape and size, but it is also sensitive to some complex movements. The sensitivity of this system diminishes with visual eccentricity and is not affected by monocular vision. For object recognition, the ventral system uses information stored in memory. Thus, the functions of this system are related to characteristics of the constructivist theory of perception (Norman, 2002).

On the other hand, the dorsal system processes incoming information from the periphery of the retina, mostly through the magnocellular pathway. It also receives information from subcortical areas through the superior colliculus and the pulvinar nucleus. In this process, information from V1 projects to the medial temporal area or V5, the medial superior temporal area (MST), and the lateral intraparietal area (LIP), among others. The
magnocellular pathway is more sensitive to high temporal frequencies, allowing the processing of movement, although it also responds to some shapes in less detail. The sensitivity of this system does not diminish with eccentricity, but is affected by monocular vision. Furthermore, the dorsal system relies on short-term memory for the execution of motor actions. Its functions are related to the ecological theory of perception (Norman, 2002).

Even though both theories of visual perception might coexist from a neuro-functional perspective, they differ in their explanation of perceptual illusions. The view that perception involves more than sensory registration is currently dominant (Gordon, 2004), and some researchers interested in visual and cognitive illusions adhere to this conception. For instance, Macknik and Martinez-Conde (2012) state that “your brain constructs reality, visual and otherwise. What you see, hear, feel, and think is based on what you expect to see, hear, feel, and think” (p. 8). They even suggested that consciousness is a mental simulation of reality. “The fact that consciousness feels like a solid, robust, fact-rich transcription of reality is just one of the illusions your brain creates for itself” (Macknik & Martinez-Conde, 2012, p. 9). This does not mean that they deny the existence of an objective reality, but that such a reality is partially veiled to us.

**Failures of visual awareness and the grand illusion.** According to the orthodox tradition of visual perception, individuals believe they have a rich, detailed, and sharp visual experience of the world. This perspective is what Noë (2002) called the “snapshot conception of experience,” (p. 2) whereas Blackmore (2002) referred to it as “the stream of vision” (p. 17).

Block’s (2011) overflow argument posits that conscious perception is richer than cognitive access to perceptual representations. Block (2011) claimed that Sperling’s (1960) experiments and similar studies provide support for this argument. In Sperling’s (1960) experiments, an array of twelve letters were presented briefly to participants. When prompted to describe the array, they were able to report only three or four letters. However, when participants were cued by a tone to report the letters of any row, they could report all four items. Block’s (2011) interpretation of this finding is that the twelve letters were consciously represented, but due to working memory constraints, only three to four letters could be accessed without the cue. Block (2011) posited that this finding vindicates
subjects’ report that they could see all the letters. Therefore, Block (2011) distinguished between phenomenal consciousness (i.e., what an experience is like) and access-consciousness (i.e., what is available to cognitive processing and report). Furthermore, he suggested that neural processes related to visual awareness are separate from those underlying attention, working memory, and explicit report.

However, failures of visual awareness such as inattentional blindness and change blindness seem to demonstrate that we do not have a rich conscious perception as the overflow argument suggests. Inattentional blindness occurs when people fail to perceive unexpected salient stimuli (Simons & Chabris, 1999), even when they are looking at them (Beanland & Pammer, 2010; Memmert, 2006). On the other hand, change blindness refers to the inability to identify unexpected changes after a brief visual disruption (Rensink, 2009). Block (2011) argued that these phenomena can be better explained by inaccessibility.

Cohen, Dennett, and Kanwisher (2016) have claimed that observers have access to a tremendous amount of information within a single glance. This occurs because the visual system represents ensembles, and not just individual items. Ensemble representations, or summary statistics, "are formed by collapsing across the measurements of individual items to form a singular description of the group" (Cohen et al., 2016, p. 327). These ensembles contain a great deal of information, which means that observers perceive more than a handful of objects. Even though peripheral vision is poor, representations of objects in the periphery are averaged to obtain an accurate measure of the group. The perception of ensembles is limited by the capacity of attention and working memory. However, Cohen et al. (2016) argued against Block’s (2011) view that conscious perception overflows cognitive access. To demonstrate that perception exceeds the capacity of cognitive mechanisms to access perceptual information, it would be necessary to show that there is visual input that can be consciously perceived without being attended to, held in working memory, or reported. This evidence is currently lacking. Instead, perceptual awareness is linked to higher-order systems, and information can only be consciously perceived when it is accessed by cognitive processes such as attention and working memory (Cohen et al., 2016).

Carruthers (2015) also attacked Block’s (2011) overflow argument from a different point of view. He claimed that data from Sperling-like experiments can be explained without making
a distinction between phenomenal consciousness and access consciousness. In a nutshell, attending visual stimuli generates neural activity that also results in the feeling of a rich perception. However, the neural activity starts to decay when the stimuli disappears. Therefore, in the absence of exogenous stimulation it would be necessary to resort to endogenous attention to globally broadcast the information. This account does not make a distinction between phenomenal consciousness and access consciousness. Instead, it posits that there is a distinction between contents that are globally broadcast through exogenous stimulation and those that are made available in working memory through endogenous attention.

Block (2015), Carruthers (2015) and Cohen et al. (2016) have claimed that subjects believe that their perception is rich. Interestingly, the subjective belief in a rich visual experience is at odds with failures of visual awareness. Moreover, we only have full acuity in a small area of the visual field that matches the position of the fovea, a structure that produces high acuity vision due to its greater concentration of cones compared to the rest of the retina. To see an object sharply, we need to move our eyes, and this movement repositions the fovea (Holmqvist et al., 2011). Because cones are sparser in the periphery of the retina, we do not have full color vision. However, it seems to us that we do (Dennett, 2005). Therefore, we could wonder whether our perceptual experience is what we think it is. In other words: “is the visual world a grand illusion?” (Noë, 2002, p. 1).

According to Blackmore (2002), the fact that sometimes we are blind to changes suggests that the stream of vision is a grand illusion. This grand illusion idea could explain why people experience surprise when in tasks of inattentional blindness they find out that they did not notice a salient stimulus, such as the person in a gorilla suit walking among players passing a basketball (Simons & Chabris, 1999). Surprise could be the consequence of realizing that we do not really have a detailed and rich visual experience.

It is important to remark that not all visual scientists agree with the grand illusion when it refers to the idea that observers believe that they have rich visual representations. Noë (2002) argued against the idea that individuals have a snapshot conception of experience. Instead, he claimed that surprise could result from the belief that we are better at detecting visual stimuli than we actually are. In fact, Noë (2002) presented a radically different view that is aligned with the ecological theory of perception according to which observers do not
need to form mental representations. Siewert (2002) pointed out that the notion of a rich visual experience is at odds with first-person reflection: specifically, we are disposed to say that in order to perceive something in detail, we need to focus our attention on it, which causes other stimuli to be perceived with lesser detail. For instance, Levin (2002) mentions that in his study, subjects were occasionally unsurprised by their failures to notice changes, and claimed that they missed the changes because they were not attentive. This seems to contradict the snapshot conception of experience. Siewert (2002) indicated that we need an accurate characterization of people’s beliefs about visual experience.

Cohen (2002) suggested that it is erroneous to attribute beliefs about visual representations to ordinary subjects because they do not explicitly theorize about perception the way that cognitive scientists do. Nonetheless, some researchers have provided evidence to support this assumption. Simons and Chabris (2011) conducted a telephone survey to ask people about their beliefs regarding the properties of memory, and found that people had beliefs that contradict what scientists know. For instance, 63% of the participants agreed with the statement, “human memory works like a video camera, accurately recording the events we see and hear so that we can review and inspect them later” (p. 3). Contrary to findings from inattentional blindness and change blindness experiments, 77.5% agreed that “people generally notice when something unexpected enters their field of view, even when they’re paying attention to something else” (p. 3). Simons and Chabris (2012) found similar results using Amazon Mechanical Turk to circumvent some of the limitations of telephone surveys.

In the course of this fascinating debate, researchers have used different methods to study failures of visual awareness. Consistent results across different methods would mean that these phenomena are robust. Illusions have been acknowledged as effective tools in studying perception and cognition (Zavagno et al., 2015). They reveal a fundamental essence of the visual brain: its fallibility. They show us that sometimes we may have a visual experience that does not fully match physical reality. What is perhaps most interesting is that we may be unaware of this fallibility. In some circumstances, we may even overestimate the power of our mental abilities. This phenomenon pertains to the realm of metacognition.

The case of change blindness blindness. Change blindness blindness is a type of metacognitive error that occurs when people overestimate their ability to detect visual
changes (Levin, Momen, & Drivdahl, 2000), whereas inattention blindness consists of overestimating the ability to detect salient stimuli (Levin & Angelone, 2008).

Levin et al. (2000) indicated that people have beliefs about their cognitive capabilities which are sometimes inaccurate. In their study, these authors found that subjects predicted that they would detect unexpected changes that usually go unnoticed. In the first experiment, four different change detection scenarios were described to participants. For example, in one of these scenarios they were asked to imagine that they were watching a movie about two actors having a conversation at a restaurant, and that the plates on the table changed from red to white between shots. The change was illustrated with static frames from the movie. Next, they were asked if they thought they would notice the change, and to rate their confidence in their response. The majority of subjects (83%) reported that they would notice the change in the four scenarios, and their confidence ratings were high. However, in previous experiments, only 11% of subjects actually detected the change. In the second experiment, respondents were asked to estimate whether they would detect the change in the four scenarios and whether someone else would notice them. They overestimated their and others’ change detection ability. This means that self-reference is not the cause of overestimation. In addition, a sub-set of subjects were asked whether they thought they would just see the changing object or whether it was important to pay attention to it. Of 25 subjects, 13 indicated that they would see the change, 9 said that they would need to pay attention to the object, and 3 gave indeterminate responses. Levin et al. (2000) provided several possible explanations for change blindness blindness. First, it might occur because people think that they become aware of visual stimuli just by looking at them. In addition, the few situations in which people successfully detect changes (e.g., continuity errors in movies) might lead them to trust in their change detection ability. Another possible explanation is that we falsely belief we have direct access to our cognitive processes. On the other hand, overestimations in these experiments may reflect that these changes are unlikely to occur in the real world.

Furthermore, Beck, Levin, and Angelone (2007a) examined whether change blindness was related to observers’ beliefs about the roles of intention and scene complexity. They expected that observers would be better at detecting changes in an intentional task than in an incidental one, and that the difference between the two conditions should grow as scene complexity increases. However, because vision seems effortless,
observers may not be aware that intention guides attention and influences their ability to monitor the visual world. This would imply that the process of allocating visual attention based on top-down knowledge is unconscious. In this vein, Beck et al. (2007a) explored the possibility that observers fail to understand that directing attention can improve their performance on a change detection task. While testing the intentional performance condition, participants were told that they had to detect changes that would occur in the scenes. In contrast, during the incidental performance condition test, subjects were told to search for a pair of eyeglasses. Those in the intentional prediction condition were asked to predict their ability to detect the changes if they expected them to occur but were unaware of what the changes would be, whereas those in the incidental prediction condition were instructed to predict their ability to detect unexpected changes (Beck et al., 2007a).

As expected, the number of participants who detected the changes was significantly higher in the intentional performance condition than in the incidental performance condition. This result confirms that intention protects against change blindness. The accuracy in the intentional performance condition was not significantly different from the predicted accuracy in that condition. In the incidental condition, significantly fewer participants accurately detected the changes than the number of participants who predicted that they would do so. Thus, participants in the incidental prediction condition showed change blindness. On the other hand, predicted success in the incidental condition and the intentional condition were not significantly different. This suggests that participants failed to understand that directing attention could improve their performance. With regard to scene complexity, the accuracy decreased as the array size increased in both the intentional and the incidental performance conditions; however, performance decreased more in the incidental condition than in the intentional condition. Finally, predictions decreased in both conditions as array size increased, though the difference between the incidental and intentional predictions did not change. This result indicates that participants were unaware of the overloading effect of scene complexity, and did not know that intention can play a role in minimizing this overloading (Beck et al., 2007a).

Smilek, Eastwood, Reynolds, and Kingstone (2007) questioned the ecological validity of the findings obtained by Beck et al. (2007a). They argued that the changes used in their experiment are artificial because people do not typically experience significant changes to stable objects. In their own study, Smilek et al. (2007) asked graduate and undergraduate
students to report their beliefs about driving. They found that for a familiar task, participants were aware that the role of intention increases with scene complexity. To rule out the possibility that this only applies to driving, Smilek et al. (2007) also used the purse theft scenario described by Beck et al. (2007a). Participants reported that intentional monitoring was more important in a more cluttered scenario than in a less cluttered one. These results are at odds with the findings of Beck et al. (2007a). Smilek et al. (2007) indicated that people’s predictions are better when they relate to real-life situations with which they have experience. In response, Beck, Levin, and Angelone (2007b) agreed that cognitive psychology should move towards an ecological approach. However, they indicated that contrary to Smilek et al.’s (2007) observations, the changes used in their experiments are likely to occur in real life. Typically, objects can change locations (e.g., a saltshaker can be replaced by a spoon). Moreover, Beck et al. (2007b) indicated that the questions used by Smilek et al. (2007) gave participants clues regarding the importance of intentionally monitoring a scene for changes, and how this importance increases with scene complexity. They removed the clues in Smilek et al.’s (2007) questionnaire and found that participants’ predictions were similar for sparse and complex scenes.

Finally, Smilek et al. (2007) suggested that people’s overconfidence might stem from their unfamiliarity with the events in these experiments. Therefore, it is important to study metacognitive errors in visual awareness using more ecological stimuli. Cognitive illusions are interesting tools for this purpose.

**Misdirection and metacognition.** The cognitive illusions used in the present study are magic tricks based on a form of misdirection that entails directing the spectator’s visual attention, which can be either understood as controlling where people look (i.e., overt attention) or where people attend to without looking (i.e., covert attention). Broadly, misdirection refers to “the employment of disguise or attention control in order to deceive. It directs or leads the spectator away from the true solution” (Fitzkee, 2009, p. 133). Other magicians frame misdirection positively as directing attention towards something, and not away from something (De Ascanio, 2000; Wonder & Minch, 1996).

The misdirection paradigm has been used to study failures of visual awareness. Kuhn and Tatler (2005) developed this paradigm to study inattentinal blindness using a magic trick. They created the effect of a disappearing cigarette and a lighter by manipulating the
subject’s visual attention. The method employed to produce this effect is fully visible and entails dropping the objects into the magician’s lap. Interestingly, the results of several studies using the misdirection paradigm suggest that it is not where people look that creates the illusion, but the misallocation of covert attention (Barnhart & Goldinger, 2014; Kuhn & Findlay, 2009; Kuhn et al., 2008b). For instance, in Kuhn et al.’s (2008b) study, half of the participants were informed about what would happen in the magic trick, while the other half were naive to it. After watching the trick, they were asked if they had seen the method used to achieve the magical effect, and how they thought the trick was done. In the first trial, 56.5% of the informed participants detected the method. In contrast, only 30.4% of the naive participants did. Those participants who did not detect the method in the first trial were included in a second trial, and only 19.2% then failed to detect the method. In the third trial, all subjects detected it. Eye movement data revealed that the distance between participants’ fixations and the dropping cigarette (i.e., visual eccentricity) did not influence detection. Specifically, naive subjects who detected the method and those who failed to notice it made fixations on the magician’s head, the lighter hand and the area between the head and the lighter hand. In contrast, the informed participants made closer fixations on the dropping cigarette compared to the naive participants. Hence, the results of this study suggest that the detection of the method involved the allocation of covert attention. This seems counterintuitive: some magicians seem to believe that they need to control eye movements to control attention. For instance, Giobbi (1996) asserted that magicians should condition spectators to follow their gaze to effectively direct their attention. In a similar vein, Lamont and Wiseman (1999) used the terms attention and looking synonymously; they pointed out that physical misdirection involves controlling the spectator’s attention, namely directing where the spectator is looking. Other members of the magic community hold a different opinion on misdirection. According to Riobóo (2002), the magician should deceive the spectator’s brain, not his eyes. De Ascanio (2000) stated that misdirection is the art of attracting the public’s gaze and attention. However, he differentiated between three different levels of misdirection in which gaze can be diverted either minimally or completely. On the first and second levels, the magician mainly controls divided attention by offering spectators two interesting stimuli, whereas the third level involves controlling both gaze and attention in such a way that the method is no longer in the spectator’s visual field.

