Review

Towards a science of magic

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It is argued here that cognitive science currently neglects an important source of insight into the human mind: the effects created by magicians. Over the centuries, magicians have learned how to perform acts that are perceived as defying the laws of nature, and that induce a strong sense of wonder. This article argues that the time has come to examine the scientific bases behind such phenomena, and to create a science of magic linked to relevant areas of cognitive science. Concrete examples are taken from three areas of magic: the ability to control attention, to distort perception, and to influence choice. It is shown how such knowledge can help develop new tools and indicate new avenues of research into human perception and cognition.

Introduction

Imagine a ball tossed into the air that suddenly disappears. Or someone uncannily predicting exactly what you will do in the next few minutes. These fantastical scenarios exist not only in science fiction but are also experienced by anyone who has ever witnessed a skilful conjurer in action. Over the centuries, magicians have learned how to perform acts that are perceived as defying the laws of physics and logic, leaving an audience baffled and amazed [1]. Yet there is nothing otherworldly about these effects – they are created entirely by natural means (Box 1).

We argue here that there is great scientific potential in studying the ways that most people can be made to believe in such 'impossible' events, even if only for a few seconds. In particular, we argue that the effects by magicians can provide us with valuable tools to investigate human perception and cognition. Although a few attempts were made in the distant past to draw links between magic and human cognition [2], this knowledge has been largely neglected by modern psychology. We propose that the time has come to examine these phenomena more closely, and to connect them to current theories and methodologies for exploring the human mind.

The history of science has shown that theories often stem from knowledge obtained from practical applications – for example, thermodynamics from the development of steam engines [3]. We argue that a similar situation exists here: over the centuries, magicians have accumulated considerable knowledge about inducing striking effects on human observers. We believe that this knowledge can be systematized and used as a source of insight into mechanisms that are central to human perception and cognition. In addition, these effects can also lead to the development of new methodological techniques to investigate the relevant processes. We will illustrate these points by examining three general methods used by magicians: misdirection, illusion and forcing.

Misdirection

There is a common belief that magicians hide their methods (i.e. the techniques used) by relying on speed. But it is simply false that 'the hand is quicker than the eye': most manipulations are carried out at a normal pace. Rather than relying on speed, the success of an effect (i.e. the experience of the spectator) usually relies on misdirection (the diversion of attention away from its method) so that the audience does not notice how it was produced.

This reliance on misdirection to achieve 'invisibility' is closely related to recent findings in vision science that only a small part of the information that enters our eyes – the part that is attended – enters our conscious awareness [4–6]. Magicians have known this for centuries, and have accumulated considerable practical knowledge about how to control the relevant mechanisms [7–9]. They have proposed a framework that distinguishes between physical misdirection, based on the physical properties of the stimulus, and psychological misdirection, based on control of higher level expectations.

Physical misdirection

Physical misdirection refers to the control of attention via stimulus properties; this is similar to the concept of exogenous control found in psychology, in which certain stimulus properties automatically capture our attention [10,11]. The goal is to create areas of high interest that capture the spectator's attention, while the method is covertly carried out in an area of low interest. A wide range of techniques have been found to be effective. For example, an important rule in magic states that the audience will look where the magician is looking. This has an interesting connection to recent work showing that eye gaze leads to automatic shifts of visual attention [12,13]. Stimulus properties such as movement, high contrast and novelty are also regarded as important; this also has been found in recent empirical studies [10,14]. Although many such cues have already been investigated scientifically, the magician's use of them indicates that they will have considerably more power when combined correctly (Box 2).

Many methods involve attentional capture, in which attention is pulled away by an irrelevant task [10]. These could be used to improve our understanding of how capture operates. For example, psychologists so far have focused on

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Box 1. An introduction to magic

What is magic?

