The durability of misdirection: eyetracking visual attention via the 3-card Monte

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Abstract

Magicians produce impossible scenarios for their audiences. Cognitive manipulations employed by magicians remain reliable even under intense scrutiny. In particular, misdirection—the practice of diverting the spectator's focus away from the hidden elements of a magic trick—offers a powerful avenue for examining how and what people attend to when observing magic. The current thesis examines misdirection using repeated viewings of a trick and investigates potential reasons for its continued efficacy, i.e., the durability of misdirection. We pair precision eyetracking with the classic 3-card Monte trick to examine how participants visually react to their answers during feedback. Furthermore, we wanted to see whether participant answers deviate from the expected distributions in an effort to counter misdirection. The methodology exposes participants to multiple viewings of four versions of the Monte with or without the presence of misdirection, presented in video format. Participant data, e.g., predictions of the target card's location and their accuracy, confidence ratings, and pupillary responses are collected via button inputs and gaze fixation recordings. Analyses of the data reveal predictions are highly inaccurate in the presence of misdirection and the pattern of answers conforms to the expected distributions. Participants seem aware that the game is rigged, as corroborated by the pupillary response analyses. However, participants do not alter their overt visual strategy even after multiple encounters with misdirection, suggesting a lack of viable alternate strategies coupled with risk aversion rather than a misallocation of attention. The findings demonstrate that effective misdirection can persist as long as participants believe there is only one way to solve the problem, even if they anticipate potential misdirection.

Résumé

Les magiciens produisent des scénarios impossibles pour leur public. Les manipulations cognitives employées par les magiciens demeurent fiables, même lorsqu’elles sont examinées minutieusement. En particulier, une directive erronée-la pratique de détourner l'attention du spectateur loin des éléments cachés d'un tour de magie-offre une avenue puissante pour examiner ce sur quoi les spectateurs portent leur attention. La thèse actuelle examine l’attention détournée lors de visionnements répétés d'un tour de magie et examine les raisons possibles de son efficacité continue. Nous jumelons un suivi des mouvements occulaires de l'oeil de précision avec le classique 3-carte Monte astuce pour examiner la façon dont les participants réagissent visuellement à leurs réponses lors de la rétroaction. De plus, nous voulions voir si participant répond diffèrent des distributions attendues dans un effort pour contrer une directive erronée. La méthodologie expose les participants à de multiples visionnages de quatre versions du Monte avec ou sans la présence de directives erronées, présentées en format vidéo. Les données des participants, par exemple, les prévisions concernant l'emplacement de la carte cible et leur précision, les cotes de confiance, et les réponses pupillaires sont collectées via les entrées de bouton et enregistrements regard de fixation. Les analyses des données révèlent prédictions sont très imprécis, en présence de mauvaise orientation et le modèle de réponse est conforme aux distributions attendues. Les participants semblent conscients que le jeu est truqué, comme confirmé par analyse la réponse pupillaire. Toutefois, les participants ne modifient pas leur stratégie visuelle manifeste même après plusieurs rencontres avec des directives erronées, ce qui suggère un manque de stratégies alternatives viables couplées à l'aversion au risque plutôt que d'une mauvaise répartition de l'attention. Les résultats démontrent que erronée efficace peut persister aussi longtemps que les participants croient qu'il ya une seule façon de résoudre le problème, même si elles anticipent une directive erronée potentiel.

Chapter 1: Introduction & Literature Review

1.1 Why investigate magic using science?

Magicians manipulate the perceptual experience of their audiences with extraordinary success, seemingly bending the laws of physics in what appear to be seamless presentations—even under the scrutiny of watchful eyes (Rieiro, Martinez-Conde & Macknik, 2013). An increasing number of empirical studies are appropriating magic as an experimental tool for extracting nuanced information about psychological processes (Barnhart, 2010; Hergovich, 2004; Kuhn & Land, 2006; Kuhn, Tatler, Findlay, & Cole, 2008; Lamont & Wiseman, 2005; Parris, Kuhn, & Hodgson, 2009; Tatler & Kuhn, 2007; Wiseman & Greening, 2005). Concurrently, efforts to explicate the psychological mechanisms underlying magic perception and to codify its essential principles have been increasing (Kuhn & Martinez, 2012). Whereas some researchers argue that "*a science of magic, in any meaningful sense, is a misguided idea*" (Lamont, Henderson, & Smith, 2010), others embrace the converse that a systematic investigation into how people perceive magic can contribute to our understanding of psychological processes (Kuhn, Amlani, & Rensink, 2008). In fact, Rensink and Kuhn (2015) provide a direct response to this claim (Lamont et al., 2010), replying that although it may be difficult to consolidate magic itself into a homogenous phenomenon, the experience of magic can nevertheless be studied in a structured manner despite the challenges of classification.

The effort to catalogue the psychological mechanisms employed by magic is primarily motivated by the sheer scale of ecological validity magicians have been able to demonstrate—magic in various incarnations has been around for hundreds of years, largely understood as performance; however, it is sometimes mistaken for supernatural powers or actual magic, especially in religious, spiritual, or medical contexts. In modern times, individuals like Uri Geller and John Edward take advantage of simple magic tricks, building successful careers with TV appearances and large followings of true believers by claiming to possess psychic abilities. Regardless of its form, magic has proven itself a reliable and effective method of manipulating the cognition and perception of naïve or unwary individuals. Surprisingly, despite using and even creating new magic tricks themselves, magicians rarely know exactly why their tricks work (Rissanen, Pitkänen, Juvonen, Kuhn, & Hakkarainen, 2014). Nevertheless, perhaps the most important aspect of magic is that whatever impossible things are happening in front of their eyes, people perceive that it is—or can be—real.

1.2 Magic as an experimental tool

This temporary *suspension of disbelief* reveals an important clue: how audiences retain a sense of reality while simultaneously experiencing a sense of wonder (Holland, 2008). Or rather, how audiences process and reconcile viewing the physically impossible event that causes the sense of wonder, i.e., thinking, "*That's amazing! It's not possible, which is why I'm amazed, but I'm ok with it because it's just a magic trick.*" Otherwise, believing that sawing a woman in half on stage then putting her back together whole is actually possible crosses the line into delusional thinking. Typically, the audience will enjoy the show at face value, but also wonder or try to logically compute how such a feat can be achieved. Indeed, belief in a false reality is a common symptom of psychosis or schizophrenia—believing magic is actually real crosses the line of separation from enjoying a carefully crafted performance to experiencing a thought disorder with loose associations and a tenuous grasp on reality. In fact, fMRI recordings show that participants who watch magic tricks activate similar areas of their brain as when experiencing impossible events, e.g., violations in causality (Parris et al., 2009). Thus, applying the rigor of scientific testing to the robust cognitive manipulations offered by magic can take advantage of the vast catalogue of perceptual controls that magicians have developed over the centuries while performing. Due to the sheer variety of possible *methods* in executing a magic trick, customizing tricks to target specific cognitive processes could become feasible. Therefore, magic could even be used as a unique diagnostic tool to test for mental disorders via reality checking and information processing.

This kind of interactive, visually salient, social paradigm works well because even babies can recognize an error in a causal chain of events. Lacking the ability to respond verbally, infants can demonstrate through increased looking times that they comprehend violations of expectation—which is a core feature of magic tricks, i.e., the presentation and perception of physically impossible events. Otherwise, a low-probability event is merely a surprising occurrence within the bounds of reality rather than magic: an impossible event that produces a sense of wonder, e.g., teleporting a flower from one part of the stage to another, or the disappearance and reappearance of an object. In fact, Onishi and Baillargeon (2005) show using an implicit, non-verbal version of the false-belief task that 15-month-olds expect an actor to behave according to the actor's belief about the state of the world (i.e., what the actor believes to be reality), whether that belief is true or not, demonstrating a rudimentary form of representational theory of mind. Just when they are old enough to start engaging in pretend play, 15-month-old infants can detect a violation in the consistency of a sequence of events involving pretense (Onishi, Baillargeon & Leslie, 2007). Babies are no different from adults when it comes to the unexpected—they look longer, e.g., when an actor does something out of line with the preceding action during pretend play like pouring water into a cup, but instead drink out of a different, empty cup—breaking the causal chain of events. Thus, not only are they able to recognize a violation of expectation in something like pretend play, babies behave in accordance with their belief about the other person's state of mind.

Considering all the cognitive advantages that an adult mind has compared to a 15-month-old, what makes magic so effective? The perception of magic is not seen as a mental disorder because logically, most adults understand magic is just performance by a skilled artist making use of clever mechanics. Indeed, the difference between what a baby may consider to be an impossibility and what an adult considers to be an impossibility is the difference in the ability to generate a plausible explanation and access to knowledge of real world phenomena that can account for the event, e.g., explaining natural disasters using science in modern times versus angry spirits in the past. Smith, Dignum and Sonenberg (2016) characterize the cognitive aspects of impossibility using logic: impossibility is a contradiction between a believed state and an expected state, where impossibility persists due to a lack of possible resolution between the two, sustained by strong perceptual evidence for the current believed state and equally strong memory-based support for the conflicting expected state. This tension between the perception of impossibility and the expectation of reality fuels the sense of wonder. As they describe it, two event sequences run concurrently—an *effect* sequence and a *method* sequence—whose "evidence relationship" provides the tension necessary for impossibility.

Thus, the perception of magic feels real despite its physically impossible nature. The inability to generate a plausible explanation for the seemingly impossible event produces the sense of wonder. Sustaining this gap in knowledge is crucial in the successful performance of a magic trick. Akin to an infant watching a sock puppet show or engaging in pretend play, the audience watching a magic trick understands that they aren't watching real magic, but sees a chain of causal events leading from one to the next, until it culminates to deliver the desired effect of the magic trick, achieving the sense of wonder. Similar to how people get invested in fictional characters and their drama, e.g., TV shows with cult followings, magic inspires a desire to believe in unreal things in order to enjoy an otherwise impossible experience. The resulting tension from a lack of reconciliation between what they see as true and what they know to be true provides the sense of wonder due to its physical impossibility. It is because the performance interacts with the audience's perception—whether live or on a television screen—that the magician is able to create a reality removed from reality. The audience has to be a willing participant to the impossibility of magic, or at least remain susceptible, but unaware of the various psychological mechanisms employed by magic.

1.3 Principles of magic

Contrary to popular belief, magicians generally do not hide things up their sleeves to achieve a magic trick. Nor does it rely on moving their hands so quickly that a human eye could not track its motion. To wit, scientists and their magician collaborators have been exploring the three core principles used to execute a magic trick. Successful performance of a trick relies on the use of one or more of the three related—yet discrete—principles: misdirection, illusion and forcing (Kuhn et al., 2008a). Most magicians consider misdirection to be the most elegant and sophisticated method, due to its manipulation of psychological processes rather than relying on gimmicks or props. Figuring out the combination of psychological mechanisms targeted by misdirection is a central mission of codifying the principles of magic into a science of magic.