The misdirection paradigm developed by Kuhn and Tatler (2005) differs in several ways from the classical inattentitional blindness paradigm (Memmert, 2010). For instance, the
former manipulates spatial attention and the critical stimulus is task-relevant, while the latter manipulates cognitive load and the critical stimulus is task-irrelevant. The misdirection paradigm shows that observers can miss salient events when they misallocate their covert attention. However, the problem with asserting that the method is detected covertly is that the eye tracking record does not provide a direct measure of covert attention. It is inferred from the fact that participants report seeing the method, while the eye movement data shows that their fixations are located elsewhere.

So far, it would seem that gaze and attention are dissociable. However, Kuhn et al. (2008b) examined eye movements after the cigarette was dropped. They found that those participants who detected the dropping cigarette made faster eye movements to the location where the method had occurred than participants with inattentinal blindness. This seems congruent with the idea that gaze follows attentional locus, and is an indicator of the information extraction process (Ballard, 2002).

The control of attention is a core technique to generate what is called the “experience of magic.” There are several accounts of this experience. For instance, it may involve suspending disbelief or it may entail conflict of belief. Recently, Leddington (2016) questioned some of these explanations, and proposed a framework in which the experience of magic is associated with a dissonance between belief and alief. Both involve representational content, but the latter does not involve endorsement. However, the alief has behavioral and affective contents. To put this into context, we can imagine a magician flying on stage. The spectator does not believe that a person can fly and will suspect that the magician might be using wires or any other method. Therefore, the magician has to demonstrate that no wires or any other thinkable method is being used. This process will continue until the spectator cannot think of any reasonable solution to the puzzle. Although he never believes that the magician can actually fly, he alieves that he’s flying, which corresponds to the belief-discordant alief (Leddington, 2016). However, this account of the cognitive dimension of the experience of magic begs the question of whether a spectator who is not trying to figure out the trick will still experience magic. Rensink and Kuhn (2015) commented that there could be individual differences in how magic is experienced. According to Lavand (2014), this is indeed the case. He explained that some spectators experience magic without trying to solve the trick at all, and others often experience frustration when they engage in an intellectual process and fail to find a solution. Therefore,
for some spectators the experience of magic may involve the aporetic process mentioned by Leddington (2016). However, this may not be a general rule. For Leddington (2016), the spectator attempts to minimize cognitive dissonance by explaining away appearances.

But is it true that spectators see a routine of magic tricks and simultaneously activate a train of thought to discover how every trick is done? As mentioned above, not all spectators engage in this intellectual process, or if they do it often occurs during the process of reconstruction after the trick is over (Lamont & Wiseman, 1999). Furthermore, Fitzkee (2009) explained that the spectator needs clues to approach the trick rationally, and there are magic tricks that offer no clues as to how they are done (e.g., mathematical magic tricks). In the trick described by Leddington (2016), in which the magician David Copperfield flies in the air, spectators can easily make assumptions (e.g., the magician is suspended by wires) and verify them as the illusion progresses. However, the experience of magic needs an alternative explanation for cases when clues are not available to approach the trick intellectually, or when the spectator has no intention of looking for clues.

Leddington (2016) referred to Ortiz’s work to support the idea that the experience of magic involves an intellectual process. However, Ortiz (2010) explained that if the trick provides clues to its solution, it may not be necessary to think too hard. Spectators will put the pieces together almost effortlessly because their brains are programmed to look for causal relationships. As Leddington (2016) put it, the search for an explanation is a natural reaction. However, whereas he stated that spectators have the experience of magic when they lose the grip on how the illusion could be produced, it could be argued that losing this grip is not a sine qua non element of the experience of magic. Contrary to Leddington’s account of the experience of magic, Ortiz (2010) claimed that magicians face the problem of preventing spectators from analyzing, and that they can solve this issue through careful design of magic tricks. In fact, Ortiz (2010) stated that the magician should quickly put an end to the intellectual process so the spectator can have the experience of magic.

Whether or not an intellectual approach is a fundamental element in the experience of magic, Leddington (2016) is right to point out that it involves a cognitive dimension. Renowned magicians such as Fitzkee (2009), Tamariz (2014), and Wonder and Minch (1996) made it very explicit that psychology is the fundamental pillar of magic. Hence, magicians are concerned with how to control the spectators’ attention, and how they
perceive and remember the magic tricks. In addition, the experience of magic also involves
a metacognitive dimension (Ekroll, Sayim, & Wagemans, 2017). Kuhn, Caffaratti, Teszka,
and Rensink (2014) stated that attentional misdirection exploits observers’ incorrect
assumptions about perception, which might give magicians an advantage to exploit their
cognitive mechanisms. Ekroll et al. (2017) stated that “spectators have unrealistic
expectations about how much they actually see” (p. 103). We can assume that something
similar apply to their beliefs about memory. It is well known to magicians that the process
of remembering a magic trick is sometimes faulty and spectators can misremember events
(Lamont & Wiseman, 1999). On the whole, unrealistic beliefs about cognition might be
regarded as important ingredients to achieve the experience of magic.
Research Problem

Nelson and Narens (1994) explained why it is important to investigate metacognition. They suggested that the lack of genuine cumulative progress in understanding cognition is due in part to an overemphasis on a non-reflective organism approach. Individuals do not only encode, store, and retrieve information: as self-reflective organisms, they can also evaluate their progress in a learning task and modify their learning strategies accordingly. Indeed, metacognitive strategies of planning, monitoring, and evaluating are essential for cognitive effectiveness (Akturk & Sahin, 2011). On the other hand, from a metarepresentational point of view, subjects can think about their thinking and therefore hold beliefs about how their and other people’s minds work (Carruthers, 2011), which plays a role in social interactions (Jost et al., 1998). However, there is another side to metacognition: namely, it can lead to errors, and these have been less investigated in the field of visual perception. Research in metacognition has been highly productive in areas such as learning and memory, decision-making, and reasoning, but much less is known about visual metacognition, and in particular about why errors such as change blindness occur.

Errors of visual metacognition are interesting because they seem to undermine the notion that we are authoritative over our visual experiences. According to Dennett (2007), people think they are experts on what occurs in their minds, but in reality, they are not. Cases of confabulation have been taken as evidence to support the view that access to our minds is limited and based on interpretation rather than introspection (Carruthers, 2009). Furthermore, empirical evidence on change blindness seems to support the idea that people are not experts on their perceptual abilities and visual experience. Dennett (2007) eloquently suggested that we have intuitions about our visual experience that are inaccurate. However, visual metacognition has been scarcely investigated compared to other metacognitive abilities.

There is scant knowledge about why visual metacognitive errors occur. Are they related to accessibility, as suggested by Levin et al. (2000)? Or are they related to a prior false belief, as the feeling of surprise seems to suggest? Do observers believe that noticing or missing
stimuli and changes depends on where they look? Could detection experiences influence metacognitive judgments about other people’s perceptual skills? In the present research, we used the misdirection paradigm to shed some light on these questions. Moreover, understanding visual metacognition has important practical implications in legal settings, road safety and cognitive ergonomics.

Cognitive illusions have been used in previous investigations of visual attention (Demacheva, Ladouceur, Steinberg, Pogossova, & Raz, 2012), the relationship between gaze and visual attention (Barnhart & Goldinger, 2014; Kuhn et al., 2008b; Kuhn & Findlay, 2009; Kuhn & Tatler, 2005), the neural correlates of causality violations (Danek, Öllinger, Fraps, Grothe, & Flanagan, 2015; Parris, Kuhn, Mizon, Benattayallah, & Hodgson, 2009), the subjective feeling of free choice (Olson, Amlani, Raz, & Rensink, 2015; Shalom et al., 2013), problem solving (Danek, Fraps, Von Müller, Grothe, & Öllinger, 2014), and the influence of social cues in perception (Cui, Otero-Millan, Macknik, King, & Martínez-Conde, 2011; Kuhn & Land, 2006). These investigations have resulted in a new research program that uses magic to study the mind (Ekroll & Wagemans, 2016; Macknik et al., 2008; Rensink & Kuhn, 2015).

There are two main reasons to use cognitive illusions as tools in the study of visual metacognition. First, people have naïve theories about how the mind works. On a basic level, magicians exploit counterintuitive failures in attention, memory, and reasoning. On a higher level, they take advantage of the spectator’s naïve theories about the mind. Thus, magic is grounded in metacognition (Ekroll et al., 2017). People’s intuitions are fairly accurate in ordinary situations; for example, they know that dividing attention reduces the ability to notice environmental stimuli (Finley, Benjamin, & McCarley, 2014). However, they are surprised by demonstrations of change blindness, which seems to disclose an inaccurate belief either about their perceptual skills or about the nature of their mental representations. For instance, consider the famous princess card trick: the magician shows five cards to the spectator and asks her to think of one. The magician shuffles the cards and pretends to vanish the chosen card. In the end, there are only four cards, and the magician shows that the card selected by the spectator has vanished. This is a very impressive trick that exploits change blindness. People are often notoriously surprised by this trick and completely unaware that it is based on limitations of memory for visual details. Second, most people have had previous experiences with magic tricks, therefore they can
Research problem

be used to study the mind ecologically and, at the same time, they can be adapted to retain a high level of experimental control (Kuhn & Findlay, 2009). Thus, magic tricks are suitable tools to explore visual metacognition.

In change blindness experiments, participants make predictions based on a change that they do not experience. Levin et al. (2000) posited that accessibility to past experiences of successful detection could explain their inflated judgments. To assess this hypothesis, we examined whether noticing or missing the method used in a magic trick influenced participants' metacognitive judgments about the likelihood that others would notice the method. Eye movement data was used to explore subjects' beliefs about the relationship between visual awareness and overt attention. Eye movements are necessary to see a stimulus with higher visual acuity (Holmqvist et al., 2011) and to overcome loss of vision due to neural adaptation (Martinez-Conde, Macknik, & Hubel, 2004). Furthermore, gaze changes according to the cognitive demands of the task (Ballard, 2002). Therefore, eye movements are important for information extraction (Ballard, 2002). However, although looking is related to visual awareness, studies on inattentional blindness show a counterintuitive fact: people can fail to perceive a salient unexpected stimulus even when it is presented in the center of their visual field (Beanland & Pammer, 2010; Memmert, 2006). This occurs because performing a demanding task presumably leaves insufficient attentional resources available to process the unexpected stimulus. Moreover, previous experiments on inattentional blindness using magic tricks and eye movement data demonstrate that one becomes aware of a critical event because of the deployment of covert attention (Kuhn et al., 2008b; Kuhn & Findlay, 2009; Kuhn & Tatler, 2005). This finding contradicts the belief held by naïve observers and even some magicians that looking at the right spot is the key to discovering how a trick is done.

People are often surprised to learn that they can be blind to salient stimuli or changes. This reported feeling of surprise has been taken to be an important dependent variable as it might be an indicator of the beliefs that people have about their perceptual abilities or visual experience (Dennett, 2002; Simons & Chabris, 2011). Surprise has been interpreted in different ways. One interpretation is that ordinary perceivers believe that they have a detailed visual experience (Blackmore, 2002; Cohen et al., 2016; Dennett, 2002), and when they find out that this belief is wrong they feel surprised. This interpretation has been challenged (Cohen, 2002; Noë, 2002). An alternative explanation is that ordinary perceivers
Errors of visual metacognition

hold a certain belief about their perceptual abilities that might be wrong in some circumstances. Broadly formulated, this belief is that they are able to notice salient objects and events. Such a belief is inductively supported by experience (Cohen, 2002). Empirical evidence in favor of this interpretation comes from experiments on change blindness (Beck et al., 2007a; Levin, Drivdahl, Momen, & Beck, 2002; Levin et al., 2000). In the present study, we measured how surprising it was for participants to miss a visual change in a magic trick as this might be an indicator of their prior beliefs.

The present research comprised several experiments designed for the following purposes: (1) to examine participants’ beliefs about their own ability to notice a stimulus or change, and their beliefs about the likelihood of noticing critical events under different attentional conditions (Experiment 1); (2) to determine whether the experience of detecting or missing a stimulus or change would result in biases in visual metacognitive judgments about others (Experiments 2 and 3); (3) to examine whether the experience of detecting or missing a change might be a source of overestimation and underestimation errors (Experiment 4); (4) to determine whether the feeling of surprise might be an indicator of prior beliefs (Experiment 4), and (5) to establish whether participants could anticipate that noticing a change might influence their metacognitive judgment (Experiment 5).
Chapter 1. An initial approximation to errors in visual metacognition

Abstract
Previous studies have shown that people overestimate their ability to notice salient changes in a visual scene; this metacognitive error is known as change blindness blindness. In real life people may be more or less susceptible to failures of visual awareness depending on their attentional deployment. However, it has not been investigated whether metacognitive judgments would vary as a function of different attentional conditions. In the current study, participants ($n = 144$) were presented with descriptions of five real-world scenarios and they were instructed to report whether they believed that they would notice a salient stimulus or change presented in these scenarios and the likelihood of detecting them in two conditions (i.e., narrow and distributed attention). Most participants predicted that they would notice the stimuli and changes (an overestimation effect). However, they expected that they would be more likely to notice them when their attention was broadly distributed than when it was narrow. Moreover, they indicated that they would be more surprised to miss the salient stimulus or change when their attention was broadly distributed rather than narrow. This study offers preliminary evidence that despite the overestimation effect, individuals believe that attentional constraints may affect visual awareness.

Keywords: metacognitive error; overestimation effect; attention; visual awareness.
1.1. Introduction

Failures of visual awareness such as inattentional blindness and change blindness demonstrate that our perceptual ability is limited. However, these phenomena are counterintuitive. For instance, people are surprised when they miss a person dressed in a gorilla suit walking among basketball players (Simons & Chabris, 1999). Even scientists have found these failures surprising (Levin, 2002). Yet, high rates of inattentional blindness and change blindness have been reported in ecological tasks. For example, Simons and Levin (1998) found that over half of subjects failed to detect changes in people during a real-world interaction. In Hyman, Boss, Wise, McKenzie, and Caggiano’s (2010) study, most participants who were walking and using their cellphones at the same time failed to notice a unicycling clown moving in their direction. Furthermore, Smith, Lamont, and Henderson (2012) used a magic trick and asked subjects to guess whether a coin would land heads or tails. The magician secretly switched the coin for another, but over half of participants missed the change even though they made eye fixations on the coin.

Surprise has been interpreted as a sign that people hold false beliefs about their visual experience (Blackmore, 2002). Observers intuitively believe that they will notice an unexpected stimulus or change (Koivisto, Hyönä, & Revonsuo, 2004), but inattentional blindness and change blindness studies challenge this idea. Indeed, research on visual metacognition has shown that people overestimate their change-detection ability (Beck et al., 2007a; Levin et al., 2000, 2002). Levin et al. (2000) asked participants to predict whether they would notice changes in four scenarios that were described to them. The majority indicated that they would notice the changes that had in fact been missed by most people in previous experiments (Levin & Simons, 1997; Simons & Levin, 1998). Furthermore, Beck et al. (2007a) found that participants failed to realize that intentionally monitoring their environment could improve change detection. However, Smilek et al. (2007) suggested that this finding might be related to the use of unfamiliar situations. They conducted an experiment using real-world scenarios and found that participants were aware that intentionally monitoring their environment was important for detecting changes. In a similar vein, we might intuitively believe that missing or noticing a stimulus or change is dependent on where we look. However, several studies have found that eye movements do not predict
inattentional blindness or change blindness. For instance, using the misdirection paradigm, Kuhn et al. (2008b) found that participants who noticed a salient stimulus and those who missed it made similar eye movements. Yet, Barnhart and Goldinger (2014) found that eye movements predict inattentional blindness in conditions of low cognitive demand and longer exposure to the critical stimulus. Moreover, inattentional blindness and change blindness may occur even when people look at the stimulus (Beanland & Pammer, 2010; Memmert, 2006; Smith et al., 2012). Magicians exploit these and other counterintuitive phenomena. They know that people can be blind to something that happens in front of them when their minds are distracted (Dessoir, 1893).

Mack (2002) has pointed out that attention is typically broadly distributed in ordinary situations, although there are moments when it is narrowly focused. Because observers make eye movements, they feel that their visual experience is rich and detailed (Noë, 2002). However, perception is in fact so rich that people can obtain the gist of a scene without making any eye movements (Cohen et al., 2016). What inattentional blindness and change blindness seem to demonstrate is that failures of visual awareness occur due to limitations in attention and memory. However, when attention is broadly distributed (Mack, 2002) or when people intentionally monitor their environment (Beck et al., 2007a), they are less susceptible to these failures.

Although previous experiments have found that observers believe that they would notice stimuli and changes that usually go unnoticed, we conducted the current experiment to determine whether this belief may vary depending on how they deploy attention to the visual scene, thus revealing that they understand the link between attention and visual awareness.

1.2. Experiment 1

This study was a first approximation to examine errors in visual metacognition. We presented participants with descriptions of five real-world scenarios to explore their metacognitive beliefs about their ability to notice salient stimuli and changes when their attention was either narrow or distributed. We were also interested in examining whether missing a salient stimulus or change would be more or less surprising depending on how attention was deployed.
1.2.1. Method

Participants. A total of 144 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.

Materials and procedure. The experiment was implemented in Qualtrics and all participants answered the questions on their laptop or tablet. Five scenarios were described in which there was either a salient stimulus or change. Scenarios B, C, and D were tested in previous studies (Hyman et al., 2010; Simons & Levin, 1998; Smith et al., 2012). Participants had to answer whether they would notice the stimulus or change, and they had to predict how likely they would be to do this in two conditions: (a) when they were looking at a particular part of the visual scene or a stimulus for a short period of time (narrow attention), and (b) when they were looking at the wider scene, or at a stimulus for a longer period of time (distributed attention). Predictions were done on a scale from 1 “Very unlikely” to 10 “Very likely.”

For instance, in scenario A participants had to imagine that they were simultaneously driving a car and having a conversation on their hands-free device. A car was about to swerve into their lane. They were asked whether they would notice the car; possible answers were yes, maybe, and no. Then, they had to rate how likely it was that they would notice the car swerving into their lane when they were looking ahead at the road (distributed attention), and when they were looking at the pedestrian traffic lights (narrow attention). For each condition, they were asked how surprised they would be if they failed to notice the stimulus or change. For the wordings of each scenario, see Appendix B.

1.2.2. Results

The majority of subjects indicated that they would detect the stimulus or change. We compared actual blindness rates and predicted blindness rates for those scenarios that were tested in previous studies (Scenarios B, C and D). Differences between predicted and empirical blindness rates were significant. In scenario B, participants predicted a change blindness rate of 18.8%, compared to an observed change blindness rate of 88.5% $X^2(1) = 82.94, p < .001$. In scenario C, they predicted a change blindness rate of 9%, compared to an observed change blindness rate of 53.3% $X^2(1) = 35.85, p < .001$. In scenario D, they
predicted an inattentional blindness rate of 4.2%, whereas the observed inattentional blindness rate was 75% \( X^2 (1) = 301.57, p < .001 \).

In scenarios A and D, participants reported that they would be more likely to notice the salient stimulus when attention was distributed than when it was narrow. In scenario B, participants reported that they would be more likely to notice that the coin changed when they followed the coin with their eyes (distributed attention) than when they looked at it only once (narrow attention). The difference between conditions was not significant for scenario E (Table 1).

**Table 1**: Difference in the likelihood of detecting the method as a function of attention

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Attention</th>
<th>Mdn</th>
<th>( T )</th>
<th>( p )</th>
<th>( r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A</td>
<td>Narrow</td>
<td>6.0</td>
<td>474.5</td>
<td>&lt; .001</td>
<td>- .49</td>
</tr>
<tr>
<td></td>
<td>Distributed</td>
<td>8.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario B</td>
<td>Narrow</td>
<td>4.0</td>
<td>788.0</td>
<td>&lt; .001</td>
<td>- .49</td>
</tr>
<tr>
<td></td>
<td>Distributed</td>
<td>7.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario D</td>
<td>Narrow</td>
<td>6.0</td>
<td>573.0</td>
<td>&lt; .001</td>
<td>- .44</td>
</tr>
<tr>
<td></td>
<td>Distributed</td>
<td>8.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario E</td>
<td>Narrow</td>
<td>6.0</td>
<td>2.062,5</td>
<td>0.195</td>
<td>- .08</td>
</tr>
<tr>
<td></td>
<td>Distributed</td>
<td>6.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Mdn = median values for the likelihood judgments; \( T \) = Wilcoxon test statistic; \( p \) = \( p \)-value; \( r \) = effect size.*

Moreover, participants reported that they would be more surprised if they failed to notice the stimulus or change when attention was distributed than when attention was narrow (Table 2).
Table 2: Difference in the level of surprise as a function of attention

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Attention</th>
<th>Mdn</th>
<th>T</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario A</td>
<td>Narrow</td>
<td>6.0</td>
<td>645.0</td>
<td>&lt; .001</td>
<td>-.43</td>
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<tr>
<td></td>
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<td>8.0</td>
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<tr>
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<td>&lt; .001</td>
<td>-.40</td>
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</tbody>
</table>

*Note. Mdn = median values for the level of surprise; T = Wilcoxon test statistic; p = p-value; r = effect size.*

1.2.3. Discussion

In the present study, we asked participants whether they would notice a salient stimulus or change in five scenarios that depicted real-life situations. Previous studies have reported inattentional blindness and change blindness rates over 50% (Hyman et al., 2010; Simons & Levin, 1998; Smith et al., 2012). Consistent with findings reported by Levin et al. (2000), we found that participants overestimated their perceptual ability, as their predicted rates of inattentional blindness and change blindness were significantly lower than observed rates. Interestingly, they predicted that they would be more likely to detect the stimulus or change if their attention was broadly distributed. This metacognitive judgment is consistent with the notion that when attention is widely distributed rather than narrowly focused on a particular part of the visual scene, subjects are more likely to notice the salient stimulus or change (Mack, 2002). Thus, our results are in line with previous findings suggesting that people overestimate their perceptual ability, and offer preliminary evidence that they have accurate intuitions about the role of attention in perception. However, a limitation of this study is that the order of the questions was not counterbalanced.
In studies on change blindness, participants have been explicitly informed about the visual changes and instructed to predict whether they would notice them (Beck et al., 2007a; Levin et al., 2000, 2002). However, dichotomous answers may not accurately reflect participants’ knowledge and uncertainty. On the other hand, it is possible that actually noticing or missing the changes would have an impact on visual metacognitive judgments. Moreover, it could also influence their belief about how their attention was deployed. Interestingly, Levin et al. (2000) reported that metacognitive judgments about one’s own change-detection ability were similar to metacognitive judgments about others. This finding raises the possibility that both types of metacognitive judgments might have the same source (e.g., prior beliefs). However, Loussouarn, Gabriel and Proust (2011) found that change blindness might derive from activity-dependent cues. In their study, participants performed a change detection task. They were instructed to click on the change as soon as they noticed it and then they had to estimate the time of change insertion. Experimenters manipulated two activity-dependent cues: the time at which the change was inserted (e.g., 4s, 8s, 12s) and the perceived success by providing subjects with optimistic or pessimistic feedback. In the optimistic feedback condition, the reported magnitude of change blindness was lower than actual change blindness, whereas in the pessimistic condition the reported magnitude of change blindness was higher than actual change blindness. The findings show that when the change was introduced at a later time, participants showed less change blindness. This was interpreted as an indication that subjects used an effort heuristic to make their metacognitive judgments, that is, when they spent more time looking for the change, they were less confident in their change-detection ability. In contrast, when they spent less time looking for the change, they were more confident. On the other hand, the results indicate that a pessimistic feedback decreased the percentage of change blindness. Moreover, participants in both conditions underestimated their change-detection ability and this effect was more pronounced in the pessimistic condition. Nevertheless, Loussouarn et al. (2011) acknowledged that their results cannot completely rule out the influence of prior beliefs. They claimed that “it is plausible to assume that naïve beliefs about perception and an effort heuristic are exerting an opposite influence on self-evaluation in a change detection task, and in other cognitive tasks as well” (p. 11). Their findings seem to be incongruent with the overestimation effect found in previous studies (Beck et al., 2007a; Levin et al., 2000; Levin et al., 2002) and in the present experiment. However, Loussouarn et al. (2011) remarked that the difference might be explained by the fact that their subjects made online
metacognitive judgments (i.e., while performing the detection task), whereas in previous change blindness experiments, participants made predictions off-line (i.e., without being exposed to the detection task).

As noted earlier, people also make metacognitive judgments about other people's perceptual abilities. For instance, Levin et al. (2000) found that subjects overestimated other's change-detection abilities. This led us to wonder whether exposure to a visual task would influence judgments about others. We explore this and other questions in the following experiments.
2. Chapter 2. Exploiting failures in metacognition through magic: Detection experience as a source of visual metacognition bias

Abstract

We used cognitive illusions/magic tricks to examine whether detection experiences (i.e., noticing or missing a stimulus or change) can be 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, and the role that fixating (i.e. eye position) the critical event had in 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. However, eye tracking data showed that, contrary to this belief, peripheral vision played a significant role in detecting the method. Overall, the findings of these studies suggest that noticing or missing a stimulus or change may bias visual metacognitive judgments.

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

Our visual experience supports the belief that we have a rich, uninterrupted visual mental representation of the world (Blackmore, 2002; Cohen et al., 2016; Dennett, 2002). However, 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 inattentive blindness (Mack & Rock, 1999) and change blindness (Rensink, O’Regan, & Clark, 1997). For example, people are often astonished to discover that 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 surprising 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 do 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 et al., 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 et al., 2007a; Levin et al., 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.

Much research has investigated 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). While there is a large body of 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 such failures are particularly prominent in visual short-term memory. In their study, the experimenter described four scenarios, and the participants were then asked if they would notice the changes that took place in them. The majority of subjects reported that they would notice the changes, yet previous experiments revealed that most were missed (Levin & Simons, 1997; Simons & Levin,
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, which suggests that visual metacognitive judgments about one’s self and about others may share some features as the theory-theory posits. Levin et al. (2000) suggested several explanations for why change blindness occurs. For example, people may think that salient stimuli will automatically capture their attention, and situations in which they successfully detect changes might lead them to overestimate their change detection ability. The latter hypothesis suggests a role for the availability heuristic, which refers to the process of judging frequency “by the ease with which instances come to mind” (Kahneman, 2011, p. 129).

In their work, 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 improved their performance. However, Smilek et al. (2007) criticized this study based on the fact that individuals rarely experience significant changes to stable objects. Indeed, they found that people’s predictions were often better when the examples related to real-life situations with which they had personal experience (e.g., driving). However, Beck et al. (2007b) argued that in real life, objects often change locations (e.g., a saltshaker is replaced by a spoon). In addition, people also exhibit inattentional blindness blindness. Levin and Angelone (2008) found that 88% of subjects predicted detecting the gorilla, as opposed to the 42% who actually detected it in Simons and Chabris’ study (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 unconscious 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) remarked 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.

Similarly, 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 their actual fixations were not reported, and participants also reported fixations that never occurred. Marti et al. (2015) hypothesized that false reports indicate introspection of covert attentional shifts. In another study, Võ et al. (2016) conducted 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 had 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, but there is no compelling evidence that they can actually remember their scanpaths.

Overall, studies on change blindness, inattentional blindness, 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). This is counterintuitive because we typically make voluntary eye movements towards a stimulus that is relevant to us, and in doing so we obtain 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 reading, it is essential to fixate the appropriate 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 among visual scientists is that peripheral vision contributes very little or nothing at all to object recognition. On the contrary, 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. However, numerous studies have shown that fixations alone cannot account for conscious visual perception. For example, Mack and Rock (1999) found that people were equally (if not more) attentionally blind to stimuli that appeared 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,

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1 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.”
Memmert (2006) demonstrated that detection of the gorilla was independent of whether it was looked at or not.

Using static scenes, Henderson and Hollingworth (1999) showed a clear relationship between visual eccentricity and change detection. However, studies using dynamic displays have found no significant relationship. For example, Smith et al. (2012) reported that people failed to detect a change even if they fixated the object that changed. This study used a magic trick that showed a pair of hands passing a coin and then dropping it on the table. In the critical trial, the coin was secretly replaced by another one. Participants watched a series of videos and had to guess whether the coin would land heads or tails. 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 et al., 2008a; Rensink & Kuhn, 2015; Thomas, Didierjean, Maquestiaux, & Gygax, 2015). Most previous research on inattentional blindness and change blindness using magic tricks has simply asked people to report whether they detected the method or not. However, while misdirection in magic tricks exploits metacognitive errors in perception, none of these previous studies investigated people’s beliefs about whether they or others would be able to detect the secret, and whether the experience of detecting or missing a stimulus or change could bias metacognitive judgments about others. As such, the present study is the first to empirically investigate the influence of detection experiences on metacognitive judgments about other people’s perceptual abilities.

Magic tricks create a conflict between our beliefs and our experience, and magicians use misdirection to create these effects (Kuhn et al., 2014). Misdirection involves exploiting counterintuitive limitations in cognition, and thus provides the ideal tool to investigate failures in metacognition (Ekroll et al., 2017). Misdirection provides effective ways to control spectators’ overt attention (Barnhart & Goldinger, 2014; Kuhn & Findlay, 2009; Kuhn & Tatler, 2005; Kuhn et al., 2008b; Kuhn & Teszka, 2017). It has therefore been useful in exploring the relationship between eye movements and failures of visual awareness. In 1893, Max Dessoir noted that 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.

For instance, in the experiment conducted by Kuhn et al. (2008b), 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 while misdirecting the spectators’ 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 vanished from a starting location and reappeared in a different location. The method used to accomplish this illusion spanned a longer period of time than in previous studies (Kuhn et al., 2008b; Kuhn & Findlay, 2009), thereby allowing more time for participants to make fixations on the critical stimulus. Their results showed that fixations predicted 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 examine whether noticing or missing a stimulus or change can be 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). We further used two tricks 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, while 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; and secondly, we examined participants’ beliefs about the relationship between looking and seeing and the extent to which their detection experience influenced their beliefs about where they were looking at the time the event took place.
2.2. Experiment 2

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, and the role that fixating the critical event had in detecting the secret.