Each magic trick can be split into two essential components: the *effect* and the *method* (Tamariz, 1988; Ortiz, 2006). The *effect* is the part the observer perceives, such as a vanishing pen; the *method* is the hidden element that actually accomplishes the trick. In order to delineate the exact mechanisms magicians use to manipulate the audience's perception, misdirection—the practice of leading the spectator's focus away from the hidden elements—has been singled out and heavily investigated (Kuhn & Martinez, 2012). Misdirection is a multifaceted concept with different types available; however, many definitions and scientific exploration of misdirection typically revolve around the idea of manipulating attention. In overt misdirection, the magician diverts the audience's attention and direct gaze away from the *method*. In covert misdirection, the magician diverts the audience's attention away from the *method* regardless of where direct gaze falls. Thus, attentional misdirection typically involves the subtle adjustment of the audience's attention by making use of various psychological mechanisms, e.g., using abrupt onset in a visual scene to redirect visual attention (Yantis & Jonides, 1990). However, a simple analogy familiar to parents would be the nurse making funny faces at your babies so they don't cry while receiving their vaccinations. In fact, misdirection can even manifest as cognitive traps such as a false solution, e.g., "*he must have used magnets!*" By offering the audience an easy solution, the magician allows the anchoring effect to take over (Tversky & Kahneman, 1974); he is then free to continue his performance using the true *method* while the audience remains none the wiser. As a caveat, a cardinal rule of magic is to never repeat a trick—repetition and prior knowledge increases the likelihood that the observer will detect the *method* (Kuhn & Tatler, 2005; Kuhn et al., 2008b).

1.4 Misdirection and eyetracking

The pairing of precision eyetracking with magic allows for a careful investigation of viewing patterns and gaze fixations during the presence of misdirection, proving fruitful in exposing subtle details in visual attention allocation. Consider the paradoxical case of magic tricks with an overtly visible *method*: eyetracking analysis on the Vanishing Cigarette illusion revealed that even when subjects directly view the *method* of a magic trick *in plain sight*, they do not necessarily comprehend the information, nor report seeing it occur, showing that covert misdirection indeed operates regardless of gaze direction (Kuhn & Tatler, 2005). *A priori* knowledge of the magic trick does not lead to differences in gaze direction when the cigarette drops from the magician's hands, i.e., the *method*. Prior information does raise the likelihood of detecting the *method* first time viewing the trick, but with minimal impact—as testament to the efficacy of covert misdirection, only two out of ten informed participants saw the cigarette dropping *in plain sight*. However, all eighteen participants—informed and naïve—successfully detected the *method* on a second viewing. Thus, covert misdirection demonstrates that when observer attention does not coincide with their gaze fixation, even directly fixating on a fully visible *method* does not necessarily equal its perception (Macknik et al., 2008).

Unsurprisingly, previous research shows dissociation between attentional processes and eye fixations (Rensink, 2000b). These findings suggest that overcoming misdirection requires adapting covert visual attention—when attention and gaze fixation operate independently—more so than overt visual attention. The neural circuits controlling both attentional systems overlap (Corbetta et al., 1998), and under normal circumstances covert and overt attention are fairly synchronous (Awh, Armstrong, & Moore, 2006). However, it is possible to shift visual attention to objects and locations in the absence of eye movements (Thompson & Bichot, 2005). In fact, covert attention can be deployed several saccades ahead of voluntary eye movements (Henderson & Hollingworth, 1999; Peterson, Kramer, & Irwin, 2004). Furthermore, covert and overt attention can be dissociated in space (Posner, 1980) and misdirection generally relies on manipulating covert rather than overt attention (Kuhn & Tatler, 2005; Kuhn et al., 2008b; Kuhn & Findlay, 2010). In the same vein, gaze fixation analysis in a different study using the Vanishing Ball illusion reveals a discrepancy between the spot people claimed to have seen the ball disappear, and whether they were even looking at that spot when the ball "*vanished*" towards the ceiling, whereas the ball actually stays in the magician's hand (Kuhn & Land, 2006). Here the magician manipulates covert attention through social cues to achieve the *effect* of a ball vanishing upwards—guided by the magician's head movements, people visually trace the imaginary path of the ball, and "*see*" it disappear up past their final gaze fixation.

Thus, misdirection is quite effective at selectively engaging covert attention in order to achieve success. This presumption remains valid where covert attention can be directly measured, i.e., when the *method* is visible and dissociation between attention and gaze fixations can be determined. However, many magic tricks rely on more than solely manipulating covert attention. Typically, the *method* of a successful magic trick is well hidden and may never be overtly visible, in contrast to the magic tricks from the aforementioned studies. Such secrecy renders a covert attentional strategy ineffective for the viewer, as there is nothing specific to attend to so much as figuring out how to achieve the trick. Furthermore, misdirection is typically categorized as covert or overt based on its effect on visual attention, which simplifies the true range of psychological mechanisms involved. Various other kinds of effective misdirection exist, e.g., cognitive misdirection, memory misdirection, etc. In addition, the possibility of using multiple *methods* to produce the same *effect* allows for the potential to continuously fool the audience using related, but discrete psychological mechanisms. Therefore, the manipulation of visual attention as the primary explanation for successful magic tricks is a reasonable one, but incomplete. Nevertheless, we wanted to explore aspects of misdirection while building upon previous empirical findings, as the current body of research does converge on the observation that misdirection is most effective when manipulating covert attention.

1.5 Investigating the durability of misdirection

Specifically, we decided to investigate the durability of misdirection—that is, how long and how well does misdirection persist—by eyetracking multiple presentations of the classic 3-card Monte trick and seeing how participants visually react to the correct answers. Variations of the 3-card Monte have existed as early as the Middle Ages, e.g., the shell game. The trick works by inducing participants to believe that the game is a simple test of visual acuity, i.e., literally, to keep your eyes on the prize. In this variant, a pea is hidden under nutshells: the shells are shuffled on a flat surface as the pea is shifted amongst them. The audience is invited to bet on the shell with the pea. The participant is misdirected into believing the game is fair, but a sleight of hand switches the pea to a different location during the shuffle in the rigged game, which occurs after a series of fair games. The 3-card Monte is so effective at fooling players that it is illegal to wager money on the game in Canada under section 206(1) of the Criminal Code. The key to winning is first realizing the game can be rigged—then, individuals must adapt their visual and attentional strategies to detect the sleight of hand and discover the real location of the target. However, they usually do not have the chance. Typically, the rigged game happens after a series of fair games, and the games end with the rigged game. Therefore, we wanted to see how participants would visually react to seeing the correct answers after multiple encounters with the exact same misdirection, i.e., if they are surprised at getting incorrect answers after viewing the same *method* and *effect* multiple times, and also how their accuracy would change.

Participants often perceive the 3-card Monte trick as a game of skill, believing their error is due to the increase in shuffling speed by the magician or because they lose sight of the target, unaware that misdirection was present. This erroneous impression produces an interesting situation wherein the participant is in a state of heightened *selective attention* (on the target) and *sustained attention* (for the duration of the play) focused entirely on finding the target. As the target is switched with a dummy using sleight of hand, one might expect the heightened state of attention to enable superior detection of any changes to the target. Furthermore, instant feedback provides impetus for participants to evaluate and adjust their strategy in case of wrong answers in subsequent games. The multiple viewings provide several chances for participants to do exactly that. We decided to also examine variations in their involuntary cognitive processing.

1.6 Measuring concurrent automatic processing

Elucidating automatic cognitive processing may reveal additional clues to how individuals react after becoming aware of misdirection. In particular, pupillometry—the measurement of pupil diameter in psychological research—can provide corroborating information. Light enters the eye through the pupil, and changes in pupil size occur spontaneously and are impossible to suppress at will (Loewenfeld, 1993). Voluntary variation of pupil dilation is difficult: pupil size changes may only be indirectly provoked by mentally simulating an object or an event that naturally evokes changes in pupil size (Whipple, Ogden, & Komisaruk, 1992). Pupil size variation has been demonstrated to be a marker or proxy for processing load, cognitive effort, and attentional resources

(Kahneman, 1973; Kahneman & Beatty, 1966; Beatty, 1982; Laeng, Sirois, & Gredebäck, 2012). This literature is remarkably consistent and without significant contradictions (Beatty & Lucero-Wagoner, 2000). Furthermore, pupil dilations can reflect cognitive processes taking place under the threshold of consciousness (Bijleveld, Custers, & Aarts, 2009). Ergo, pupil dilations offer a window into real time cognitive processes present in successful magic perception, allowing misdirection to be analyzed via gaze fixation patterns as a proxy of overt attention, and pupil dilations as a measure of concurrent cognitive processing.

1.7 The investigation plan

Thus, a novel eyetracking study examining visual attention allocation (using gaze fixations and pupillometry) during the feedback phase for the 3-card Monte was conducted to test the hypothesis that misdirection is durable. That is, despite multiple exposures to the same 3-card Monte with immediate feedback, participants would be resistant to changing their decision-making behavior. Using naïve individuals (those unfamiliar with misdirection), we examine visual attention to assenting and dissenting information in outcomes of the 3-card Monte, and whether accuracy would be different from the expected distribution. If participants are consistently wrong under deceptive circumstances after multiple encounters, then they must not be utilizing an appropriate decision-making strategy, and may reflect a misallocation of covert attention. Moreover, because the *method* always happens on-screen—that is, it is physically present in the scene, if not necessarily obvious—successful cases of the 3-card Monte hinges on properly diverting the attention of the audience. As such, investigating how participants visually evaluate during feedback after multiple viewings provides a valuable source of information to better understand the mechanisms behind the continuing efficacy of misdirection over cognition.

Chapter 2: Methods

2.1 Participants

Our study recruited a sample of convenience of 30 undergraduate students at McGill University. A screening filter granted sign-ups only to those who met the required inclusion and exclusion criteria. The inclusion criterion was having normal or corrected-to-normal vision. The following exclusion criteria were in effect: any previous experience with magic as a performer or knowledge of misdirection; those wearing hard contact lenses due to risk of interference with the eyetracking hardware. The study granted students extra credit in an undergraduate Psychology course for their participation. 16 of 30 participant data were used for analysis upon further inspection, described in the results section. Ethics approval for the study was obtained from the Jewish General Hospital Research Ethics Committee in Montreal, QC, Canada.