2.2.1. Method

Participants. A total of 144 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.

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 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 the participants that the backs of the cards have changed from blue to red. To accomplish this effect, the magician uses a set of blue and red cards. Only the red-backed cards are shown in the reveal. We filmed the magic trick 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

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2 These subjects previously participated in Experiment 1.
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%).
change takes place and the red cards remain visible lasts 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 and moves his hand away. He then shows that the flame is gone. Next, 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’s (2009) study, 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.** In this trick, 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 pretends to make the chosen 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 chosen card is no longer present. While this trick involves 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. We filmed the magic trick 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 is to make the coin slide across the placemat from one location to another. The video clip lasts 32 seconds, and the moving coin is visible for 550 milliseconds. In Barnhart and Goldinger’s (2014) study, 15 participants (45.4%) noticed the moving coin (supplementary video S4). The study was conducted in a classroom and the data were collected online using Qualtrics. 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 C). On the first page, they had to report whether they had seen the magic trick before and whether they had noticed how it 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 discovered the secret after a reasoning process, and not because they perceptually noticed it (Kuhn et al., 2008b). 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 that disallows inference, that is, the secret of the trick is difficult to figure out unless observers actually see it. Similarly, it is very difficult to figure out how the princess card or color-change trick works without noticing the change. We are therefore confident that the participants’ reports of the method reflected their perceptual experiences.

For each of the tricks, participants were shown different figures that described the method, and they were asked to answer metacognitive 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).
Figure 1: Method and misdirection areas.

a.  

In the color-change trick figure (a), the green circle indicates the area where the color change takes place and the yellow circle highlights 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 the magician’s face. In the coin trick figure (c), the green circle shows the space where the coin moved and the yellow circle indicates the location of the empty cup shown by the magician.

Figure 2: The change in the Princess Card trick.

a.  

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

2.2.2. Results

Participants were classified as having detected the method if they answered yes to whether they had 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% in the lighter trick, 75% in the coin trick, and 43.4% in the princess card trick.

Influence of detection experience on the metacognitive judgment about whether someone else would notice a salient stimulus. We explored the relationship between people’s own ability to detect the method and their judgments about others. Table 3 shows the likelihood estimates of detecting the method as a function of whether or not the participants detected the method themselves. Two things become apparent when looking at Table 3. First, participants generally overestimated other people’s ability to detect the method. While an average of 44% of participants noticed the method across all four tricks, they judged that other people would be rather likely to do so. Second, participants’ judgments about other people’s perceptual abilities were related to their immediate perceptual experience. Noticing the method significantly increased participants’ estimates that others would notice it too.
Table 3: Likelihood judgment of whether someone else would notice the method as a function of detection

<table>
<thead>
<tr>
<th>Trick</th>
<th>Detection</th>
<th>n</th>
<th>%</th>
<th>Mdn</th>
<th>U</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-change trick</td>
<td>No</td>
<td>75</td>
<td>59%</td>
<td>5</td>
<td>2862</td>
<td>&lt; .001</td>
<td>.38</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>53</td>
<td>41%</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter trick</td>
<td>No</td>
<td>113</td>
<td>85%</td>
<td>5</td>
<td>1590</td>
<td>.003</td>
<td>.25</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>20</td>
<td>15%</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coin trick</td>
<td>No</td>
<td>34</td>
<td>25%</td>
<td>5</td>
<td>2820</td>
<td>&lt; .001</td>
<td>.47</td>
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<tr>
<td></td>
<td>Yes</td>
<td>102</td>
<td>75%</td>
<td>8</td>
<td></td>
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<tr>
<td>Princess card</td>
<td>No</td>
<td>69</td>
<td>57%</td>
<td>3</td>
<td>2736</td>
<td>&lt; .001</td>
<td>.43</td>
</tr>
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<td>Yes</td>
<td>53</td>
<td>43%</td>
<td>6</td>
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</tr>
</tbody>
</table>

Note. Mdn = median values for the judgments; U = Mann-Whitney’s U statistic; p = p-value; r = effect size.

Influence of detection experience on the metacognitive judgment about the deployment of overt attention. Next, we examined participants’ reports on where they believed they were looking at the time the method took place, as a function of whether or not they saw how the trick was done. Table 4 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 4: Likelihood judgment of having deployed overt attention to the method area as a function of detection

<table>
<thead>
<tr>
<th>Trick</th>
<th>Detection</th>
<th>n</th>
<th>Mdn</th>
<th>U</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-change trick</td>
<td>No</td>
<td>75</td>
<td>4</td>
<td>3116</td>
<td>&lt; .001</td>
<td>.49</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>53</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter trick</td>
<td>No</td>
<td>113</td>
<td>4</td>
<td>1660</td>
<td>.001</td>
<td>.29</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>20</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coin trick</td>
<td>No</td>
<td>34</td>
<td>4</td>
<td>2924</td>
<td>&lt; .001</td>
<td>.52</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>102</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Mdn = median values for the judgments; U = Mann-Whitney’s U statistic; p = p-value; r = effect size.

The princess card trick. There is no physical method area for the princess card trick, 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 they were more likely to notice that the cards changed if they looked at all the cards than if they looked only at the selected card $\chi^2(1, n = 122) = 17.3, p < .001$. 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 do so $U = 1.474, z = -1.84, p = .065$.

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 people were 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 people were more (or equally) likely to detect the method using peripheral vision than (or as) using foveal vision. For all three
effects, a significantly higher number of participants indicated that people were 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 5).

Table 5: Differences between foveal and peripheral judgment

<table>
<thead>
<tr>
<th>Trick</th>
<th>Type of judgment</th>
<th>Mdn</th>
<th>z</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-change trick</td>
<td>Foveal</td>
<td>8</td>
<td>-8.24</td>
<td>&lt; .001</td>
<td>-.51</td>
</tr>
<tr>
<td></td>
<td>Peripheral</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter trick</td>
<td>Foveal</td>
<td>8</td>
<td>-8.42</td>
<td>&lt; .001</td>
<td>-.52</td>
</tr>
<tr>
<td></td>
<td>Peripheral</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coin trick</td>
<td>Foveal</td>
<td>9</td>
<td>-8.63</td>
<td>&lt; .001</td>
<td>-.52</td>
</tr>
<tr>
<td></td>
<td>Peripheral</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Mdn = median values for the judgments; z = z statistic; p = p-value; r = effect size.*

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

**Peripheral vision judgment.** To obtain a sense of how likely participants believed people
were 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 are in line with the previous results. Participants clearly believed that
detection of the method was contingent upon fixating the method area.

2.2.3. Discussion

Our results show that participants generally overestimated other people’s ability to notice
the method, and that noticing or missing a stimulus or change influenced 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, thus showing an
egocentric bias. 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 have shown that misdirection is effective to control both where people look and their covert attention (Barnhart & Goldinger, 2014; Kuhn & Findlay, 2009; Kuhn & Tatler, 2005; Kuhn et al., 2008b), and thus it is likely that our participants looked elsewhere. Although detection experience 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. Using a similar trick, Smith et al. (2013) found that all participants fixated the faces of the cards while they were counting. In addition, subjects in the current experiment believed that they were more likely to notice the method if they foveated it. Although the relationship between fixation and detection was not examined in the present 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 of our 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., 2008b).

A limitation of our study is that because the magic tricks were presented in a classroom, it was not possible to counterbalance the order of the clips nor to control the viewing distance. However, while these factors could have affected the overall detection rates, it is unlikely that they would have systematically affected people’s metacognitive judgments.
2.3. Experiment 3

The second experiment 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 detection experience rather than eye movements, and to gain additional insights into the relationship between looking and seeing, and in particular people’s beliefs about this relationship.

2.3.1. Method

Participants. A total of 69 undergraduate students at the 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

Materials and procedure. Participants were tested individually in the Cognitive Neuroscience and Communication Laboratory. We used the video clips from Experiment 2, and displayed them 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 clip. We used the questionnaire from the first study.

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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%).
**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, which drops the lighter (method area), (2) the magician’s face (misdirection area), and (3) the magician’s right arm (supplementary video S6).

**Coin trick.** Five AOIs were defined 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 conveyed the information about the identity of the cards (supplementary video S8).

**2.3.2. 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% in the lighter trick, 78.5% in the coin trick, and 50% in the princess card trick.
Influence of detection experience on participants’ judgment about whether someone else would notice a salient stimulus. We examined whether participants’ own detection experience influenced their beliefs about other people’s perceptual abilities (Table 6). For the color-change trick and the coin trick, participants who detected the method were more confident that others would spot the tricks than those who missed it. While the medians for the lighter trick and the princess card trick went in the predicted direction, the differences were not significant.

Table 6: Likelihood judgment of whether someone else would notice the method of the magic trick

<table>
<thead>
<tr>
<th>Trick</th>
<th>Detection</th>
<th>n</th>
<th>%</th>
<th>Mdn</th>
<th>U</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-change trick</td>
<td>No</td>
<td>35</td>
<td>60%</td>
<td>4</td>
<td>658</td>
<td>&lt;.001</td>
<td>.54</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>23</td>
<td>40%</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter trick</td>
<td>No</td>
<td>28</td>
<td>46%</td>
<td>5</td>
<td>586</td>
<td>.07</td>
<td>.23</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>33</td>
<td>54%</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coin trick</td>
<td>No</td>
<td>14</td>
<td>22%</td>
<td>4</td>
<td>586</td>
<td>&lt;.001</td>
<td>.46</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>51</td>
<td>78%</td>
<td>7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Princess card</td>
<td>No</td>
<td>30</td>
<td>50%</td>
<td>4</td>
<td>566</td>
<td>.08</td>
<td>.22</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>30</td>
<td>50%</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Mdn = median values for the judgments; U = Mann-Whitney’s U statistic; p = p-value; r = effect size.

Relationship between detection and fixation. We examined whether method detection was related to fixating the critical event. Table 7 shows the number of participants who detected the method as a function of whether or not they fixated the method area.
Table 7: Number of participants as a function of detection and fixated area

<table>
<thead>
<tr>
<th>Trick</th>
<th>Detection</th>
<th>Fixated the method area</th>
<th>Did not fixate the method area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-change trick</td>
<td>No</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>Lighter trick</td>
<td>No</td>
<td>0</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>10</td>
<td>23</td>
</tr>
<tr>
<td>Coin trick</td>
<td>No</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>14</td>
<td>37</td>
</tr>
</tbody>
</table>

**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 noticed 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 shows 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 noticed 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.

**Influence of detection experience on participants’ 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 that they had moved their eyes to the method area compared to those who missed it (Table 8).

**Table 8:** Likelihood judgment of having deployed overt attention to the method area as a function of detection (only peripheral detectors are included)

<table>
<thead>
<tr>
<th>Trick</th>
<th>Detection</th>
<th>n</th>
<th>Mdn</th>
<th>U</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-change trick</td>
<td>No</td>
<td>35</td>
<td>3</td>
<td>556</td>
<td>&lt; .001</td>
<td>.62</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>18</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter trick</td>
<td>No</td>
<td>28</td>
<td>3</td>
<td>524</td>
<td>&lt; .001</td>
<td>.54</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>23</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coin trick</td>
<td>No</td>
<td>12</td>
<td>2.5</td>
<td>408</td>
<td>&lt; .001</td>
<td>.62</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>37</td>
<td>8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note. Mdn = median values for the judgments; U = Mann-Whitney’s U statistic; p = p-value; r = effect size.*

**The princess card trick.** Thirty participants (50%) detected that the cards changed. Those who failed to notice this 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 people were more likely to notice that the cards changed if they looked at all the cards than if they looked only at the selected card. Results from the princess card trick provide further evidence that participants’ belief about where they look is driven by their experience of detection rather than eye movements.

**Looking and seeing.** We performed the same analysis as in Experiment 2 to examine participants’ beliefs about the relationship between seeing the method and fixating the critical event. Like in Experiment 2, for all three effects, most participants indicated that
detecting the critical event was more likely when fixating the method area than when fixating the misdirection area: color-change trick (97%), lighter trick (95%), coin trick (93%) (Table 9). Once again, this suggests that people assume a strong relationship between eye movements and detection.

Table 9: Differences between foveal and peripheral judgment

<table>
<thead>
<tr>
<th>Trick</th>
<th>Type of judgment</th>
<th>Mdn</th>
<th>Z</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color-change trick</td>
<td>Foveal</td>
<td>9</td>
<td>-6.53</td>
<td>&lt; .001</td>
<td>-.61</td>
</tr>
<tr>
<td></td>
<td>Peripheral</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighter trick</td>
<td>Foveal</td>
<td>9</td>
<td>-6.31</td>
<td>&lt; .001</td>
<td>-.58</td>
</tr>
<tr>
<td></td>
<td>Peripheral</td>
<td>3.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coin trick</td>
<td>Foveal</td>
<td>9</td>
<td>-6.54</td>
<td>&lt; .001</td>
<td>-.57</td>
</tr>
<tr>
<td></td>
<td>Peripheral</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. Mdn = median values for the judgments; Z = z statistic; p = p-value; r = effect size.

Peripheral vision judgment. As we did in Experiment 2, 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 detecting the method.
Figure 3: Detection under peripheral vision.

Fewer than 30% of participants indicated that 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.

2.3.3. Discussion

Like in Experiment 2, participants who detected the method of the tricks judged it to be more likely that others would also notice it, thus showing an egocentric bias. In addition, they believed that they moved their eyes to the method area, but eye tracking data revealed that most of them were peripheral detectors. Failure to detect the change in cards in the princess card trick (Experiment 3), 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 detection experience 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 were more likely to notice the method when looking at the critical event. However, the number of peripheral detectors was significant, which contrasts their underestimation of
peripheral vision and disproves their belief that they made eye movements to the method area.

All in all, these results show that relying on detection experiences 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.

### 2.4. General discussion

Previous studies have shown that we are often blind to salient stimuli and changes to which we do not attend (Mack & Rock, 1999; Rensink et al., 1997; Simons & Chabris, 1999). However, we do not only fail to notice things: we are typically also surprised that we failed to notice them, and surprise is a compelling sign that we have false beliefs about cognition. In this study, we expanded the scientific knowledge about visual metacognition by examining the influence of detection experiences on metacognitive judgments about one’s self and others.

We used magic tricks to study biases in visual metacognition, as they naturally exploit counterintuitive limitations in cognition (Kuhn et al., 2014). Our four magic tricks relied on four different types of cognitive failures: inattentional blindness for sustained and brief events, and change blindness for changes that occur in full view or are occluded. Yet, the same pattern of results was found for all illusions in Experiment 2 and for two illusions in Experiment 3. These magic tricks provide a natural way of studying cognitive failures, and our results demonstrate that subjects’ metacognitive judgments about themselves and about others were biased by their detection experiences.

First, participants were biased by their detection experience when making metacognitive judgments about their deployment of overt attention. Other experiments have shown that people report fixations that they never made (Marti et al., 2015; Võ et al., 2016), but these studies did not assess how confident subjects were about their responses, which could have revealed more about their meta-attention. In Experiment 2, 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 resulted from not looking at the critical event. However, in Experiment 3 we found that the majority of participants who detected the method used peripheral vision. Hence, we suggest that people’s beliefs about where they are looking are driven by their detection experience, 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 had a demand characteristic to infer that they looked there. People’s beliefs about their fixations may have been influenced not only by their subjective memory of the locations they fixated, but also by knowledge of their detection performance.

Second, participants showed an egocentric bias when making metacognitive judgments about others. 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. Kelley and Jacoby (1996) provided evidence in a non-perceptual domain that illustrates how subjective experience biases judgments about other people’s capabilities. They showed that the ease with which participants solved anagrams influenced their judgment about how difficult it would be for other people to solve them.

Why do these biases in metacognition occur? A dual-process perspective (Koriat et al., 2008) presumes that metacognitive judgments are based on two types of processing: System 1 and System 2 (Stanovich & West, 2000). System 1 comprises unconscious, fast, and automatic processing, while System 2 is deliberate, slow, and effortful processing (Kahneman, 2011). System 1 processing may lead to biased metacognitive judgments because it is 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 gain more control over the factors that come into play by applying rules and theories systematically (Kelley & Jacoby, 1996).

Stanovich and West (2000) explained 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) explained 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" (p. 80). 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, and that others would be less likely to detect a salient event when they themselves have missed it. This heuristic might explain overconfidence in that participants’ judgments may rely on the accessibility of past successful change-detection experiences (Levin et al., 2000).

Our results also suggest that people underestimated the role of peripheral vision. In contrast, scientific evidence has shown that peripheral vision plays an important role in object recognition (Rosenholtz, 2016). In a study comparing the 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 brief exposure suggest that we can extract a great deal of information from a scene through a single glance, thus relying significantly on peripheral vision (Greene & Oliva, 2009; Rousselet, Joubert, & Fabre-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 would be more likely to notice a salient stimulus if they fixated it. The results of the eye tracking study support this intuition, but also indicate that fixations are not necessary for visual awareness. Other studies using tasks exploiting the limits of central attention have found that inattentinal blindness occurred even when the unexpected stimulus appeared at fixation (Beanland & Pammer, 2010; Memmert, 2006; Most et al., 2000). Furthermore, studies using the misdirection paradigm have reported a dissociation between where people looked and what they saw (Kuhn & Findlay, 2009; Kuhn & Tatler, 2005; Kuhn et al., 2008b). Together, these findings indicate that fixations alone cannot account for conscious visual perception.
All in all, the findings of the present study do not support the widely held notion that observers believe that their experience of the world is uniformly rich from the center out to the periphery of their visual fields (Dennett, 2005). Noë (2002) termed this notion “the snapshot conception of experience.” On the contrary, this study 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. Indeed, Noë (2002) pointed 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 believe that participants’ metacognitive judgments are at odds with the snapshot conception of experience, whereas these judgments are congruent with the notion that perception is a process of actively extracting information from the environment through eye movements.

Thus far, we have argued that the availability heuristic may account for biases in visual metacognitive judgments. We have suggested before that surprise at missing visual stimuli may indicate that subjects have false beliefs about cognition. However, we did not measure this variable in the current experiments. Therefore, we designed the following two experiments to examine how surprised observers are at missing visual changes and whether noticing or missing these changes would lead to errors of overestimation and underestimation.

**Supplementary material**

Supplementary material associated with this article can be found at the following link: [https://drive.google.com/open?id=1To7zrW-gkG9p9rhR6DXxo48PxjC9oFM](https://drive.google.com/open?id=1To7zrW-gkG9p9rhR6DXxo48PxjC9oFM)
3. Chapter 3. Errors of visual metacognition exposed through magic: An account from the availability heuristic and prior beliefs

Abstract
In the previous experiments, we found that noticing or missing a salient stimulus or change may be a source of biases when making visual metacognitive judgments about others. However, the findings did not provide direct evidence that detection experience led to errors of overestimation or underestimation. In Experiment 4, participants \((n = 95)\) watched a magic trick exploiting change blindness and estimated the probability that others would detect a subtle change or a salient one. Noticing the subtle change led to an overestimation effect whereas missing the salient change led to an underestimation effect. Those who missed the change in both conditions reported a high and similar level of surprise, which suggests that they have prior beliefs about their change-detection ability. In Experiment 5 \((n = 92)\), the change was described and shown to participants. Half of the subjects anticipated that noticing the change would increase their estimated detection rate. Contrary to what we found in Experiment 4, they believed that missing the salient change would be more surprising than missing the subtle change. Our findings suggest that the availability heuristic and prior beliefs underlie errors when making visual metacognitive judgments about others.

Keywords: visual metacognition; metacognitive judgment; change blindness; availability heuristic; prior beliefs; theory-theory; simulation theory.
3.1. Introduction

Cognitive scientists and philosophers use the term “metacognition” in different ways (Carruthers, 2009; Frith, 2012; Nelson & Narens, 1994; Proust, 2013). One perspective views metacognition as the process of monitoring and controlling one’s own cognitive processes (Nelson & Narens, 1994). On the other hand, Jost et al. (1998) proposed an expansionist definition of metacognition which includes beliefs about cognition in general (folk theories), as well as beliefs about one’s own cognitive skills and those of other people. This view assumes that metacognition about oneself is similar to metacognition about others because the properties of cognition are universally shared, although they may derive from different sources of information (Carruthers, 2011; Jost et al., 1998). The social metacognition perspective has practical implications. For instance, in legal testimony, jurors often think about the witness’s ability to perceive or remember (Levin et al., 2002) and they also make use of witness’s confidence in order to decide whether to trust her testimony (Shea et al., 2014). In the present study, we agree that metacognition can include cognition about others’ cognitive skills and we studied errors in visual metacognition by asking participants to predict the probability that others would detect a visual change.

Several theories have been advanced to account for the attribution of mental states to others: the theory-theory and the simulation theory. Some theorists even support a hybrid account (e.g., Goldman, 2006). The theory-theory, in its purest form, assumes that metacognition about others (or mindreading) is based on theoretical reasoning that is guided by principles of folk psychology (Goldman, 2006). According to Carruthers (2011), knowledge about the self and knowledge about others share similar behavioral cues, cognitive mechanisms, and conceptual resources. However, metacognition about oneself involves access to information that is not transparent in others (e.g., visual imagery, inner speech). According to the simulation theory, subjects run mental simulations of others’ mental states using imagination, perspective taking, and mental pretense (Goldman, 2006; Shanton & Goldman 2010). The mindreader uses information about the target (e.g., desires, beliefs) and then creates pretend desires and beliefs that are fed into a decision-making mechanism. The output of this process is a pretend decision that is attributed to the
target (Goldman, 2006). Although there are other theories, the theory-theory and the simulation theory are the most relevant to discuss our findings.

Several studies have shown that metacognitive judgments about others might be based on one’s own beliefs or experiences. For instance, Kelley and Jacoby (1996) found that the time subjects spent solving anagrams correlated with their judgment of how difficult it would be for others to solve them. Koriat and Ackerman (2010) suggested that making metacognitive judgments about one’s self might serve as a basis for making metacognitive judgments about others. They found that when people did a self-paced study task their judgments of learning were negatively correlated with the time they spent studying each item. That is, the more time they spent studying an item the lower was their predicted likelihood of recalling it later. According to Koriat and Ackerman (2010), this finding indicates that subjects used a memorizing-effort heuristic to make judgments of learning. The researchers wanted to find out whether subjects would spontaneously apply this heuristic when making metacognitive judgments about others. However, when participants made judgments about others without having done the self-paced study task themselves, they failed to apply the memorizing-effort heuristic and instead their judgments were based on the belief that the recall should increase with the amount of study. On the other hand, when they made judgments about others after doing the task themselves, they applied the memorizing-effort heuristic. Koriat and Ackerman (2010) proposed that subjects articulated a rule based on their own experience in order to make judgments about others. This finding is consistent with the theory-theory. However, they also acknowledged that it is not possible to completely rule out that subjects simulated the effort experienced by others when making their judgments.

Occasionally, people make mistakes when ascribing mental states to others. For instance, sometimes they erroneously impute their knowledge to others. This phenomenon is known as the curse of knowledge (Camerer et al., 1989). Birch and Bloom (2004) suggested that cognitive inhibition might be responsible for the curse of knowledge in that it is difficult to inhibit one’s own knowledge when attributing mental states to others. This phenomenon may be accounted for by the quarantine failure posited by the simulation theory which occurs when the mindreader’s own mental states and processes intrude into the simulation leading to egocentric biases (Goldman, 2006; Shanton & Goldman, 2010). On the other hand, egocentric biases might also result from a folk psychology principle which assumes
that people share identical mental states. However, Wallin (2011) asserted that neither mindreading theory is better than the other to explain egocentric biases.

Studies in the visual awareness domain suggest that people have preexisting beliefs about their own and other people’s abilities to detect visual stimuli (Beck, Levin, & Angelone, 2007; Levin & Angelone, 2008; Levin et al., 2002; Levin, Momen, & Drivdahl, 2000). In these studies, participants made predictions about their visual performance in different situations that were described to them. Interestingly, people’s intuitions led to overestimation and underestimation effects. For instance, Levin and Angelone (2008) reported that subjects were overconfident about their ability to detect visual changes and unexpected stimuli. On the other hand, they were underconfident in their ability to remember large sets of unrelated pictures. Levin et al. (2000) also asked participants to predict whether others would notice unexpected changes, and again they found an overestimation effect. This error of overconfidence might stem from prior beliefs. For instance, people might believe that violations of the apparent stability of the natural world would be immediately noticed or that visual information is available just by looking at it (Levin et al., 2000). However, overconfidence errors might also stem from the availability heuristic. Kahneman (2011) defined the availability heuristic as the process of judging frequency “by the ease with which instances come to mind” (p. 129). This heuristic might explain overconfidence in that participants’ judgments may rely on the accessibility of past successful change-detection experiences (Levin et al., 2000).

In the previous experiments we found that when participants successfully detected a stimulus or change in the context of a simple magic trick, participants predicted a higher likelihood that others would also notice them, whereas those who experienced change blindness or inattentional blindness predicted a lower likelihood. Therefore, the experience of noticing or missing the secret biased their judgments about other people’s perceptual skills, suggesting a role for the availability heuristic in visual metacognitive judgments. However, these findings did not provide evidence that noticing or missing a stimulus or change would lead to metacognitive errors about others’ visual capacities.

In the present study, we examined whether noticing or missing a visual change in a magic trick leads to metacognitive errors such as overestimating or underestimating others’ ability to notice it. Moreover, we asked those participants who experienced change blindness how
surprised they were about missing the change. Arango-Muñoz (2014) argued that epistemic feelings (e.g., surprise) carry information about mental states, thus playing a metacognitive function by implicitly representing the cognitive states of the agent (e.g., what she believes). The feeling of surprise is triggered by the violation of expectations (Dennett 2002; Kahneman, 2011). However, there is no agreement what constitutes the underlying expectation (Noë, 2002; Siewert, 2002). Blackmore (2002) posited that people find change blindness surprising because they believe that they have rich visual representations. On the other hand, surprise may result from a different kind of expectation, for instance thinking that changes will capture our attention and enter into our awareness (Levin et al., 2000) or believing that we are better observers than we actually are (Noë, 2002).

We believe that surprise is an interesting dependent variable that can be explored ecologically using magic tricks. People often experience surprise when watching a magic trick as a result of causality violations (Danek et al., 2015; Parris et al., 2009). We examined whether missing a salient change would be more surprising than missing a subtle change. According to Foster and Keane’s (2015) metacognitive explanation-based theory of surprise, some surprises are more surprising than others because they are more difficult to explain. Missing a salient change would be more difficult to explain than missing a subtle change, and should therefore be more surprising.

In Experiment 4, we studied errors of visual metacognition for an experienced change and a non-experienced change. We used two versions of the Princess Card trick that differ in the saliency of the change. In this trick, the magician secretly changes the identity of five playing cards, a change that typically goes unnoticed. One group was asked to watch the trick in which the change is subtle, and the other group was asked to watch the trick in which the change is more salient. This manipulation of saliency was expected to result in different detection rates. Afterwards, participants had to estimate the probability that other people would notice the change. We compared actual detection rates with predicted rates to determine whether noticing or missing the change altered subjects’ metacognitive judgments about others. Furthermore, we were interested in examining participants’ metacognitive judgments for a non-experienced change that differed in saliency. We examined whether their previous experience would generalize to a non-experienced change.
In Experiment 5, we blocked participants’ subjective experience of the trick by providing a description of the subtle change before presenting the trick. One group was asked to imagine that they had noticed the change and the other group was asked to imagine that they had missed it. They were instructed to predict how many people would detect the change. We wanted to explore whether they had prior beliefs about the influence of detection experiences on metacognitive judgments. Moreover, we examined whether they would predict differences between the level of surprise for missing the subtle change and for missing the salient change.

In sum, we predicted that detecting or missing a visual change will lead to errors when making metacognitive judgments about others: Noticing a visual change will lead to overestimate other people’s change detection ability, whereas missing a visual change will lead to an underestimation effect. As mentioned earlier, these egocentric biases might be explained by assuming identical mental states (theory-theory) or by quarantine failures (simulation theory). However, the feeling of surprise at missing a visual change might indicate that subjects have a prior belief, consistent with the theory-theory.

3.2. Experiment 4

The aim of the first experiment was to examine whether people are better at noticing a salient change than a subtle change, and to measure participants’ metacognitive judgments about the probability that others would notice these changes. Moreover, we tried to establish whether noticing or missing a visual change would be a source of metacognitive errors. To this end, we created two experimental conditions. One group watched a version of the Princess Card trick in which the change of the cards is subtle, while the other group watched a version in which the change is salient. We measured participants’ susceptibility to this illusion and asked them to estimate the probability that others would detect the change. This design allowed us to examine differences in predicted detection rates as a function of whether the change was detected or not, as well as a function of how salient the change itself was. We also aimed to investigate whether the effect of detecting or missing a change would generalize to a different type of change, one not experienced first-hand. Finally, we also measured the level of surprise of those who missed the change.
3.2.1. Method

Participants. A total of 95 undergraduate students at the National University of Colombia participated in the study in exchange for partial fulfillment of a class requirement (mean age: 21.6, SD = 3.1; 50 females). All participants had normal or corrected-to-normal vision and were naïve about the aim of the study. We excluded participants who had seen the trick before (12) or had incomplete questionnaires (3), resulting in a sample of 80.

Materials and procedure. To exploit change blindness, we used the Princess Card trick and manipulated the saliency of the change, thus creating two conditions. In this trick, the magician displays five cards in a fan and asks the spectator to think of one. Afterwards, the magician shuffles the cards and says that she can make the thought-of card disappear. She pretends to vanish the selected card with a hand movement. At the end, she counts only four cards and shows that the chosen card has vanished. To accomplish this trick, the magician uses trick cards that have different suits on the top and bottom. By manipulating the trick cards, the magician ensures that the chosen card no longer appears to be present. Both versions of the trick were filmed at 29 fps using a Nikon COOLPIX L830 digital camera. The videos were edited in MAGIX Movie Edit Pro 2014 Plus and have durations of 47 seconds and 45 seconds.

Participants were randomly assigned to the subtle or the salient condition. In the subtle condition, participants were asked to watch the trick in which the only modification is the suit of each card, whereas the figures and the color remain the same. For example, the jack of spades changes to the jack of clubs (Figures 4a and 4b) (supplementary video S9). In the salient condition, participants were asked to watch the trick in which the cards presented at the beginning are black and red, while those presented at the end are all red (Figures 4c and 4d) (supplementary video S10).