2.2 Apparatus

A desktop-mounted EyeLink 1000 system with a 2000 Hz sampling rate (SR Research, Mississauga, ON, Canada), 35 mm monocular PENTAX lens, and a chin-rest were utilized. The viewing configuration was set to a Stabilized Head, Monocular (right eye) mode at 2000 Hz. Video stimuli were presented on a 22" widescreen Samsung SyncMaster 2233 HD monitor set 605 mm from the center of the screen (615 mm to top of screen, 625 mm to bottom of screen) to the participants' eyes, as fixed in place by the chin-rest. The viewing window consisted of a 4:3 aspect ratio, 1024x768 pixel display area with display corners set 197.5 mm horizontally and 148 mm vertically from the center of the screen. Eye movements were calibrated with a 9-point grid with inclusion criteria set to an average of 0.5 visual degrees of error or less, and a maximum of 1.0

visual degrees of error or less for any one fixation target in the calibration grid (Holmqvist, 2011, p.128-129). Illumination for pupillometry was controlled using a single light source; the room was kept dark by turning off all other sources of light and by using black curtains and partitions to surround the testing station. The single light source was situated above the participant to cast an even, diffuse white light that would not be overpowering. The lamp utilized a 13-watt CFL rated at 4100K *cool white* in appearance and 900 lumens in output. See **Figure 1.**

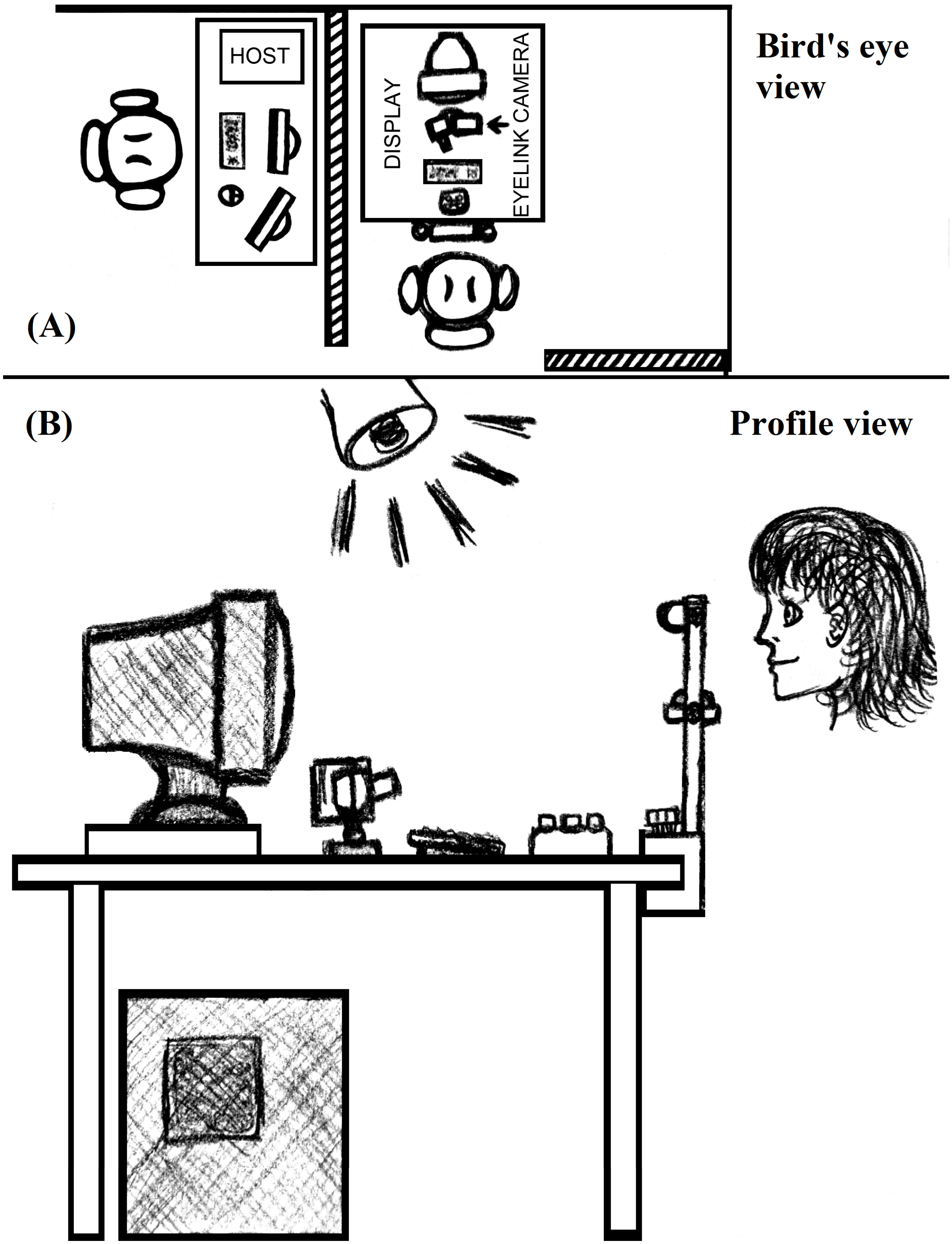

FIGURE 1. *The testing station*

Figure 1 Legend

(A) Bird's eye view of the testing station. To the left is the Host PC area where the researcher runs the eyetracking program. To the right is the Display PC area where the participants sit and view the magic videos. (B) Profile view of the Display PC area. From left to right: the CRT monitor, the EyeLink camera, the keyboard for calibration purposes, the 5-button response input controller, the chin-rest. Note the presence of the single light source above the station.

2.3 Experimental stimuli & variables

Videos of four versions of the 3-card Monte trick were created[1]. Each version had the same target: the Queen of Hearts (the dummies consisted of a 6 of Clubs and/or a 6 of Spades for stark contrast). The four versions are named Flat, Bent, Bent Corner, and Torn (**Figure 2**). Each 3-card Monte version also has a Normal condition and a Sleight-of-Hand condition (active misdirection condition where the target is quietly switched with a dummy using sleight of hand). The video stimuli were cropped to include only the torso and hands of the magician in order to limit the influence of social cues as a confounding factor in misdirection (Kuhn et al., 2009).

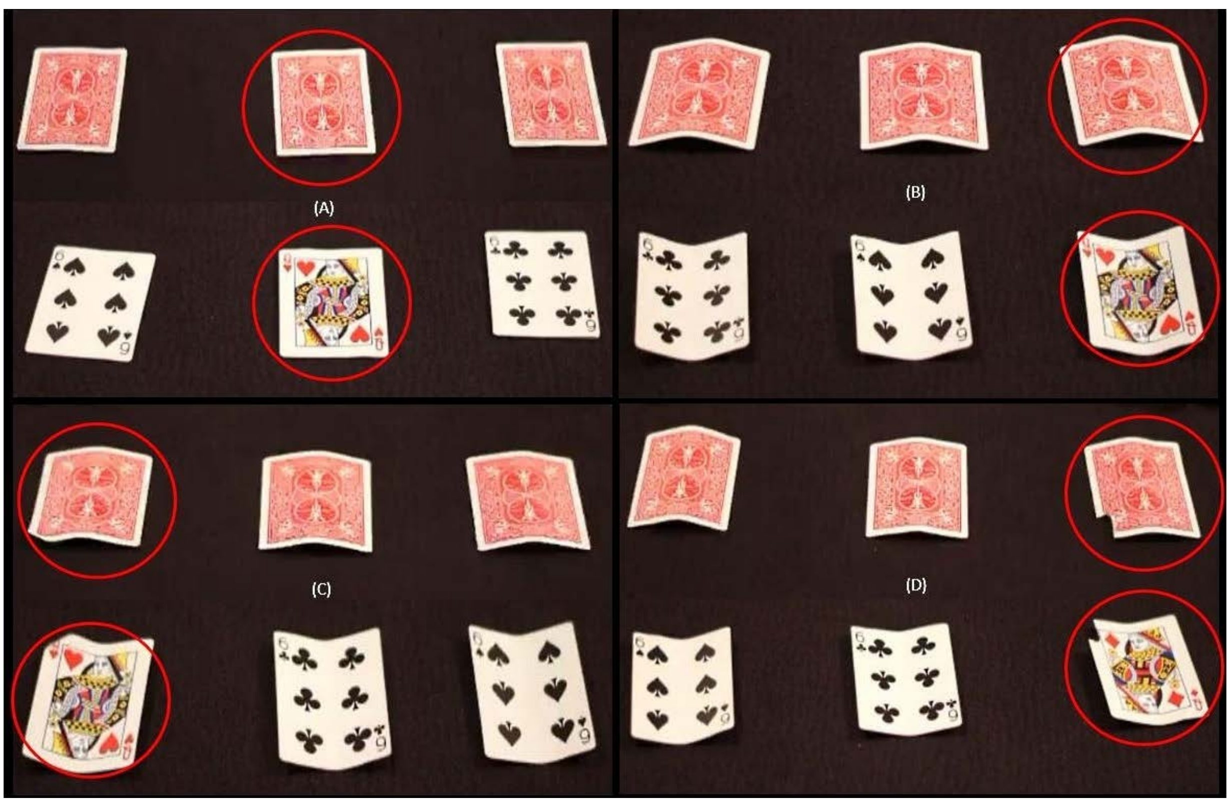

FIGURE 2. *The four versions of Monte*

[1] For all Trick videos used in the experiment:
https://www.youtube.com/playlist?list=PLZAiUYbYTbqJ5XALmAyQ21PXkCFGG6i4L
For all corresponding Reveal videos used in the experiment:
https://www.youtube.com/playlist?list=PLZAiUYbYTbqKS_HjexCivcEzG2NMr-SUD

Figure 2 Legend

The four versions of the 3-card Monte trick (within each panel, the top image represents before the Reveal; the bottom image represents after the Reveal): In the 1st version, the target is flat (A). In the 2nd version, the target is bent lengthwise (B). In the 3rd version, the target is bent lengthwise and has a bent corner (C). In the 4th version, the target has a ripped corner (D). The target is circled in red for clarity.

2.4 Procedure

We told participants in advance they would be watching magic tricks and that their job was to follow the target (the red Queen of Hearts versus two black cards as dummies) and locate it after the shuffle, i.e., find the correct answer. After calibrating the eyetracking camera, all participants watched the same sequence of 3-card Monte videos presented in their full 720x480 resolution: Habituation (3 trials), and then the experimental conditions Flat (4 trials), Bent (4 trials), Bent Corner (4 trials), and Torn (2 trials). Each of the four versions has a Normal condition and a Sleight-of-Hand condition (where misdirection is applied and the target quietly switched with a dummy using sleight of hand). There were an equal number of Normal and Sleight-of-Hand videos presented, i.e., exactly half the trials were deceptive and contained misdirection. Conditions were randomly presented for each experimental version of 3-card Monte. There were 14 experimental trials total. See **Table 1** for details.

Table 1: Video stimuli details & answers

Video Name	Trick Length	Predetermined Outcome Position	Actual Position	Reveal Length	Target Reveal Time
~~Habituation 1~~	0:00:29	MIDDLE	MIDDLE	0:00:13	0:00:08
~~Habituation 2~~	0:00:27	LEFT	LEFT	0:00:15	0:00:10
~~Habituation 3~~	0:00:32	RIGHT	RIGHT	0:00:13	0:00:06
FlatNormal1	0:00:29	MIDDLE	MIDDLE	0:00:13	0:00:08
FlatNormal2	0:00:32	LEFT	LEFT	0:00:14	0:00:10
FlatSleight1	0:00:31	RIGHT	MIDDLE	0:00:13	0:00:07
FlatSleight2	0:00:27	RIGHT	LEFT	0:00:14	0:00:10
BentNormal1	0:00:30	RIGHT	RIGHT	0:00:13	0:00:06
BentNormal2	0:00:28	LEFT	LEFT	0:00:13	0:00:09
BentSleight1	0:00:26	RIGHT	LEFT	0:00:13	0:00:09
BentSleight2	0:00:26	MIDDLE	RIGHT	0:00:13	0:00:05
BentCornerN1	0:00:29	LEFT	LEFT	0:00:13	0:00:08
BentCornerN2	0:00:29	RIGHT	RIGHT	0:00:13	0:00:05
BentCornerS1	0:00:30	LEFT	RIGHT	0:00:13	0:00:05
BentCornerS2	0:00:30	MIDDLE	RIGHT	0:00:14	0:00:06
TornNormal	0:00:46	RIGHT	RIGHT	0:00:19	0:00:06
TornSleight	0:01:03	LEFT	MIDDLE	0:00:21	0:00:08

Table 1 Legend

Video Name refers to the version of Monte (Habituation videos are crossed out); Trick length is the length of the Trick video in seconds; Reveal length is the length of the Reveal video in seconds; Target Reveal Time is when the actual location of the target is first revealed and completely flat on the table, unoccluded from any obstructions; Predetermined outcome position is where the card “should” end up, regardless of misdirection, i.e., *the expected answer*; Actual position is where the card actually ends up, regardless of misdirection, i.e., *the actual answer*. The two are one and the same when misdirection is not present, i.e., when the condition is Normal.

Participants first habituated to the experimental paradigm by predicting the target in the Flat version without misdirection three times, ending up in each of the three possible positions (Left, Center, Right). This data was not included in the analyses. The versions of Monte were not counterbalanced and thus presented in a predetermined order, which was by how easy each version made tracking the target possible by marking the Queen of Hearts—we first presented Flat, then Bent, then Bent Corner, then Torn versions, making the target easier and easier to follow. We decided to present the four versions in this specific order for this novel experimental design since previous literature indicate participants become less susceptible to misdirection when the same magic trick is repeated using the same method (Kuhn & Tatler, 2005; Kuhn & Findlay, 2010; Kuhn & Martinez, 2012). This would give the participants an advantage in multiple viewings. Since we are probing the durability of misdirection, we felt this action was appropriate in reducing any advantages the magician may hold by utilizing the same kinds or sets of misdirection only once. Thus, if misdirection remains robust even with all the handicap provided to participants in beating the 3-card Monte, then it could help rule out practice or repeated viewings as a relevant factor for beating misdirection and help focus analysis on other aspects of how misdirection still remains effective. A future study with counterbalancing of versions would be necessary to fully corroborate this effect.

Each video is split into two continuous parts: participants watch the first half called Trick where the cards are first presented and shuffled. Following the shuffle, participants make their predictions and provide a Confidence rating on a 5-point Likert scale. The last frame of the Trick video remained onscreen until participants finish choosing. Immediately afterwards, the video resumes and participants view the corresponding Reveal video (showing the true position of the target and allowing time for participants to visually assess their accuracy, i.e., the feedback), which starts playing from the last frame of the Trick (**Figure 3**). The eyetracking camera records all real time gaze fixations and pupil dilations for the duration of the study.

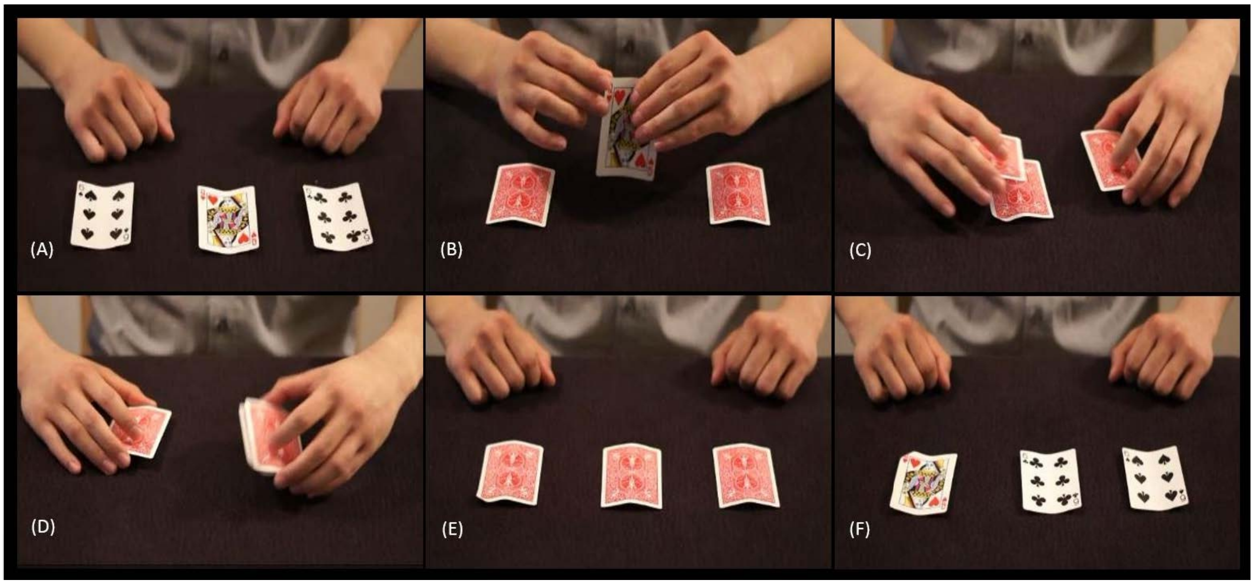

FIGURE 3. *The 3-card Monte in action*

Figure 3 Legend

The sequence of events in the 3-card Monte trick: the desired effect was to make the target card appear in a different position from where it “should” end up. In this trick, the magician shows three cards (A) and asks the participant to follow the red Queen of Hearts (B). He then begins to shuffle the cards (C) and redirects attention away from the target using a sleight of hand (D). The cards are then presented facedown and the participant is asked to locate the target card (E). The magician finally reveals the position of the target card (F).

2.5 Measures

We collected three sets of measures to assess the durability of misdirection.

1) The gaze fixation measure consists of the time spent looking at one of the three answers (Left, Center or Right) as a percentage of the total duration of the Reveal video. As the facedown cards are flipped and placed back into the same spot, the three answers (Left, Center and Right) are encapsulated as static Interest Areas (aka, Regions of Interest) conforming to the borders of the cards.

2) Accuracy-related measures:

a) Correctness (the percentage of correct answers across all experimental trials).

b) ShouldHave—short for *should have picked this one*, a measure of effective misdirection. While shuffling, the magician leads the target into the predetermined outcome position. If misdirection is present, then the target does not end up in its normal predetermined outcome position. ShouldHave compares the predetermined outcome position—regardless of the presence or absence of misdirection in the trial—versus the participant’s actual answer. Thus, a participant should always choose the predetermined outcome position if they are fooled by misdirection, regardless of the actual answer.

ShouldHave is represented as the percentage of matching responses between the predetermined outcome position and the participant's answer.

c) Confidence rating on the prediction (Likert-scale 1-5; 1 = not very confident, 5 = very confident).

3) Pupillometry measures:

a) Change in the maximum pupil size during the critical period before the Reveal of the target compared to the maximum pupil size after the Reveal (the first critical period lasts from the beginning of the Reveal video until the first card to be flipped is touched; the second critical period lasts from the moment the target is flipped and fully visible, until the video ends) relative to baseline.

b) Pupillary response latency, i.e., the time elapsed from the start of a critical period after the Reveal to maximum pupil dilation (the critical period starts as soon as the target is fully visible after being flipped and ends when the video terminates; refer to **Table 1**).

Chapter 3: Results

Data Analysis Summary: Three sets of related analyses were conducted to test the overall hypothesis that misdirection is durable. All gaze fixation and accuracy-related statistical analyses were conducted in IBM SPSS Statistics 21.0 (IBM Corporation, August 2012) for MAC OS 10.6.8. All pupillometry-related statistical analyses were conducted in IBM SPSS Statistics 21.0 (IBM Corporation, August 2012) for MAC OS 10.6.8 and in IBM SPSS Statistics 20.0 (IBM Corporation, August 2011) for Windows 7. In order to ensure a dataset as free of measurement errors as possible, the analyses utilized 16 of 30 collected participant data according to inclusion criteria established by the calibration procedure. From the 16 usable participant data, one participant's data was excluded for the pupillometry analyses as an outlier (identified as having extreme values after standardizing) in the pupillometry data distribution.

3.1 Gaze fixation analyses

The gaze fixation analyses consist of a One-Way ANOVA on the three possible answer choices during the Reveal with each unique version of Monte treated as a separate analysis. Each ANOVA investigates the amount of time spent looking at one of the three possible answers during the feedback period, and if that time significantly differs from one another (H_0: $\mu_{Expected} = \mu_{Actual/Dummy1} = \mu_{Dummy2}$ & H_A: $\mu_{Expected} \neq \mu_{Actual/Dummy1} \neq \mu_{Dummy2}$). If misdirection is durable and participants continue to remain unaware of its presence, then viewing times should widely vary between the three possible answers when participants check their accuracy for each new Monte video, giving preference to their choice rather than spend an equal amount of time investigating each answer as a possibility.

3.2 Accuracy analyses

The accuracy analyses consist of two separate dependent samples t-tests to determine the extent to which “Correctness” and “ShouldHave” proportions differ between Normal versus Sleight-of-Hand conditions (for both analyses, H_0: $\mu_{Normal} = \mu_{Sleight}$ & H_A: $\mu_{Normal} \neq \mu_{Sleight}$). If misdirection is durable, then Correctness will differ between conditions, but ShouldHave will not. Furthermore, the average confidence rating for each trial condition was calculated, provided in **Table 2**. The confidence scores were collapsed over like-versions and assessed for a linear relationship over time, found in **Figure 4**.

Table 2: Average confidence ratings

Trial Name	Average Confidence Rating
FlatNormal1	3.19
FlatNormal2	3.50
FlatSleight1	4.31
FlatSleight2	3.94
BentNormal1	3.56
BentNormal2	4.00
BentSleight1	4.31
BentSleight2	3.50
BentCornerN1	3.38
BentCornerN2	3.88
BentCornerS1	4.00
BentCornerS2	3.31
TornNormal	2.88
TornSleight	3.38