After watching the video clip, participants were asked to answer a questionnaire (Appendix D). On the first page, subjects had to report whether they had seen the magic trick before and whether they noticed anything unusual about the trick. If subjects answered yes to the latter question, they were asked to describe what they saw. On the second page, participants were presented with two figures that showed the change of the cards, and asked whether they had noticed that the cards presented at the end of the trick were
different from the cards presented at the beginning. Participants who had not noticed the change were asked to indicate on a 10-point scale how surprised they were about missing the change (1 = “not surprised”; 10 = “very surprised”). Subjects were then asked to estimate how many people out of 10 would notice the change (0 to 10 scale). Finally, participants were shown two figures corresponding to a non-experienced change: namely, the subtle group had to imagine that the cards changed as shown in Figure 4c and 4d (salient change), and the salient group that the cards changed as shown in Figure 4a and 4b (subtle change). They were instructed to predict how many people out of 10 would detect the change.

**Figure 4:** The subtle and the salient change in the Princess Card trick.

Subtle change. The cards presented at the beginning of the trick (a) have a different suit than the cards presented at the end of the trick (b) while the figures and colors remain the same. Salient change. The cards presented at the beginning of the trick (c) are black and red, while the cards presented at the end are all red (d).
Figure 5: Flowchart of Experiment 4 for the subtle and salient conditions.

Statistical analysis. We ran non-parametric tests when assumptions of normality and homoscedasticity were violated. To control for Type-1 error due to multiple testing, we used a Bonferroni correction as follows: With 13 tests being considered, we rejected the null hypothesis if the p-value was less than .004.

3.2.2. Results and Discussion

Detection rates and saliency manipulation. Participants were classified as having detected the change if they reported noticing it. In total, 22.5% of the participants noticed the subtle change, while 72.5% detected the salient change. We ran a Chi-Square test and, as expected, the salient change was more easily detected than the subtle one, $X^2 (1, n = 80) = 20.05, p < .001$.

Estimated detection rates for the experienced change. Table 10 shows the mean estimates for each change as a function of whether participants detected the change or not. The first analysis focuses on participants’ estimates of the probability of others noticing the change that they themselves had observed or missed. A two-way ANOVA with change detection (missed, detected) and change condition (subtle, salient) as between-subjects factors found a significant main effect of change detection, $F(1, 76) = 31.67, p < .001$, $\eta^2_p = .294$, in that participants who detected the change provided significantly higher estimates ($M = 5.71, SD = 2.07$) than those who missed it ($M = 2.95, SD = 1.58$). In contrast, the main
effect of change condition was non-significant, $F(1, 76) = .184, p = .67, \eta^2_p = .002$, as was the interaction between change detection and change condition, $F(1, 76) = 3.49, p = .065, \eta^2_p = .044$.

Next, we compared actual detection rates with mean estimates. The Chi-Square goodness of fit test revealed that participants who detected the change in the subtle condition overestimated the detection rate $X^2 (1) = 11.16, p = .001$, whereas those who missed the salient change underestimated the detection rate, $X^2 (1) = 49.82, p < .001$. Although participants in the salient condition who detected the change underestimated the detection rate, the effect was non-significant $X^2 (1) = 2.72, p = .1$ (Table 10).

**Table 10:** Actual detection rates and mean estimates of detection rates as a function of change condition (subtle, salient) and change detection (missed, detected)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Actual detection rates</th>
<th>Change detection</th>
<th>Estimated detection rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subtle</td>
<td>22.5%</td>
<td>Missed</td>
<td>31.3%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detected</td>
<td>48.9%</td>
</tr>
<tr>
<td>Salient</td>
<td>72.5%</td>
<td>Missed</td>
<td>24.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Detected</td>
<td>59.7%</td>
</tr>
</tbody>
</table>

**Influence of change detection on a non-experienced change.** We were interested in whether participants’ previous noticing or missing experience would also bias their judgments for a non-experienced change. We compared estimates for the non-experienced change between those who had previously detected the change and those who had missed it. The Mann-Whitney test revealed that the difference was non-significant in the subtle condition $U = 186.5, z = 1.55, p = .13$, and in the salient condition $U = 175, z = .47, p = .65$. Therefore, the bias did not generalize to the non-experienced change.

**Surprise as a function of type of change.** We also looked at the level of surprise experienced by those participants who missed the change. The majority of participants in the subtle condition (87.1%) and in the salient condition (90%) were very surprised at missing the change (6 and above). However, the Mann-Whitney test showed that those who missed the salient change were no more surprised ($Mdn = 8$) than those who missed the subtle change ($Mdn = 8$), $U = 210, z = 1.151, p = .269$. 
As noted earlier, being surprised is an indicator of an expectation violation. If participants had a prior belief that they should be able to detect visual changes, missing the change would conflict with this belief and trigger surprise. However, metacognitive judgments about others did not reflect their prior belief. Instead, it was influenced by their failure to detect the change preventing an overestimation error in the subtle group and leading to an underestimation error in the salient group. This result suggests that participants made metacognitive judgments about others based on updated beliefs. However, quarantine failures could also explain the bias (Wallin, 2011). We did not measure surprise for those participants who detected the change. Presumably, successful change-detection would confirm these participants' prior beliefs, leading to them being unsurprised at detecting the change.

Taken together, these findings indicate that prior beliefs about change-detection ability and the actual experience of detecting or missing a change may generate errors in metacognitive judgments about others. Levin et al. (2000) found that people tend to overestimate their own and others' abilities to detect subtle changes. However, our results point towards a more complex interpretation, in that when the change is particularly salient, people may also underestimate others' perceptual abilities. Differences in metacognitive judgments as a function of change detection suggest that the availability heuristic might be related to this bias. This is further supported by the finding that when a change was not experienced, those participants who noticed the change and those who missed it made similar judgments.

In Experiment 5, we examined whether participants could anticipate these metacognitive errors, and whether they would predict differences in the level of surprise between participants who missed the subtle change and those who missed the salient one.

### 3.3. Experiment 5

Experiment 4 provided evidence that noticing or missing a change biases visual metacognitive judgments about others, resulting in overestimation and underestimation errors. The aim of the second experiment was to test whether participants could anticipate these metacognitive errors without having the experience of noticing or missing a change.
Providing participants with answers and solutions denies them the subjective experience that can be used as a basis for judgment (Bjork, Dunlosky, & Kornell, 2013). Hence, in this experiment participants were explicitly informed about the visual change that occurred to the cards. However, one group of participants was instructed to imagine that they noticed the change (change-detected) and the other group had to imagine that they missed it (change-missed). After watching the trick, all participants were required to predict the probability that others would notice it and rate how surprised a person would be to have missed the subtle and the salient change.

3.3.1. Method

Participants. A total of 174 undergraduate students at Goldsmiths, University of London participated in the study in exchange for class credit (mean age: 21.6, SD = 3.1; 50 females). All participants had normal or corrected-to-normal vision and were naïve about the aim of the study. We excluded participants who had seen the trick before (22) or reported that they did not notice the change of the cards when they watched the videoclip (60). The final sample consisted of 92 participants (mean age: 18.9, SD = 1.65; 70 females).

Materials and procedure. We conducted this experiment during a class. Participants were randomly assigned to the change-detected condition or the change-missed condition. After providing informed consent, the experimenter read the description of the trick (the experiment was implemented in Qualtrics and all participants answered the questions on their laptop or tablet). We used an English version of the Princess Card trick with the subtle change (supplementary video S3). The experimenter displayed two figures showing the change of the cards and projected the video of the trick onto a large screen in the lecture theatre. After watching this video, participants completed a questionnaire (see Appendix E).

First, participants were asked to indicate whether they had seen the trick before and whether they had noticed the change when they watched the video. Participants in the change-detected condition were instructed to imagine that they were watching the trick for the first time and that they noticed that the cards changed. In contrast, participants in the change-missed condition were instructed to imagine that they were also watching the trick for the first time, but that they failed to notice that the cards changed. Both groups were
asked to predict how many people out of 10 would detect the change. Subsequently, they were instructed to indicate whether or not they believed that noticing the change would affect their probability judgments, either by increasing or decreasing their estimates.

Next, participants were shown figures corresponding to the subtle change (Figures 4a and 4b) and to the salient change (Figures 4c and 4d). They were asked to predict which change would be detected by more people. Finally, they had to rate how surprised a person would be to have missed the subtle change and to have missed the salient change. We counterbalanced the order of these questions so that half of the group had to rate surprise for change A and then change B, and the other half had to rate surprise for change B and then change A. In contrast to the previous experiment, in which we compared the level of surprise between independent groups, we used a within-subject design to activate a comparative mode of processing and examine whether there would be a difference in the predicted direction: namely, that it would be more surprising to miss a salient change than to miss a subtle one.

3.3.2. Results and Discussion

We compared the estimated detection rates between the change-detected group ($Mdn = 4$) and the change-missed group ($Mdn = 3$). The Mann-Whitney test showed a non-significant difference, $U = 1130$, $z = .57$, $p = .57$. Although the mean estimates (42%) were higher than actual detection rates from Experiment 4 (22.5%), the difference was not significant after the Bonferroni correction $X^2 (1) = 6.24$, $p = .01$.

Participants’ probability judgments do not indicate that they could anticipate the influence of noticing or missing a change on their metacognitive judgments about others. On the other hand, it is possible that participants might not have engaged in the requested thought process of imagining that they had detected or failed to detect the change. However, when we explicitly asked participants whether noticing the change would influence their judgment, 51.1% indicated that their predicted detection rate would increase and 43.5% indicated that it would not be affected. This result suggests that participants have different theories about the influence of detection experience on their metacognitive judgments about others.

Furthermore, most participants (83.7%) indicated that the salient change would be detected by more people than the subtle change would. This is consistent with the observed
difference between the detection rates for the subtle and the salient change in Experiment 4. Moreover, the Wilcoxon test showed that participants predicted that a person would be more surprised to miss the salient change ($Mdn = 8$) than the subtle change ($Mdn = 5$), $T = 2911$, $z = 5.04$, $p < .001$, $r = .37$. We also calculated the percentage of subjects who believed that the level of surprise would be high (6 and above) when missing the subtle change (47.8%) and when missing the salient change (76.1%). This finding suggests that, in the absence of experience, participants’ beliefs about change-detection ability take into account information about the saliency of the change. Presumably, using a within-subject design may have induced participants in the current experiment to adopt a comparative mode of processing (Koriat, Bjork, Sheffer, & Bar, 2004), which resulted in a difference in the predicted direction.

### 3.4. General Discussion

Change blindness studies suggest that people may have incorrect preexisting beliefs about their own and others’ change-detection ability. We aimed to explore whether noticing or missing a change may be a source of metacognitive errors, and whether participants who missed the salient change would be more surprised than those who missed the subtle change. Experiment 4 showed that participants were more likely to notice a salient change than a subtle one, but this difference in detection rates was not reflected in their metacognitive judgments. On the other hand, participants who noticed the change in both conditions predicted a higher probability of detection than those who missed it. Moreover, participants who noticed the change in the subtle condition overestimated other people’s ability to detect it, whereas those who missed the change in both conditions made conservative judgments. In particular, missing a salient change led to an underestimation error. These findings show egocentric biases in visual metacognitive judgments that may be related to the availability heuristic.

We found that predictions for a non-experienced change were similar between those who had previously noticed the change and those who missed it. This finding suggests that, in the absence of experience, it is likely that participants based their predictions on their beliefs about saliency rather than on previous detection success or failure.
We expected that those who missed the salient change would report a higher level of surprise than those who missed the subtle change, but this was not supported by our data. At first glance, the high level of surprise seems incongruent with the low detection rate predicted by participants who missed the salient change. However, it might reflect an erroneous preexisting belief about change-detection ability whereas the metacognitive judgment might reflect an updating of this belief based on their failed detection experience. In a similar vein, Bjork et al. (2013) pointed out that people have beliefs about memory, although they may fail to apply these beliefs to judgments of learning when they are simultaneously influenced by experience-based cues.

In Experiment 5, participants were explicitly informed about the visual change that occurred to the cards. One group had to imagine that they detected the change, and the other group that they missed it. We found no significant differences in their estimated detection rates. However, when we asked them explicitly whether they believed that their experience of noticing or missing the change would influence their metacognitive judgment, half of the subjects reported that they believed it would increase their judgment about the probability of detection whereas around half of the subjects believed that it would have no effect.

Furthermore, we asked participants to rate how surprised a person would be at missing the subtle change and at missing the salient change. In this case, we found a significant difference in the predicted direction: They believed that a person would be more surprised at missing a salient change. However, it is likely that the difference would disappear if we asked one group to predict the level of surprise for the subtle condition and another group would make the prediction for the salient condition.

What is the basis of errors in metacognitive judgments about others? Thompson (2009) explained that one source of metacognitive judgments might be beliefs. Sometimes these beliefs might be wrong. For instance, Simons and Chabris (2011) found that 63% of their participants agreed that “human memory works like a video camera, accurately recording the events we see and hear so that we can review and inspect them later” (p. 5) and 77.5% of participants agreed that “people generally notice when something unexpected enters their field of view, even when they’re paying attention to something else” (p. 5).
We posit that the overestimation error is consistent with the existence of a prior belief (Levin et al., 2000), and we think that the experience of successful detection may have reinforced participants’ theories about change-detection ability. This result could be interpreted in favor of the theory-theory. In contrast, participants who missed the change in the salient condition significantly underestimated the detection rate, thus indicating that the failure to detect the change updated their belief. Since metacognitive judgments are influenced by personal detection experiences and the feeling of surprise, we suggest that these judgments are driven by both heuristic processing and prior beliefs. As pointed out by Wallin (2011), egocentric biases might also be explained by the simulation theory. However, we believe that the fact that participants experienced surprise at missing the changes suggests that they hold a theory about change-detection ability. Nonetheless, their metacognitive judgments were instead influenced by their experience of failed detection.

What is the belief or expectation underlying the feeling of surprise? Several points support the notion that people believe that they and others are better at detecting changes than they actually are. First, perception seems effortless and it works wonderfully for most daily life purposes without our awareness of how it works. As Hoffman (1998) put it, “vision is normally so swift and sure, so dependable and informative, and apparently so effortless that we naturally assume that it is, indeed, effortless” (p. xi). Second, people often experience failures of memory, whereas they might be less familiar with failures of visual awareness (Levin, 2002). Anyone who has seen magic tricks knows that failures of perception happen, but hardly anybody would expect them to happen frequently in daily life. Why is that? Mack (2002) pointed out that in ordinary situations, attention is broadly distributed, whereas in inattentional blindness and change blindness experiments, it is narrow. According to this line of reasoning, we are less susceptible to these failures in daily life situations, although by no means invulnerable. On the other hand, these failures may be more common than we think, although we do not become aware of them in the same way that we become aware of failures of memory which are often accompanied by efforts to retrieve the information or relearn the material. In most instances, when something fails to capture our attention, we are oblivious to that fact. Therefore, we lack evidence of our inattentional blindness that could be used to update our beliefs about awareness. Third, we posit that our successful interactions with the environment induce a general belief that our perceptual capabilities are dependable. After all, such capabilities allow us to carry out survival activities (e.g., procuring food, reproduction, shelter building, defense, etc.,) and
they are pivotal in the construction of tools that have increased the complexity of our visual world. Demonstrations of inattentional blindness and change blindness contradict the belief that our perceptual capabilities are dependable, but our successful interactions with the environment indicate that such belief is generally true. However, people might not be able to verbalize their beliefs in a precise way (Cohen, 2002), which highlights the role of surprise in understanding visual metacognition.
4. Conclusions and discussion

The findings of the present research can be summarized as follows.

4.1. Metacognitive judgments about one’s self

In Experiment 1, we found that participants overestimated their own ability to notice visual changes and stimuli in scenarios that were described to them. However, they weighted the likelihood of noticing critical stimuli differentially depending on the locus of their overt attention. Overestimation suggests that they had prior beliefs about their perceptual abilities, this finding is consistent with the theory-theory. In regards to change blindness, Levin (2002) offered several reasons for why this metacognitive error may occur: (1) “People believe that a perceptual transient akin to apparent motion will make the change immediately visible”; (2) “People may believe that they have a powerful short-term visual memory that can retain visual detail over short periods”; (3) “People do not appreciate the degree to which visual attention typically focuses on only a small subset of the information in a scene”; and (4) people believe that “they can ‘chunk’ the entire scene into a single percept and therefore track any detail change within that chunk” (p. 116). According to Levin (2002), initial experiments on change blindness suggest that this error is not caused by explicit beliefs about memory for visual details or expected perceptual transients. However, it might be caused by implicit beliefs. According to the nativist version of the theory-theory, the theories are not available to consciousness (Carruthers, 2004). Against intuition, Carruthers (2015) proposed that beliefs are always unconscious. Given that participants might not be able to articulate their beliefs, the feeling of surprise might be a tell-tale sign of what they believe. We think that the feeling of surprise at missing visual changes (Experiment 4) is an important indicator that subjects’ metacognitive judgments about their own change-detection ability were influenced by prior beliefs. In fact, Kahneman (2011) explained that a basic function of System 1 is to set expectations and trigger surprise
when they are violated. It might be objected that overestimation errors as well as the feeling of surprise might be related to a belief in a detailed visual representation of the world (i.e., the grand illusion). However, as we will discuss later, our findings are at odds with this notion. Participants’ metacognitive judgments about attention and its relationship with visual awareness seem to be in agreement with Noë’s (2002) claim that “we take ourselves to have access to that detail, not all at once, but thanks to movements of our eyes and head and shifts of attention” (p. 6).

In regards to judgments about the likelihood of noticing a stimulus or change in different attention conditions (narrow, distributed), participants in Experiment 1 reported that they would be less likely to notice a stimulus or change if their overt attention was directed towards an irrelevant stimulus as opposed to being widely distributed. In Experiments 2 and 3, we found that those who detected the critical event believed that they had moved their eyes to look at it, thus revealing their intuition that detection was related to looking at the location of the stimulus or change. In fact, their foveal and peripheral judgments revealed their belief that it is more likely to notice a stimulus or change if they look at them than if they look elsewhere. However, eye tracking data from Experiment 3 showed that participants’ intuition about their deployment of overt attention was wrong because most of them detected the secret of the trick through peripheral vision. This evidence suggests that: 1. Subjects did not have introspective access to their deployment of overt attention. Instead, their judgments about where they looked were driven by their detection experiences rather than eye movements themselves, and 2. They underestimated the role of peripheral vision in visual awareness.

4.2. Metacognitive judgments about others

In Experiments 2 and 3, we found that those who detected the critical event estimated that others would be very likely to notice it. In contrast, those who missed the critical event made lower estimates. In Experiment 4, participants who noticed the subtle change of cards overestimated others’ ability to detect it, whereas those who missed the salient change underestimated others’ ability to detect it.
Conclusions and discussion

Interestingly, we found overestimation errors when participants made metacognitive judgments about themselves (Experiment 1) and also when they made metacognitive judgments about others (Experiment 4). The similarity between self and other predictions might be accounted for by positing that beliefs influence metacognitive judgments.

In Experiment 5, the subtle change of cards was described and shown to participants (thus blocking subjective experience), and they tended to overestimate other people’s change detection ability. They predicted that more people would detect a salient change than a subtle one, this finding coincides with difference in detection rates in Experiment 4. Moreover, participants in Experiment 5 predicted that missing a salient change would be more surprising than missing a subtle change. However, in Experiment 4, the level of surprise was similar between those missed the change in both conditions. We think that judgments in both experiments were driven by different information. In Experiment 4, the level of surprised was related to a prior belief (e.g., about change-detection ability), whereas in Experiment 5 the judgments were driven by the comparison between the saliency of both changes.

4.3. The availability heuristic, egocentric biases and the influence of prior beliefs

Why do biases and errors in visual metacognition occur? Metacognitive judgments might be based on information (e.g., beliefs, theories) or experience cues (e.g., ease of retrieval, perceptual fluency). Metacognitive errors occur when observers make inferences based on false beliefs or when the application of heuristics is biased (Koriat, 1997). Heuristics are simplified methods to help us cope with our cognitive limitations; they frequently lead to acceptable results, but they are error prone (Keren & Teigen, 2004).

It would appear that the availability of detection experiences (success or failure) underlies egocentric biases. The availability heuristic has been proposed as a key contributor to egocentric judgments (Kelley & Jacoby, 1996; Hinds, 1999). Kahneman (2011) argued that personal experiences can influence judgments and Kelley and Jacoby (1996) demonstrated how subjective experience might result in egocentric biases when making judgments about other people’s capabilities. Data from our experiments strongly suggest that metacognitive
judgments about one’s self and others were biased by detection experiences. It is not clear whether people may apply rules to override the influence of their experience on visual metacognitive judgments. Future studies could examine whether participants who are motivated to be accurate or use explicit rules would dismiss their experience as a source for making visual metacognitive judgments.

In the end, it seems that observers resort to a simple although imperfect procedure to produce visual metacognitive judgments. A possible mechanism that might account for metacognitive errors is inhibitory control. One of the functions of System 2 is to inhibit automatic responses from System 1 (Evans, 2003). Inhibitory control has been related to egocentric biases in false belief reasoning (Bernstein, Coolin, Fischer, Thornton, & Sommerville, 2017) and plays a role in suppressing biased beliefs (Evans, 2003).

Our data further suggests that participants’ metacognitive judgments might be influenced by prior beliefs. In Experiment 4, participants were very surprised to have missed the change. It has been suggested that the feeling of surprise reveals a subject’s beliefs, for instance, that she is better at noticing changes than she in fact is (Noë, 2002).

Typically, demonstrations of inattentional blindness and change blindness generate surprise in naïve observers. Surprise is an interesting dependent variable because it might be an indicator of an individual’s beliefs (Dennett, 2002). For instance, the belief in similar mental states and abilities entails important implications for social interactions, allowing us to explain and predict people’s behavior. Therefore, assuming identical mental states and abilities might be a well-justified principle of folk psychology (Wallin, 2011). Nevertheless, egocentric attributions sometimes lead to unfavorable results (e.g., the curse of knowledge, the curse of expertise). In the last section of this chapter, we discuss how visual metacognitive errors in particular may be detrimental in legal settings. However, we found that missing a salient change may have overridden or updated their previously held belief, leading to an underestimation error (Experiment 4). In contrast, those who noticed the change confirmed their prior belief and made an inflated judgment.

Arango-Muñoz (2014, p. 145) posited that metacognitive feelings (e.g., feeling of knowing, feeling of confidence, feeling of error) “point towards mental capacities, processes, and dispositions of the subject.” These feelings play a key role in non-transparent self-
ascriptions: “when a subject self-ascribes a mental state without having access to its intentional content” (Arango-Muñoz, 2014, p. 147). For example, when asked “what is the capital of Canada?” an individual might feel that she knows the answer, although she may not be able to retrieve it. In turn, this metacognitive feeling may lead to the application of an epistemic rule to construct a self-ascription. In this example, the subject self-ascribes the following mental state: “I know what the capital of Canada is.”

Carruthers (2017) criticized this claim, positing that these feelings can be explained from a first-order perspective and that they do not represent mental states explicitly or implicitly. However, surprise appears to be different than other epistemic feelings. Carruthers (2017) stated that surprise “seems to constitutively involve expectation or belief (which is contradicted by the surprising object or event)” (p. 60). However, he declared that taking surprise to explicitly represent mental states would be to over-intellectualize this feeling. While it is caused by a conflict, it may not represent this conflict explicitly. According to Carruthers (2017), agents may become aware that they are surprised, which is an explicit metarepresentational state, but being surprised in itself is not metarepresentational. He claimed that if surprise is a metacognitive feeling, it should not only carry information about other mental states (i.e., belief), but should also be used by other processes to exert control functions. He further stated that reactions to surprise, such as information-gathering movements, do not imply that surprise is a metacognitive feeling, and explains that other functions that are not metacognitive (e.g., vision) are also accompanied by such movements. Instead, Carruthers (2017) posited that reactions caused by surprise can be explained by a first-order state and that information-gathering movements can be motivated by emotions directly, without intervention from decision-making processes.

Consider the following magic trick to see how surprise may be explained. A magician presents an egg to the public. He allows a spectator to check the egg to confirm that it is an ordinary egg. Then the magician drops the egg, but it does not break; this triggers surprise in the audience. The magician now offers the egg and a spoon to another spectator and tells her to crack it gently. The egg now cracks. In this magic trick, people may experience surprise because the event of the egg not breaking when it was dropped to the floor is in conflict with the belief that eggs break when they are dropped. The feeling of surprise could be further augmented when the same egg is broken gently. Perhaps a spectator believes that the egg is not ordinary after all, or that the magician has hidden
pockets where he stores ordinary and false eggs. Thus, she may want to check the remains of the egg and the magician’s jacket. Because she wants to learn something or modify her beliefs, it may be said that she has metacognitive goals motivated by surprise. However, Carruthers’ perspective on this is that surprise simply motivated a first-order question: Was it an ordinary egg? Does the magician have hidden pockets? These questions are directed to the world, and there is therefore nothing metacognitive about surprise. We think that while this interpretation may be true, it does not exclude the possibility that some actions might be motivated by a metacognitive goal. According to Carruthers (2017), if we think that information-gathering behavior is motivated by metacognitive goals that are caused by epistemic feelings, then we have to accept either that all animals have metacognitive abilities or that some animals are motivated by metacognitive goals while others are not. He states that the former option is implausible and that the latter requires that there be an unmotivated discontinuity in evolution. Therefore, we are left with the sensorimotor route to action and dismiss the goal-directed route. Dennett (2000) seemed to support the sensorimotor route when he states that apes that use props to find the solution to a problem are manipulating objects, and their actions are not driven by internal manipulations of representations of those objects. Nevertheless, in our view, the metacognitive status of surprise is a plausible hypothesis given that in Experiment 4, we asked participants to report how surprised they were at missing the change, and not how surprised they were by the trick, therefore their feeling conveyed information about a first-order state.

4.4. Surprise and the grand illusion

Surprise has been interpreted as a sign that people believe that they have a rich and high-resolution visual experience (the grand illusion). According to the grand illusion described by Noë (2002), “you open your eyes and – presto! – you enjoy a richly detailed picture-like experience of the world, one that represents the world in sharp focus, uniform detail and high resolution from the centre out to the periphery” (p. 2).

Levin (2002) offered an interesting anecdote showing that even scientists seem to be victims of this illusion:
“When we edited our first films we thought that people would surely see the glaring inconsistencies we put in them. When they did not, we made changes to central objects and again suspected that we had gone too far – surely everyone would see when we substituted one actor for another! Again, subjects missed the changes and we once again upped the ante by changing real-world conversation partners. This time, we nervously set up the experiment and suspected we would spend a few afternoons getting laughed at by our subjects. Once again, however, our prediction (and the confident predictions of others) was strikingly confounded when half of our subjects missed the substitution and continued the conversation as if nothing had happened. Apparently, we had rather strong intuitions about seeing that led us astray repeatedly despite the fact that we understood something about attention, scene perception, visual search, and even change blindness” (p. 114).

Based on findings from change blindness, Levin (2002) argued that the grand illusion is real, as people’s beliefs can be dramatically different from reality. Nevertheless, he states that “metacognitive errors do not necessarily imply that people are generally deluded about visual experience, or that their ability to reason about vision is poorly suited to visual survival in everyday environments. People’s beliefs about vision may actually be well suited to most environments where visual information is stable in many respects across views” (p. 128).

However, other explanations of surprise have been advanced that deny the grand illusion (Cohen, 2002; Mack, 2002; Noë, 2002; Siewert, 2002). For instance, Noë (2002) posited that a subject might be surprised because he believed that he was a better observer than he in fact is, or less vulnerable to attentional constraints. According to Mack (2002), observers are surprised because in ordinary situations they enjoy a rich visual experience as a result of distributing their attention broadly, whereas inattentional blindness and change blindness procedures induce a narrow attentional state that is not typical. In contrast, Siewert (2002) claimed that we do not need to attribute to ourselves a belief in a rich mental representation to explain surprise: when asked about our visual experiences, we are simply likely to use words that refer to mental pictures, presumably because our theory of vision has been shaped by the pervasiveness of photographic images in our lives. On the other hand, Cohen (2002) stated that people are surprised because they tacitly believe that they will notice large and unoccluded objects and events.
Change blindness seems to indicate that observers are victims of the grand illusion. However, two of our findings are at odds with this idea: First, participants believed that visual awareness changes as a function of attentional shifts. Data from Experiments 2 and 3 suggest that observers believe that detection of visual stimuli and changes occurs as a result of eye movements. Second, they underestimated the role of peripheral vision in visual awareness. Even those who detected the critical event, being peripheral detectors themselves, believed that detection under peripheral vision was unlikely. We think that our results are at odds with the grand illusion hypothesis, and might be taken as indirect evidence that subjects do not attribute a rich mental representation of the world to themselves.

Noë (2002) endorsed a sensorimotor theory that denies that people form mental representations, and posited that phenomenology should be better understood as perceptual access to detail through the motor system and our knowledge that we have this access. If the notion of perceptual access is correct, people should predict less visual awareness under certain conditions, such as peripheral vision and constrained attention. Results from Experiments 1-3 show that this might be the case. Participants predicted less likelihood of noticing a critical stimulus with narrow attention compared to distributed attention, and with peripheral vision compared to foveal vision. Thus, it seems that their judgments are in line with the notion that observers believe they can access the richness of the visual world through the sensorimotor system and that this access will be constrained under some conditions, rather than believing that their perceptual representations are rich (Noë, 2002). However, whether people form mental representations or not is still a matter of debate. As mentioned earlier, we think that our successful interactions with the environment induce a general belief that our perceptual capabilities are dependable. However, subjects may not be able to verbalize some of their beliefs. In this case, surprise reveals that they have prior expectations that have been violated by demonstrations of inattentional blindness and change blindness. Future studies are needed to determine the specific beliefs that may underlie the feeling or surprise.
4.5. Implications of understanding errors of visual metacognition

What do we have to gain from understanding errors in visual metacognition? If we lived in a pre-industrial world, these failures would be trivial. However, as more distractions are available and the demand for multitasking increases, these failures become relevant in different contexts (e.g., road safety, eyewitness testimony).