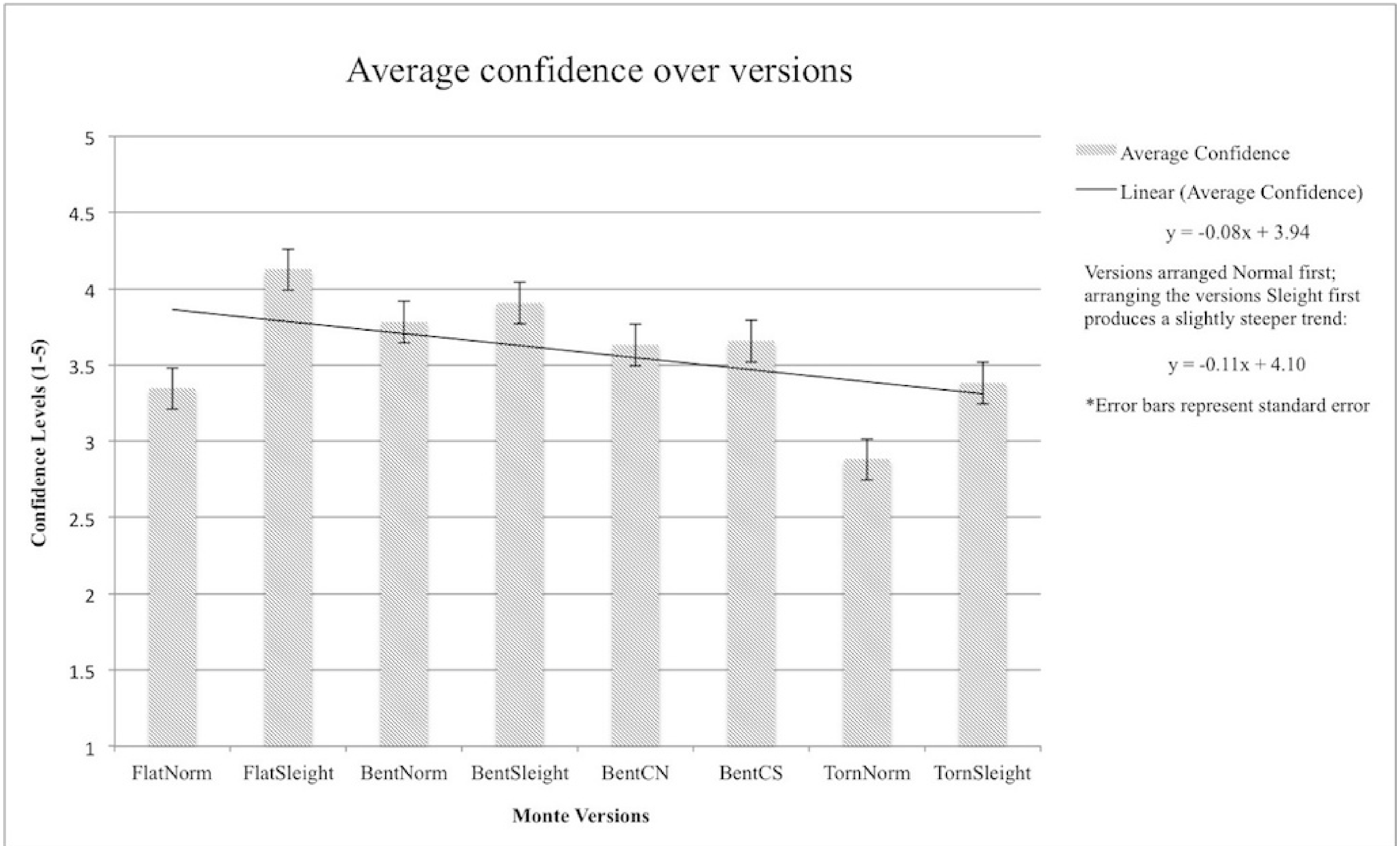

FIGURE 4. *Average confidence over versions*

Figure 4 Legend

A linear model of the average degradation of confidence ratings as the trials of 3-card Monte is presented one by one. The independent variable X is the initial confidence rating provided by the participant in the first trial, and the linear model predicts the gradual decline in confidence as the trials progress. Measured in a 5-point Likert scale, each bar presented is an average score of the collected data for that particular trial within the 5-point Likert scale.

3.3 Pupillometry analyses

The peak amplitude of pupil dilation typically occurs about 900ms-1200ms after the beginning of an experimental trial and dilation generally begins with a delay of 300ms-500ms (Beatty, 1982). The peak amplitude of pupil dilation, i.e., maximum pupil sizes relative to baseline were measured during two time periods per Monte routine: a critical period lasting about 4 seconds immediately before the Reveal of the target card, and a comparison critical period lasting about 4 seconds immediately after. Thus, peak amplitudes occurred within the recording interval. The first pupillometry analysis consists of a Repeated Measures 2-Way ANOVA to determine whether pupil size changes would differ between viewings of Normal and Sleight-of-Hand routines, as well as between the four Monte versions. Presuming that seeing the answer is more cognitively demanding than viewing the cards facedown, the maximum pupil size during the critical period before the Reveal of the target was subtracted from the maximum pupil size after the Reveal of the target for each of the trials (H_0: $\mu_{2\text{-}1} = 0$, H_A: $\mu_{2\text{-}1} \neq 0$).

The second pupillometry analysis consists of a Repeated Measures 2-Way ANOVA to determine if the response latency, i.e., the time elapsed from the start of a critical period after the Reveal to the peak pupil dilation would differ between the conditions and their respective levels (H_0: $\mu_{NormalLatency} = \mu_{SleightLatency}$ & H_A: $\mu_{NormalLatency} \neq \mu_{SleightLatency}$; H_0: $\mu_{FlatLatency} = \mu_{BentLatency} = \mu_{BentCornerLatency} = \mu_{TornLatency}$ & H_A: $\mu_{FlatLatency} \neq \mu_{BentLatency} \neq \mu_{BentCornerLatency} \neq \mu_{TornLatency}$). Because of the lack of counterbalancing for Monte Version due to the methodology, any effects must be interpreted via the omnibus effect and assessing specific differences between levels is not theoretically supported. If misdirection is durable and participants remain unaware of its presence, then maximum pupil size contrasts should differ across conditions, and latency should also differ across conditions as participants evaluate the accuracy (or inaccuracy) of their answer choice.

Hypothesis Testing Outcomes

3.4 Gaze fixation analyses outcomes

One-Way ANOVA: The results of the ANOVA support the hypothesis that if misdirection is durable, then viewing times should differ between answers as participants assess their answers in each subsequent trial, giving preference to their own choice rather than evaluate each possible answer equally after encountering misdirection. **Tables 3** and **5** present the outcomes of the Normal Monte ANOVA and subsequent post-hoc Tukey's HSD ($\alpha = .05$) between the Expected answer, i.e., the predetermined outcome position, and the two Dummy answers. **Tables 4** and **6** present the outcomes of the Sleight-of-Hand Monte ANOVA and subsequent post-hoc Tukey's HSD ($\alpha = .05$) between the Expected answer, i.e., the predetermined outcome position, the Actual answer, and the remaining Dummy answer. In addition, heat maps of gaze fixations for each version of Monte were produced to further clarify the statistical analyses—the heat maps are arranged by Normal (**Figure 5**) versus Sleight-of-Hand (**Figure 6**).

Table 3: Normal Monte ANOVA results after Bonferroni correction (at 0.05/14 = 0.00357)

Normal Monte	DF	Mean Square	F-statistic	*p*-value
FlatNormal1	2	.932	75.690	.000*
FlatNormal2	2	.259	18.094	.000*
BentNormal1	2	.563	21.356	.000*
BentNormal2	2	.126	8.386	.001*
BentCornerN1	2	.134	13.236	.000*
BentCornerN2	2	.645	26.217	.000*
TornNormal	2	.160	63.762	.000*

Table 4: Sleight-of-Hand Monte ANOVA results after Bonferroni correction (at 0.05/14 = 0.00357)

Sleight-of-Hand Monte	DF	Mean Square	F-statistic	*p*-value
FlatSleight1	2	.927	51.556	.000*
FlatSleight2	2	.086	8.296	.001*
BentSleight1	2	.066	4.326	.019
BentSleight2	2	.647	40.785	.000*
BentCornerS1	2	.160	22.498	.000*
BentCornerS2	2	.560	49.188	.000*
TornSleight	2	.331	23.231	.000*

Table 5: Normal Monte post-hoc Tukey's HSD (α = .05)

Monte Version	Contrasts	Mean Difference	Standard Error	*p*-value	95% CI
	Expected v. Dummy 1	.471	.039	.000*	[.376, .567]
FlatNormal1	Expected v. Dummy 2	.325	.039	.000*	[.230, .420]
	Dummy 1 v. Dummy 2	-.146	.039	.002*	[-.241, -.051]
	Expected v. Dummy 1	-.202	.042	.000*	[-.305, -.100]
FlatNormal2	Expected v. Dummy 2	.033	.042	.721	[-.070, .135]
	Dummy 1 v. Dummy 2	.235	.042	.000*	[.132, .338]
	Expected v. Dummy 1	.354	.057	.000*	[.215, .493]
BentNormal1	Expected v. Dummy 2	.069	.057	.461	[-.070, .208]
	Dummy 1 v. Dummy 2	-.285	.057	.000*	[-.424, -.146]
	Expected v. Dummy 1	-.090	.043	.105	[-.195, .015]
BentNormal2	Expected v. Dummy 2	.087	.043	.120	[-.018, .193]
	Dummy 1 v. Dummy 2	.178	.043	.001*	[.073, .283]
	Expected v. Dummy 1	-.013	.036	.926	[-.100, .073]
BentCornerN1	Expected v. Dummy 2	.151	.036	.000*	[.065, .238]
	Dummy 1 v. Dummy 2	.165	.036	.000*	[.079, .251]
	Expected v. Dummy 1	.398	.055	.000*	[.263, .532]
BentCornerN2	Expected v. Dummy 2	.247	.055	.000*	[.112, .381]
	Dummy 1 v. Dummy 2	-.151	.055	.024*	[-.286, -.017]
	Expected v. Dummy 1	.441	.039	.000*	[.346, .536]
TornNormal	Expected v. Dummy 2	.246	.039	.000*	[.151, .341]
	Dummy 1 v. Dummy 2	-.195	.039	.000*	[.100, .290]

Table 6: Sleight-of-Hand Monte post-hoc Tukey's HSD (α = .05)

Monte Version	Contrasts	Mean Difference	Standard Error	*p*-value	95% CI
	Expected v. Actual	.099	.034	.013*	[.017, .180]
FlatSleight1	Expected v. Dummy	.332	.034	.000*	[.250, .413]
	Actual v. Dummy	.232	.034	.000*	[.151, .314]
	Expected v. Actual	-.114	.036	.001*	[-.057, -.006]
FlatSleight2	Expected v. Dummy	-.094	.036	.033*	[-.181, -.006]
	Actual v. Dummy	.051	.036	.344	[-.036, .138]
	Expected v. Actual	-.165	.045	.002*	[-.272, -.057]
BentSleight2	Expected v. Dummy	.236	.045	.000*	[.128, .343]
	Actual v. Dummy	.400	.045	.000*	[.292, .508]
	Expected v. Actual	.111	.030	.002*	[.039, .183]
BentCornerS1	Expected v. Dummy	.199	.030	.000*	[.127, .272]
	Actual v. Dummy	.089	.030	.013*	[.016, .161]
	Expected v. Actual	-.169	.038	.000*	[-.261, -.078]
BentCornerS2	Expected v. Dummy	.204	.038	.000*	[.113, .296]
	Actual v. Dummy	.374	.038	.000*	[.282, .465]
	Expected v. Actual	-.046	.042	.526	[-.148, .056]
TornSleight	Expected v. Dummy	.223	.042	.000*	[.121, .325]
	Actual v. Dummy	.269	.042	.000*	[.167, .371]

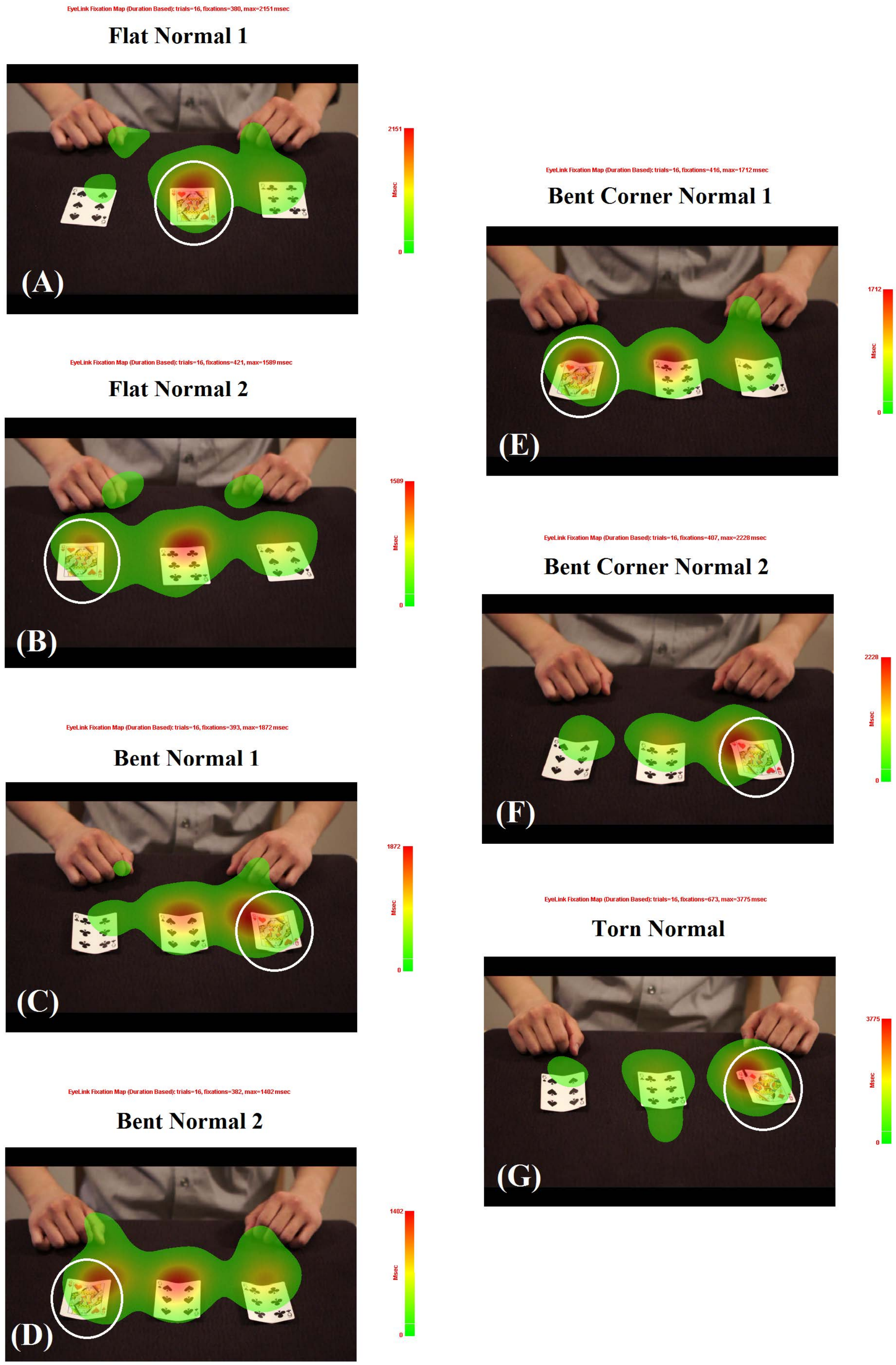

FIGURE 5. *Normal Monte heat maps*

Figure 5 Legend

(A) Flat Normal 1, (B) Flat Normal 2, (C) Bent Normal 1, (D) Bent Normal 2, (E) Bent Corner Normal 1, (F) Bent Corner Normal 2, (G) Torn Normal. A white circle encapsulates the predetermined outcome position, i.e., the *expected answer*. Heat maps based on total number of fixations across participants, with intensity based on millisecond-resolution durations of said fixations.

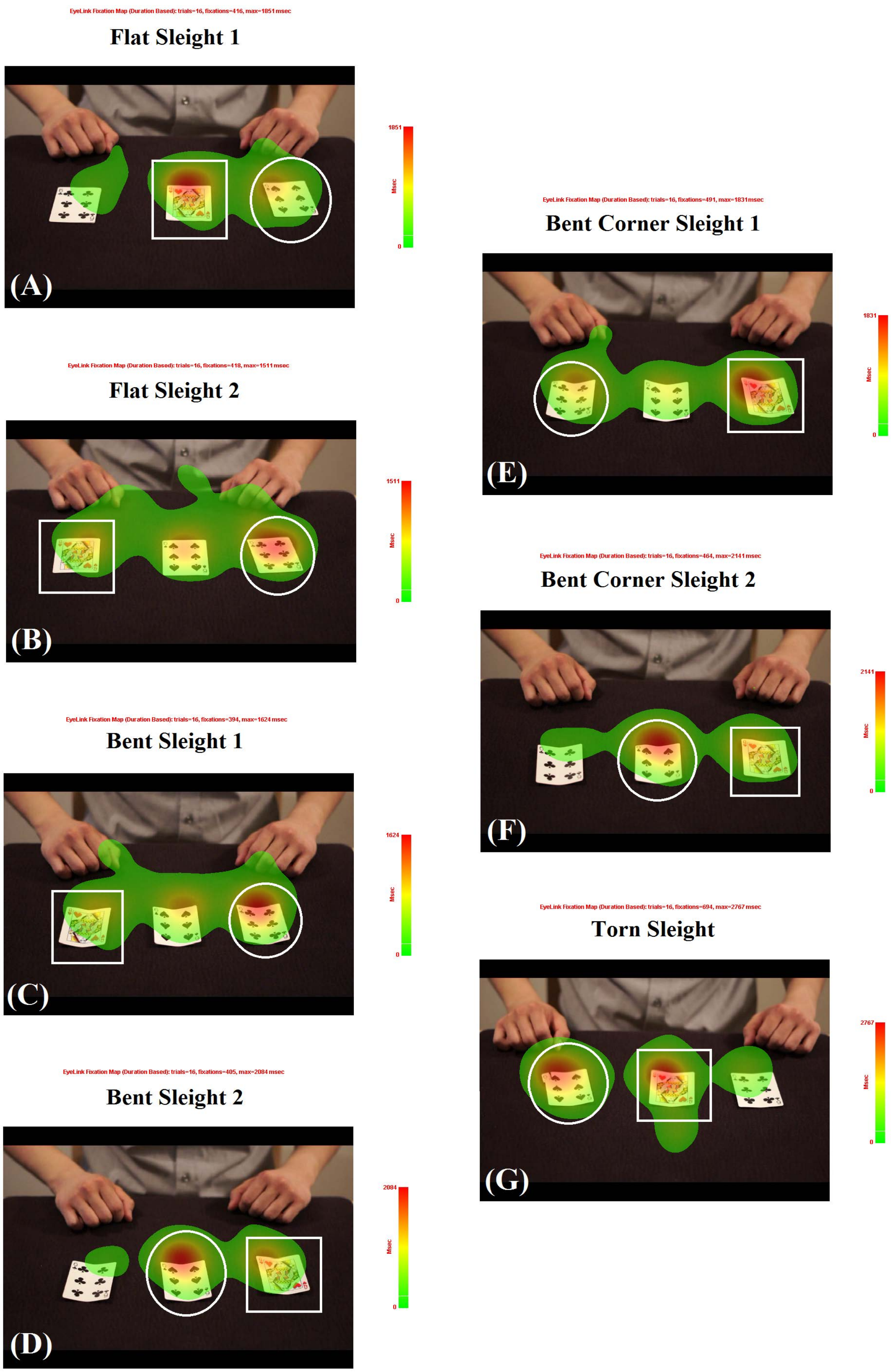

FIGURE 6. *Sleight-of-Hand Monte heat maps*

Figure 6 Legend

(A) Flat Sleight 1, (B) Flat Sleight 2, (C) Bent Sleight 1, (D) Bent Sleight 2, (E) Bent Corner Sleight 1, (F) Bent Corner Sleight 2, (G) Torn Sleight. A white circle encapsulates the predetermined outcome position, i.e., the *expected answer*. The Actual position, i.e., the *actual answer*, is encapsulated by a white rectangle. Heat maps based on total number of fixations across participants, with intensity based on millisecond-resolution durations of said fixations.

3.5 Accuracy analyses outcomes

Dependent Samples t-Test: The results of the dependent samples t-test support the hypothesis that if misdirection is durable, then Correctness will be different between Normal and Sleight-of-Hand versions, but ShouldHave will not (see **Table 7** for descriptive statistics):

The presence of Sleight-of-Hand results in a marked decrease ($M_{difference}$ = .795, $SE_{difference}$ = .054, 95% CI [.680, .909]) in the accuracy of participant answers—this difference of means is statistically significant: $t(15) = 14.792$, $p = .000$, 2-tailed.

The presence of Sleight-of-Hand results in a small increase ($M_{difference}$ = -.054, $SE_{difference}$ = .034, 95% CI [-.126, .019]) in the ability of the magician to get participants to select the predetermined outcome position—this difference of means is not statistically significant: $t(15) = -1.566$, $p = .138$, 2-tailed.

Table 7: Proportions of correct answers and ShouldHave matches

		Paired Samples Statistics			
		Mean	*SE*	*SD*	*N*
Correctness	Normal	.875	.032	.126	16
	Sleight	.080	.054	.215	16
ShouldHave	Normal	.884	.033	.130	16
	Sleight	.938	.018	.073	16

3.6 Pupillometry analyses outcomes

2-Way Repeated Measures ANOVA: The guidelines set forth by Girden for interpreting values of Epsilon were followed for the results (Girden, 1992). The Greenhouse-Geiser correction for violations of sphericity was chosen due to its conservative nature and as a compromise between the more liberal Huynh-Feldt correction and the even more conservative Lower-Bound correction. The results of the ANOVA support the hypothesis that if misdirection is durable, then pupil size contrasts should differ across conditions, and latency should also differ across conditions, as participants evaluate the accuracy of their answers.

Differences in Pupil Size Changes: An interaction effect between the conditions Misdirection and Monte Version was not found. However, the main effect of Monte version on pupil size change is statistically significant, ($F(1.851, 25.912) = 4.171$, $p = .029$). The average contrasts in descending magnitude: Torn (670.0 pixels), Flat (598.7 pixels), Bent (537.5 pixels), BentCorner (481.9 pixels). Misdirection also exerts a statistically significant main effect on pupil size change, ($F(1, 14) = 5.250$, $p = .038$) where the pupil dilates more in the Sleight-of-Hand condition (634.4 pixels) than the Normal condition (509.6 pixels). See **Table 8** for descriptive statistics:

Table 8: Mean maximum pupil size contrast before and after Revealing the target (in pixels)

Monte Version	Misdirection	
	Normal	Sleight-of-hand
Flat	543.5	653.9
Bent	495.9	579.0
BentCorner	432.1	531.6
Torn	566.7	773.3

Pupillary Response Latency: A statistically significant interaction effect between Monte Version and Misdirection was found, (F(1.613, 22.586) = 15.581, p = .000). The main effect of Monte version, (F(1.619, 22.660) = 9.134, p = .002) shows longer overall response latencies for Flat (7948 ms) than for Bent (7229 ms), Torn (6885 ms) and BentCorner (6256 ms). Misdirection also exerted a statistically significant effect on the response latency, (F(1, 14) = 11.499, p = .004), indicating that responses to Sleight-of-Hand (7480 ms) were markedly longer than Normal routines (6678 ms). See **Table 9** for descriptive statistics:

Table 9: Mean response latencies after Revealing the target (in milliseconds)

Task	Misdirection	
	Normal	Sleight-of-Hand
Flat	7888	8007
Bent	7330	7128
BentCorner	6144	6367
Torn	5351	8418
Mean	6678	7480

Chapter 4: Discussion

A caveat in attentional studies is their ecological validity (Kuhn & Land, 2006; Laidlaw, Foulsham, Kuhn & Kingstone, 2011; Risko & Kingstone, 2011). We decided to utilize a classic magic trick as a natural way to direct eye movements to address this issue. We chose the 3-card Monte especially for its intuitively defined goal and immediate feedback: the trick requires participants to pay attention to and correctly guess the location of a single target amongst three after a shuffle. Under normal circumstances, the target is easy to follow and locate. When misdirection is present, the magician surreptitiously switches the target with one of two dummies—the target does not end up in its normal, predictable position. To beat the game, participants must realize the shuffle may be rigged and adapt their attentional strategy to detect the sleight of hand and find the actual location of the target.