According to the National Highway Traffic Safety Administration (NHTSA, 2018), in 2016 there were 444 fatal crashes in the US that involved cell phone use. The World Health Organization (2011) states that those involved in road safety are mostly concerned about the growing number of new electronic devices that are not integrated into the car (e.g., mobile phones, laptops, etc.). Atchley, Hadlock, and Lane (2012) found that subjects recognized the risk of distracted driving, but they assigned similar punishments to distracted drivers and attentive drivers, which presumably suggests that they perceived distracted driving as a normative behavior. In Finley et al.’s (2014) study, subjects accurately anticipated that dividing attention between a visual-manual tracking task and an auditory n-back task would decrease performance in the visual task. However, those participants with worse performance did not predict the largest decrement, which suggests that they had limited awareness of their vulnerability to the risk of dividing attention. Moreover, intuitions about the relationship between overt attention and visual awareness might be important for road safety. The popular phrase “keep your eyes on the road” illustrates the common-sense idea that looking means attending. However, empirical evidence shows that looking and attention are related but dissociable (Kuhn et al., 2008b). Therefore, a driver who is looking at the road but whose attention is elsewhere might miss relevant stimuli in her visual field.

In another vein, Levin et al. (2002) indicated that beliefs about visual perception may impact visual performance and guide people’s judgments about others’ perceptual abilities in legal settings. According to them, “it appears that incorrect metacognitive beliefs can lead jurors to falsely convict people based on confident eye witness testimony” (p. 523). In fact, Shea et al. (2014) noted that jurors make use of metacognitive representations (e.g., witness’ confidence). Jaeger, Levin, and Porter (2017) showed that overconfidence may have serious consequences in legal settings. A dramatic case of wrong conviction illustrates this point.
In 1991, 17-year-old Francisco Carrillo was accused of murdering a man (Fraser, 2012). One of the teenagers who was present at the scene pointed to Mr. Carrillo in a photo array, claiming that he saw him shoot the man from a car. Mr. Carrillo was sentenced to life imprisonment. In the petition for a retrial, a forensic neurophysiologist demonstrated that although the teenagers claimed that they could see very well, they could not have seen the person who committed the crime because the observation conditions were unfavorable. Under those circumstances, color perception would be unreliable, thus rendering face recognition extremely difficult, if not impossible. Moreover, the teenagers would have had to be closer to the car than they actually were to have seen the shooter. Experts even reenacted the crime under identical conditions, and the judge, who agreed to participate in this experiment, was unable to see the person posing as the shooter despite being closer to the car than the teenagers were. The judge granted the petition for a retrial, but the prosecution decided not to retry Mr. Carrillo and he was freed. The jurors initially based their decision on the witness’ confidence. Thus, this case illustrates the importance of understanding the limitations of perception and visual metacognitive errors.

It would appear that a strong feeling of confidence does not necessarily mean that the testimony is accurate. In this vein, Perfect (2004) asserted that the relationship between confidence and accuracy can be assessed in different ways and therefore have different results. One way is to correlate the level of participants’ confidence with their accuracy; another is to calculate the correlation between confidence and accuracy across items for the same individual. Perfect (2004) indicated that studies using the former approach have found low correlations, whereas studies using the latter have found higher correlations. The latter approach is more similar to what happens in real life because the conditions in which people witness an event may vary: one witness could have been more attentive and has an introverted personality, while another could have been farther from the scene and has an extroverted personality, etc. Perfect (2004) explained that in traditional experiments, inter-subject variation is minimized through control – that is, participants come from the same population, they have a similar level of attention and motivation, they read the same instructions, and they witness the same event under the same conditions. This produces low inter-subject variability, which results in low correlations.

Consider Perfect’s (2004) example of two witnesses to a crime. One of the witnesses – Jake – was very confident that the thief had dark hair, while the other witness – Sam – was
fairly confident that the thief had blond hair. Common sense would tell us to believe Jake. However, what if we were to learn that “Jake was an outgoing, confident individual whilst Sam was more reserved? Could their personalities have more to do with their expressed confidence than their actual abilities as witness?” (p. 95). Moreover, “what if Jake had been looking into the shop window that was burgled, whilst Sam was standing 50 meters away? Or what if Jake had seen the thief for 30 seconds before the crime, whilst Sam only glimpsed him as he ran past?” (p. 99). It is clear that in real life, there is more variability in the encoding conditions than in laboratory experiments. Perfect (2004) indicated that for a reliable correlation to emerge, it is necessary to have variation in accuracy and confidence. In sum, by manipulating variability among participants or the selection of test materials, the result will be either a low or a high correlation. This situation is unsatisfactory to establish the relationship between confidence and accuracy.

Finally, we believe that understanding visual metacognition has important implications for the way we transform our environments and design the tools that we use, because design has to take cognitive abilities and limitations into account. The information revolution has shifted the demand for physical endurance to a demand for vigilance and sustained attention (Hollnagel, 1997). Ergonomics has been concerned with the design of machines and work environments that match human capabilities and limitations; and more specifically, cognitive ergonomics focuses on how cognition affects work and vice versa (Hollnagel, 1997). For instance, an important issue in human-computer interaction is how the information is presented in displays, the use of alarms and warnings, etc. (Hollnagel, 1997). We believe that the development of artificial intelligence reflects people’s need to cope with the growing complexity of the world that exceeds human capabilities. If we take road safety as an example again and imagine a future with more complicated transportation systems, perhaps intelligent machines would deal with navigational intricacies far better than we do. These machines could process more visual stimuli and produce faster and more accurate responses without experiencing failures such as change blindness and inattentional blindness.
4.6. Limitations and future research directions

Although magic tricks are ecological stimuli to explore visual metacognitive errors, observers might try to infer how they were performed. Thus, it may be argued that participants’ reports about what they saw actually reflect a guess about the method. To address this issue, we used magic tricks that minimize - although probably never quite eliminate - the problem of inference.

We think that understanding how our visual experience seems to us has important and fascinating implications for theories of consciousness. Just like we have intuitions about the physical world (naïve physics), we also have intuitions about consciousness (folk psychology) that deserve scrutiny. Some of our intuitions about physics are wrong. For example, people intuitively believe that moving objects have a natural tendency to stop moving. We don’t seem to have any problem giving up this intuition once we learn that in fact moving objects will continue to move unless a force is applied to them (Newton’s first law). Similarly, we have wrong intuitions about the mind, but we might be more reluctant to give them up. The snapshot conception of experience seems to be a wrong intuition. However, we think that participants’ metacognitive judgments about the likelihood of detection when looking at the method area or elsewhere, reveal an intuitive understanding about the relationship between attention and visual awareness that conflicts with the snapshot conception of experience and at the same time discloses an underestimation of peripheral vision. Yet, these judgments are not a direct measure of participants’ beliefs about their visual experience.

On the other hand, claiming that we enjoy a “richly detailed picture-like experience of the world” (Noë, 2002, p. 2) does not seem to be the same as claiming that this experience is gap-free all the time. Dennett (2005) proposed that the science of consciousness should take into account people’s beliefs about the mind and not just conscious experiences themselves. For instance, Blackmore (2002) claimed that the illusion of a rich mental representation shatters when we engage in first-person reflection about our visual experience. Therefore, we could benefit from a more straightforward exploration of people’s beliefs.
We have posited that a general belief that our perceptual capabilities are dependable is a key factor to overestimation errors. This belief arises from our successful interactions with the environment. However, specific beliefs about attention and memory could also underlie the feeling of surprise generated by demonstrations of inattentional blindness and change blindness. Furthermore, it would be interesting to examine whether it is possible to mend visual metacognitive errors by means of incentives or explicit rules.

Finally, we recruited undergraduate students for our experiments which limits the generalizability of our findings. We think that neuropsychological studies might shed light on the cognitive mechanisms that underlie visual metacognitive errors. For instance, children, older adults and patients with frontal injuries might show larger overestimation and underestimation effects compared to controls due to deficits in inhibitory control.
A. Appendix: Visual Illusions

Figure 1. The Müller-Lyer Illusion

*Figure 1.* The three horizontal lines have the same length. Image by Fibonacci, distributed under a Creative Commons Attribution ShareAlike 2.5 license.
Figure 2. The Ames Room

Figure 2. Image released into the public domain by Alex valavanis.
Figure 3. The Necker Cube

Figure 3. By shifting the observer’s point of view, the orientation of the cube can be altered. Image by BenFrantzDale, distributed under a Creative Commons Attribution-Share Alike 3.0 Unported license.
Figure 4. We perceive an illusory triangle because of the arrangement of Pac-Man figures. Image by Fibonacci, distributed under a Creative Commons Attribution-Share Alike 3.0 Unported license.
B. Appendix: Questionnaire Used in Experiment 1

**Scenario A.** You are simultaneously driving a car and having a conversation on your hands-free device. A car is about to swerve into your lane.

1. Would you notice the car? (Yes/No/Maybe)
   Rate on a scale from 1 (very unlikely) to 10 (very likely):
   If you were looking ahead at the road...
2. How likely is it that you would notice the car swerving into your lane?
3. How surprised would you be if you failed to notice the car?
   If you were looking at a traffic sign...
4. How likely is it that you would notice the car swerving into your lane?
5. How surprised would you be if you failed to notice the car?

**Scenario B.** A man passes a 50p coin between his hands and then drops it onto the table.
You have to guess whether the coin lands with heads or tails facing up. However, the man has secretly switched the coin and instead dropped a 10p coin.

1. Would you notice the change? (Yes/No/Maybe)
   Rate on a scale from 1 (very unlikely) to 10 (very likely):
   If you followed the 50p coin with your eyes...
2. How likely is it that you would notice the change?
3. How surprised would you feel if you failed to notice the change?
   If you only looked at the 50p coin once...
4. How likely is it that you would notice the change?
5. How surprised would you feel if you failed to notice the change?

**Scenario C.** A stranger asks you for directions to a nearby building. Suddenly, two men carrying a door walk between you and the stranger, blocking you from each other’s view.
After this brief interruption, you resume the interaction. However, the stranger is now a different person.

1. Would you notice that the person is now different? (Yes/No/Maybe)
   Rate on a scale from 1 (very unlikely) to 10 (very likely):
   If you looked at the stranger’s face before the interruption...
2. How likely is it that you would notice that the person was now different?
3. How surprised would you be if you failed to notice the change?

**Scenario D.** You are crossing the street while having a conversation on your hands-free device. A clown wearing a brightly colored outfit is riding a unicycle on your route.

1. Would you notice the clown? (Yes/No/Maybe)
   Rate on a scale from 1 (very unlikely) to 10 (very likely):
   If you were looking ahead at the pedestrian crossing...
2. How likely is it that you would notice the clown?
3. How surprised would you be if you failed to notice the clown?
   If you were looking at the pedestrian traffic lights...
4. How likely is it that you would notice the clown?
5. How surprised would you be if you failed to notice the clown?

**Scenario E.** A juggler stands behind a covered table and starts juggling five balls. Each ball has a different color. You have to count the times he drops a ball. Every time he drops a ball on the floor, he secretly picks up a red ball from under the table. At the end, he is juggling five red balls.

1. Would you notice that all the balls he picked up are red? (Yes/No/Maybe)
   Rate on a scale from 1 (very unlikely) to 10 (very likely):
   If you counted the times the juggler dropped a ball...
2. How likely is it that you would notice that all the balls he picked up were red?
3. How surprised would you be if you failed to notice that all the balls he picked up were red?
   If you saw the video without counting the times the juggler dropped a ball...
4. How likely is it that you would notice that all the balls he picked up were red?
5. How surprised would you be if you failed to notice that all the balls he picked up were red?
C. Appendix: Questionnaires Used in Experiments 2 and 3

**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)
4. If yes, please describe when you saw it:
5. 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.”)
6. How likely is it that someone else would notice that the back of the cards changed color?
7. 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?
8. If you looked at the area indicated by the green circle, how likely is it that you would notice that the back of the cards changed color?
9. If you looked at the area indicated by the yellow circle, how likely is it that you would 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)
3. If yes, please describe how:
4. 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.”)
5. How likely is it that someone else noticed the magician drop the lighter?
6. How likely is it that you moved your eyes to look at the area indicated by the green circle just as the magician dropped the lighter?

7. If you looked at the area indicated by the green circle, how likely is it that you would notice that the magician dropped the lighter?

8. If you looked at the area indicated by the yellow circle, how likely is it that you would 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:

3. 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.”)

4. How likely is it that someone else would notice that the coin slid across the placemat?
5. How likely is it that you moved your eyes to look at the area indicated by the green circle just as the coin slid across the placemat?
6. If you looked at the area indicated by the green circle, how likely is it that you would notice that the coin slid across the placemat?
7. If you looked at the area indicated by the yellow circle, how likely is it that you would 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:

3. Did you notice that the cards shown at the end (Fig. B) were 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.”)

4. How likely is it that someone else would notice that the cards shown at the end were different from the cards displayed at the beginning?
5. How likely is it that you only looked at the selected card at the beginning of the trick and not the others?

6. If you looked at all the cards at the beginning of the trick, how likely is it that you would notice that the cards shown at the end were (Fig. B) different from the cards displayed at the beginning (Fig. A)?

7. If you looked only at the selected card at the beginning of the trick, how likely is it that you would notice that the cards shown at the end (Fig. B) were different from the cards displayed at the beginning (Fig. A)?
D. Appendix. Questionnaire Used in Experiment 4 (Subtle Condition)

1. Have you watched this video clip before? (Yes/No)
2. Did you notice anything unusual in the trick? (Yes/No)
   If yes, please describe.

Look at Figures 1 and 2.

3. When you watched the video, did you notice that the cards shown at the end (Fig. 2) were different from the cards displayed at the beginning (Fig. 1)? (Yes/No)
4. If you did not, how surprised are you that you did not notice the change?
   (Participants have to rate on a scale from 1 – “Not surprised” – to 10 – “Very surprised.”)

5. How many people out of 10 do you believe would notice that the cards change when watching the trick?

Now look at Figures 3 and 4. Imagine that the cards change from Figure 3 to Figure 4 and answer:

6. How many people out of 10 do you believe would notice that the cards change when watching the trick?
E. Appendix: Description and Questionnaire Used in Experiment 5

Read the following description attentively:

Imagine that you are watching a magic trick. The magician shows 5 cards and asks you to pick one and think intently of it. The magician tells you that she will try to read your mind from a distance to know which one is your card. At the end, she shows you that she has made one card disappear: she shows you 4 cards and you realize that your card has vanished. To accomplish this trick, the magician secretly changes the cards. As a result, the cards that are shown at the beginning (Figure 1) are different from the cards that are shown at the end (Figure 2).

Please look at the figures displayed on the screen and watch the video of the trick. After watching the video, click Next.

1. Have you seen this video clip before? (Yes/No)
2. Did you notice that the cards changed? (Yes/No)
3. Imagine that you are watching the trick for the first time and you don’t know how the trick is done. If you notice that the cards change, how many people out of 10 do you believe would notice that the cards change?
4. This question assesses your beliefs about how noticing the change influences your judgment about other people noticing the same change. Please click one response:
   a. Me noticing the change has no impact on my judgments.

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5 In the change-missed condition, the instruction is, “Imagine that you are watching the trick for the first time and you don’t know how the trick is done. If you fail to notice that the cards change, how many people out of 10 do you believe would notice that the cards change?”
b. Me noticing the change increases my judgment about the probability that others will notice the same change.

c. Me noticing the change decreases my judgment about the probability that others will notice the same change.

Please look at the figures displayed on the screen and answer the following questions:
Imagine that the cards changed as shown in Change A (Figures 1 and 2), or that they changed as shown in Change B (Figures 3 and 4).
5. Which change would be noticed by more people? (Change A/Change B/, Both would be detected by a similar number of people).
6. How surprised would a person feel to NOT have noticed Change A?
( Participants have to rate on a scale from 1 – “Not surprised” – to 10 – “Very surprised.”)
7. How surprised would a person feel to NOT have noticed Change B?
( Participants have to rate on a scale from 1 – “Not surprised” – to 10 – “Very surprised.”)
References


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