4.1 Decomposing visual behaviour by the numbers

In order to give participants the best possible advantage, there are multiple viewings of the same Monte videos as part of the experiment, breaking a fundamental rule of magic: don't show the same trick twice (Kuhn & Tatler, 2005; Kuhn et al., 2008). Nevertheless, our participants performed poorly. An incredible 79.46% reduction (p = .000, 2-tailed) in the accuracy of answers occurs when the magician employs sleight of hand to switch the target, indicating that participants were not very successful in overcoming misdirection. The 87.5% accuracy with a Normal shuffle drops to a mere 8% when Sleight-of-Hand is present. A major reason we chose the 3-card Monte is because of the availability of immediate feedback; participants immediately learn whether they are right or wrong—we wanted to see how participants would visually assess the three possible answers, and if accuracy would differ from the expected distribution of 50% overall after multiple encounters with misdirection. Participants accurately answer at a rate of 45.98% across all trials, whereas the actual distribution of trials with misdirection is 50%, indicating no statistically significant difference from 50%, i.e., chance. Participants often believe they momentarily lost sight of the target or the shuffle was too fast to follow, rather than recognizing the game is rigged. Yet, the stark contrast between 87.5% accuracy in a Normal shuffle versus 8% under misdirection suggests that an inability to track the target is not likely to be responsible for this difference. This kind of erroneous explanation mirrors how individuals confabulate their choice blindness (Johansson, Hall, Sikström, & Olsson, 2005).

The ShouldHave ("*should have picked this one*") analysis is elucidating in context: the presence of misdirection actually results in a small increase in participants selecting the predetermined outcome position—although the difference is small -5.4% ($p = .138$, 2-tailed). Participants choose the predetermined outcome position 88.39% of the time for Normal shuffles versus 93.75% under misdirection. The total rate is 91.07% across all trials. While shuffling, the magician leads the target into the predetermined outcome position. If misdirection is present, then the target is switched with a dummy and does not end up in its normal predetermined outcome position. A participant should always choose the predetermined outcome position if misdirection remains effective—and it does seem misdirection is durable after multiple uses. Even when participants have access to immediate feedback for their efforts, they are consistently wrong under misdirection. More revealing is the fact that they choose the predetermined outcome position nearly every time—they repeatedly use the same attentional strategy and stick to the same decision-making behavior. Why are participants so poor at overcoming misdirection when it should be anticipated? They know in advance they will be watching a magic trick, and run into misdirection multiple times over the course of the experiment. Participants average 3.82 on a 5-point confidence scale under misdirection, 3.48 with a Normal shuffle, and 3.65 across all trials ($n = 224$) despite the poor accuracy. Assuming participants would change up their choice or attentional strategy once they realize the game is rigged, the heightened sense of confidence relative to accuracy is puzzling, especially considering the ShouldHave results. Although there are four different versions of the 3-card Monte in the experiment, this factor does not seem to exert any robust effect on the accuracy judging by the results. That is, because the task is the same each time (locate the target card) with multiple viewings of the same version of 3-card Monte regardless, any distortions on the resulting accuracy due to differences in shuffling or version of 3-card Monte is not statistically significant. For example, each individual member of a species of any organism is unique, but the species as a whole is structurally the same, allowing for a macroscopic analysis of the core characteristics that define the species. Therefore, the minor difference between versions of 3-card Monte is less important than their defining characteristics as a 3-card Monte.

Delving into the results of the gaze fixation ANOVA provides more clues, i.e., how are participants looking at the three possible answers when they find out whether they're correct or not? Every single ANOVA on the time spent on each of the three possible answers (Expected, Actual or Dummy 1, and Dummy 2) for both Normal and Sleight-of-Hand feedback are statistically significant ($ps<0.05$). Further decomposing the contrasts for each ANOVA result between the three positions yields an interesting picture. In Normal feedback, all contrasts are statistically significant between positions ($ps<0.05$), except for the following 5 out of 21: Expected (Left) versus Dummy 2 (Right) in FlatNormal2; Expected (Right) versus Dummy 2 (Center) in BentNormal1; Expected (Left) versus Dummy 1 (Center) & Expected (Left) versus Dummy 2 (Right) in BentNormal2; Expected (Left) versus Dummy 1 (Center) in BentCornerNormal1. For Sleight-of-Hand feedback, all contrasts are statistically significant between positions ($ps<0.05$), except for the following 4 out of 21: Actual (Left) versus Dummy (Center) in FlatSleight2; Expected (Right) versus Dummy (Center) & Actual (Left) versus Dummy (Center) in BentSleight1; Expected (Left) versus Actual (Center) in TornSleight. Of course, the lack of statistical significance for these contrasts indicates that viewing times were very similar between the positions. Thus, it appears that when participants more or less look at two positions equally, they are generally between adjacent positions. For the majority of contrasts, participants give ranked priority to each position, typically spending the greatest amount of time on the predetermined outcome position. Coupled with the previous accuracy outcomes, the results indicate that participants generally do not change their visual behavior when reviewing the answers. Considering there are 14 trials with half of the trials being deceptive, the consistency of the viewing patterns during feedback suggests participants are sticking with one kind of attentional strategy in choosing their preferred answer despite encountering misdirection multiple times, indicating some deficiency in their decision-making behavior.

Complementing the gaze fixation patterns are heat maps that translate the statistical analyses of attention allocation into a visual representation. **Figure 5** contains all Monte versions with a Normal shuffle, whereas **Figure 6** contains all Monte versions shuffled with Sleight-of-Hand. Participants seem to consider the three positions preferentially—typically, participants concentrate on the predetermined outcome position for Normal shuffles with most of their heavy fixations spent on the target, along with the occasional extended dwells on the Center position. This bias is likely due to a "resting gaze" phenomenon, because the Center position coincides with the central position on the screen, i.e., participants may be "resting" their gaze in the default position during the initial onset of the video, resulting in elevated dwell times for the Center position independent of condition. Sleight-of-Hand shuffles produce a similar response in participants, who spend most of their time on the correct answer (the unexpected position), then the predetermined outcome position (the expected answer), and then the other dummy card. However, accuracy results suggest that even if participants are heavily scrutinizing the correct answer during feedback for deceptive trials, they don't fare well in subsequent encounters, repeating their mistake. That is, they are spending most of their time looking at the correct answer, but only once it has been revealed. Because Sleight-of-Hand shuffles are randomly interspersed between Normal shuffles, the similarity in viewing patterns during feedback for both conditions suggests participants are unable to figure out when misdirection is present or do not actively consider it a possibility, even when they have the chance to view the same routines and videos multiple times.

4.2 Pupillometry

In order to better understand how participants are utilizing the feedback period, we measured pupillary responses to examine cognitive processing load during feedback for deceptive trials. Pupillary response varies as a function of task difficulty (Hess & Polt, 1964; Kahneman & Beatty 1966; Hyönä, Tommola, & Alaja, 1995). As baseline pupil size does not affect pupillary response when it is around the middle of its dynamic range under constant and normal illumination (Beatty & Lucero-Wagoner, 2000), we can presume other factors contribute to the contrast in maximum pupil dilation, i.e., the revealing of the target. One must expend greater cognitive effort to make sense of the Reveal if the target fails to show up in the predetermined outcome position. Participants show greater contrast in maximum pupil size before and after revealing the target for misdirection trials: 634.4 pixels compared to 509.6 pixels for Normal feedback (p = .038). We are unable to determine whether the larger pupil dilations are due to arousal, i.e., surprise at being wrong, or due to additional cognitive load, i.e., trying to figure out why they got it wrong. However, the latter seems the more likely explanation. Variations in task difficulty are likely to be attributable to inherent task differences. On the one hand, we assume Normal feedback is a simple perception task, because there is no need to further decipher the results, as the target ends up in the expected position. On the other hand, Sleight-of-Hand feedback is likely to be a reasoning task, because greater cognitive effort is needed to make sense of the unexpected outcome. The results parallel Beatty's (1982) summary of peak amplitudes of pupillary response in different cognitive tasks, which indicated that a perception task induced lower levels of pupil dilation than a reasoning task. Indeed, participants are generally less and less "surprised" as the trials progress, indicating growing familiarity with the potential for misdirection: Flat (598.7 pixels), Bent (537.5 pixels), BentCorner (481.9 pixels), and Torn (670.0 pixels). Torn may produce the largest pupillary response due to its unique feature of having a corner of the target physically torn and placed onto the mat before the shuffle.

Overall, pupillary responses reflect greater cognitive load at the unexpected answers for misdirection trials—at the same time, familiarity with the presence of misdirection also increased as the experiment progressed. The pupillary latency data are in line with the pupillometry results. Pupillary latency measures the delay onset of maximum pupil dilation following the reveal of the target. Longer response latency typically accompanies a larger pupillary contrast. Responses (p = .004) in Sleight-of-Hand feedback (7480 ms) are markedly longer than during Normal feedback (6678 ms), mirroring a similar pattern of cognitive load with the pupillometry results. Latencies generally decrease as the trials progress: Flat (7948 ms), Bent (7229 ms), BentCorner (6256 ms), and Torn (6885 ms), again indicating growing familiarity with the presence of misdirection and surprise at the novelty of the Torn shuffle. Referring to **Figure 4**—the slope for confidence over trials is almost flat, but there is a large drop in scores for the Torn version. Participants seem to retain their confidence despite knowing the game is rigged, perhaps because of the inclusion of fair versions of the Monte. That is, at least until encountering Torn. The high confidence for the first three versions of Monte seem attributable to the perception that failure is a result of increased shuffling speed or because they lost sight of the target—that the misdirection involved is an increase in speed because they were right a few times. In such a case, being more vigilant may be a winning and effective strategy. However, there is no chance of missing the target due to visibility for Torn, since the torn corner is clearly obvious and the shuffle is deliberately slow. Thus, participants seem aware of misdirection but not its exact shape or form (the sleight of hand); the pupillometry results likely reflect a relaxing of cognitive effort as they gradually stop trying as hard, and resignation at Torn due to their expectation that the game will be rigged, rendering a normal attentional strategy useless.

4.3 What makes misdirection durable over repeated use?

Indeed, awareness of the potential for misdirection may not confer an advantage in countering its effects. The durability of misdirection over its repeated use may instead reflect how well the *method* has been spirited away from visual attention altogether. Chisholm & Kingstone (2014) demonstrate that being previously aware of distractors yielded a performance benefit in oculomotor capture tasks, but the benefit was actually eliminated when participants were instructed to actively avoid the distraction. Based on performance, our participants did not seem to be actively trying to avoid looking at suspicious moves—rather, they were aware of its presence but did not change their overt viewing patterns (or covert attentional strategy) because they could not even recognize the distraction in the first place. Indeed, mobile eyetracking research using a real world visual search task shows top-down knowledge or goals affect viewing behaviour more so than bottom-up salience (Foulsham, Chapman, Nasiopoulos & Kingstone, 2014). Thus, participants know the game is rigged even if they cannot detect its *method* through covert attention, and seem reluctant to adapt their overt visual strategy to even try. This resistance is very surprising, given that participants know they will be rewarded with extra credit—the incentive for participating in the study—regardless of performance, and are told to find the correct answer. Furthermore, because there are multiple trials, the penalty or risk for being "wrong" and missing the *effect* is practically nonexistent.

Construing magic as a kind of cognitive entanglement in the context of a psychologically based taxonomy (Kuhn, Caffaratti, Teszka & Rensink, 2014) may help explicate the durability of misdirection. Reducing the basis for success in magic tricks to differences in the allocation of covert attention versus overt attention simplifies the actual complexities and mechanisms involved in effective misdirection. In order to address this issue, Kuhn and colleagues propose using a psychologically based taxonomy of effective misdirection rather than the performance-based categorizations of past efforts. This new arrangement organizes misdirection based on two fundamental taxonomic principles: 1) the principle of maximal mechanism, where the taxonomy incorporates as many known psychological mechanisms and principles as possible, and 2) the principle of effect priority, where the mechanisms being *affected* (underlying the *effect* of the magic trick) comprise the highest levels of the taxonomy. The mechanisms *controlling* these (underlying the *method* of the magic trick) become relevant only after exhausting the first set of mechanisms. As noted by Kuhn and colleagues, a psychologically based taxonomy of misdirection is advantageous because it can appropriate well-established terms and concepts from the behavioral sciences, thereby avoiding the issue of arbitrary or ambiguous categories. By making the link to known psychological mechanisms evident, it minimizes the effect of subjective elements. This taxonomy includes three types of misdirection, based on the kind of mechanism affected: 1) perceptual misdirection, 2) memory misdirection, and 3) reasoning misdirection.

Participants choosing the predetermined outcome position at a rate of 91.07% confirm the inertia of their strategy—track the target card to the exclusion of everything else, even after encountering misdirection. Therefore, the 3-card Monte likely operates based on different kinds of misdirection simultaneously targeting several cognitive mechanisms at once, rather than simply through the manipulation of covert attention. Based on the psychologically based taxonomy, perceptual misdirection and reasoning misdirection are the most likely methods. The mechanisms targeted by *perceptual* misdirection are: 1) control of attentional focus through a physical, external/reflexive trigger (the visually salient red target card as opposed to the two black dummy cards) and an internal/contextual trigger (explicit instruction to track the red target card through the shuffle), as well as by implicit control (the same sequence of events across videos rendering the “boring” actions invisible) and motivational control (e.g., an increase in the shuffling speed in some of the videos acting as a red herring); 2) control of attentional timing through physical and semantic cues (gathering the cards versus shuffling) and; 3) control of attentional resources (“keep your eyes on the prize”). The *reasoning* misdirection include: 1) a ruse (e.g., throwing down a card especially hard during the

Bent shuffles); 2) feigning actions (e.g., gathering up the cards while actually making a switch) and most importantly; 3) wrong assumptions ("this is a fair game"). Based on our results, the 3-card Monte seems to heavily utilize reasoning misdirection, i.e., the Monte may be rigged, but participants think that the game can be beaten if they stick to the strategy they know works—at least some of the time.

4.4 Complementary solutions from behavioral economics

In fact, an even simpler explanation accounting for this kind of risk-averse behavior exists in behavioral economics. Prospect theory states individuals make decisions based on the potential value of losses versus gains rather than the final outcome (Kahneman & Tversky, 1979), suggesting our participants fear trying and failing more so than gaining satisfaction from being right—sometimes. That is, the utility of normally observing the magic trick is greater than the utility of trying to figure it out and maybe missing the show, because the utility of extra credit far outweighs the mental effort necessary to deconstruct a magic trick in the tens of seconds of viewing time (even with multiple viewings). Indeed, individuals generally prefer to avoid losses rather than make gains (Kahneman & Tverksy, 1984) and loss is felt twice as deeply as a similar sized gain (Tverksy & Kahneman, 1992).

By failing to notice misdirection, participants frame the magic trick in a positive light, meaning they become more risk averse to disrupting their enjoyment or observation of the performance (Tversky & Kahneman, 1981). Hence, they stick to the same attentional strategy and decision-making behavior trial after trial. In this instance, framing the 3-card Monte in a negative light, e.g., as a swindle or a scam, would have elicited a more risk seeking behavior such as looking at the magician's hands rather than the cards (leading to the discovery of misdirection) or deliberately choosing a different card during selection (leading to the correct answer). Therefore, our participants may be overestimating the potential loss from guessing incorrectly. Aiding this cognitive bias is the inclusion of a decision-making component at the end of the trick. The requirement of a choice creates a risk of loss, no matter how small. Taking a risk requires courage, but taking a risk when there is already a proven solution requires even more courage, or rather—a greater incentive. There is a strong *Einstellung* effect at play—using a familiar solution in lieu of more efficient solutions (Luchins, 1942), e.g., filing income tax returns by post instead of filing online. Thus, given a pre-existing solution, our participants may have felt less motivated to search for alternative strategies to combat misdirection, not knowing where to even begin.

4.5 Misdirection as cognitive problem solving

Ergo, the durability of misdirection in the 3-card Monte may stem from a lack of an ability or opportunity to generate alternative solutions: individuals often process events based on expectations rather than transcribe an objective recording of physical reality. Numerous studies have provided compelling evidence that expectation affects perception even at the neural level (Bunzeck, Wuestenberg, Lutz, Heinze, & Jancke, 2005) as well as the detection of unexpected stimulus (White & Davies, 2008). If the participant believes the shuffle was just too quick, or that they merely lost sight of the target for a moment as the reason for their failure, then wrong answers may instead reinforce their adherence to the *de facto* strategy. However, participants seem aware of misdirection in the current study and have nothing to lose—it seems strange they wouldn't try to change up their attentional strategy, e.g., looking for a sleight of hand maneuver that switches the target instead of looking at the target itself. Risk aversion explains some of this behavior. Yet, when individuals expect a particular result, they tend to block out other possibilities and exclude important aspects afforded by the scene (Rohenkohl, Gould, Pessoa & Nobre, 2014).

The durability of misdirection in the 3-card Monte likely exists as a kind of cognitive illusion—that of a fair game of skill. Making sense of feedback when it differs from expectation requires a higher degree of cognitive processing, e.g., restructuring of the problem. In fact, any problem can conceivably be solved with or without restructuring, i.e., with or without insight, depending on whether a constraint in problem representation exists through prior knowledge (Bowden, Jung-Beeman, Fleck & Kounios, 2005). Thus, participants watching the 3-card Monte could have restructured their thinking to accommodate the possibility of misdirection, that their typical attentional strategy isn't the best attentional strategy. In fact, considering they knew they would be watching a magic trick, they should have expected misdirection from the beginning. Danek and colleagues (2014) demonstrate that magic tricks could be solved either with or without insight, allowing for a direct comparison in differential problem solving processes without changing the task type or stimuli utilized. Individuals who are good at solving insight problems are also good at switching attention, whereas they are not necessarily as good at tasks requiring selective or sustained attention (Murray & Byrne, 2005). In addition, solving insight problems may require individuals to switch their attention between several alternative possibilities in mind.

4.6 Final words

Therefore, poor performance in the 3-card Monte could reflect a kind of *cognitive fixedness* on beating the game as one of fairness and skill. This mental parallel to Gestalt psychology's functional fixedness with physical objects—as defined by Duncker (1945): "a cognitive bias where an individual possesses a mental block against using an object in a new way that is required to solve a problem"—encapsulates the phenomenon of using the same cognitive strategy every time despite immediate feedback, thus failing to beat the 3-card Monte. Misdirection persists under this expectation as participants misallocate visual attention and adhere to the *de facto* strategy, lacking viable alternatives such as knowing how to recognize a sleight of hand maneuver. As long as participants believe they can beat the 3-card Monte only one way, i.e., by keeping a closer eye on the target card, then the durability of misdirection is more like a cognitive problem rather than a dysfunction of covert attention allocation. Focused attention is needed to see changes in the scene (Rensink, 2000a). Participants are likely focusing all their attention on tracking the target, to the neglect of other important details or changes in the scene (Simons & Chabris, 1999). Here, the right viewing strategy is to take a step back from the target and look at the scene holistically, and especially at the magician's hands. Without revealing any secrets, there is a way to detect misdirection since every instance of sleight of hand occurs onscreen and is noticeable.

This type of misdirection would be most effective with magic tricks that provide an initial frame of reference on how to view the performance, or require a belief in fairness or regularity in presentation with multiple possible answers. Basically, any magic trick that requires careful overt attention to detail with a number of potential correct answers could resist multiple viewings and maintain its misdirection, whereas a magic trick that requires a redirection of covert attention with less dynamic or moving visual elements would likely be discovered upon a second viewing. Indeed, misdirection in the 3-card Monte may take advantage of a *forest for the trees* phenomenon. The participant, vigilantly tracking every movement of the target does not realize she may be stuck using the wrong visual search strategy, failing to switch attention to a different aspect of the scene, e.g., the magician’s hands during shuffling rather than the target being shuffled. The fact that participants seem to stick to one particular strategy may also stem from risk-aversion, i.e., an unwillingness to try a different strategy in lieu of one that works 100% of the time—sometimes. If multiple incorrect answers do not force the participant to attack the task differently, then restructuring of the task does not occur and misdirection remains durable.

Chapter 5: Conclusion

The analyses paint a compelling picture: participants drastically fail to counter misdirection even after multiple encounters. The similar viewing patterns during feedback for Normal and Sleight-of-Hand conditions suggest participants generally have no idea whether or not misdirection was used in the shuffle. However, decreasing pupil dilations and shorter latencies were present as trials progressed, indicating participants are at least aware of and expect misdirection. A restructuring of the reason for poor accuracy—that the game is rigged and simply tracking the target is the wrong strategy—by the observer may lead to an insightful solution and subsequent reconfiguration of visual search strategy to discovering the solution, i.e., detecting the sleight of hand in the 3-card Monte by switching attention to different aspects of the scene. Ignoring this possibility may lead to an inertia of strategy in the face of poor accuracy due to risk aversion. An explanation of *cognitive fixedness* in the context of a psychologically based taxonomy of misdirection is offered to account for the resistance to changing behaviour that ensured the durability of misdirection. Preconceived notions about a magic trick may narrow perception to exclude important aspects of the scene from attention. Indeed, stressful situations often force individuals to offer solutions before all available alternatives are systematically considered (Keinan, 1987). Lacking alternative strategies, participants stick to what they know to be true—following the target guarantees correct answers some of the time. Therefore, durable misdirection likely involves manipulating the cognitive framework of the audience and taking advantage of pre-existing cognitive biases rather than primarily manipulating covert attention.

There are caveats to the methodology: Monte Version was not counterbalanced, which will be addressed in future studies. In addition, the quantification of ocular behavior may be expressed in multiple different measures. As such, the scope of our investigation—particular types of gaze fixation data and pupillometry—is limited in fully understanding the entire range of cognitive mechanisms in play during magic perception. Indeed, replication with a much larger sample size would be a prudent first step to ensure that the observed effects extend to the general populace. Nevertheless, these findings enhance our understanding of continued and effective misdirection. Additionally, it presents misdirection as an effective multimodal paradigm to study attention. Expanding upon this line of research could prove invaluable in consolidating the mechanisms underlying endogenous control of attention, as well as information processing and validation. Our experimental results demonstrate the durability of misdirection and suggest proper covert attention allocation may only explain a portion of the efficacy of misdirection. Our results indicate that participants are aware of misdirection, although they could not counter it, nor did it lead to a subsequent reconfiguration of their overt visual strategy. In particular, the 3-card Monte has been tested to be an effective paradigm for studying misdirection—overall, the present thesis adds to the growing literature on visual attention and cognitive processing in the realm of magic perception.

Chapter 6: References

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