At heart, magic is about producing a sense of wonder in the spectator. The performance of magic requires a method (how the trick works) to achieve an effect (what the spectator sees). Successful magic relies on the spectator experiencing an effect while being unaware of the method [9]. For example, the effect might be the disappearance of a coin, with the method a concealment of the coin in one hand rather than an actual transfer from one hand to the other. One of the central aims in magic is to prevent the audience from detecting this method. If this is done successfully, the spectator can be made to experience effects beyond anything that could occur in everyday life.

Why does magic work?

Much of human cognition relies on assumptions about the world. For example, object permanence assumes that objects continue to exist even when they are no longer visible. Although such assumptions are often correct, they sometimes are not, leading to erroneous conclusions that require considerable effort to overcome. A skilled conjurer can manipulate these assumptions, leading to a result that is entirely inconsistent with what actually occurred (B.A. Parris *et al.*, unpublished). The illusions created by the conjurer are not that different from the tricks the mind plays on us in everyday life, which most of the time go unnoticed. For example, our subjective experience of colour is not only determined by the physical proprieties of the object itself but also by the colour of the neighbouring objects, a phenomenon known as colour constancy. What magicians have done is find ways that enhance the power of these illusions and point out the discrepancy between our subjective perception and reality in often theatrical and dramatic ways.

What do magicians know about cognition?

Successful conjuring requires a solid understanding of human cognition. Although the magicians' motives could differ from those of scientists, the methods that have led to this knowledge are similar. Any serious magician has a theory about how to deceive his or her audience. If this theory is wrong, the magic trick will fail and the audience will spot the secret. A magician hoping for future engagements must, therefore, learn from such failures and change the trick in order to improve its effectiveness. As such, each performance can be viewed as an experiment that tests the magician's theory; this theory being continually revised until it agrees with experience.

Years of such testing enables a magician to learn much about human cognition. Moreover, much of this knowledge is shared with fellow magicians and is passed on from one generation to the next, resulting in an extensive source of potentially valuable information. As we argue in the main text, psychologists and magicians should combine forces to better exploit and further develop this resource.

properties that capture attention in space, paying less attention to issues of time [11]. Magicians have found that control can also be achieved through repetition, or 'off beat' moments, which lead to a momentary relaxation (such as after a joke), during which the spectator's attentional 'hold' is relatively weak.

Magicians also use non-verbal signs such as body posture to manipulate the level of vigilance, which then affects attentional allocation. Slydini, for example, emphasized this as a way to create tension and relaxation, carrying out the method while relaxing in a chair, with the effects created while leaning forward [15]. Experiments based

Box 2. Misdirection

Kuhn and colleagues [16,17,32] investigated the mechanism behind misdirection by developing a special magic trick. The effect was the disappearing of a lighter and a cigarette; the method was for the magician to simply drop the items into their lap. Although the dropping cigarette was fully visible, misdirection prevented most of the observers from seeing this event. Moreover, detection of this event was not related to where people were looking, a phenomenon also encountered elsewhere [33].

How the misdirection works

Figure I shows a timeline of this trick. The area covered by the dotted circle represents the area of high interest, and the area in the solid circle represents the areas of low interest. A cigarette is removed from the packet and deliberately placed in the magician's mouth the wrong way round (1–7 s). The magician then pretends to light the cigarette (7 s). The flame creates a high luminance and attracts attention. Both the spectator and magician then notice this mistake, which raises the interest in the cigarette (8 s). The magician then turns the cigarette around, while keeping his gaze fixed on the cigarette and the hand manipulating it (8–9 s). During this manoeuvre, the hand holding the lighter is lowered to the tabletop and drops the lighter into the magician's lap. This dropping of the lighter happens in a low area of interest. The disappearing lighter is dramatically revealed by snapping his fingers and waving his hands (11 s).

The method for making the cigarette disappear relies on it being dropped into the lap. This action is fully visible, with the cigarette dropped from ~15 cm above the table top (11 s). Surprisingly, most participants did not see this: at the time the cigarette is dropped it is an area of low interest (the other hand is an area of high interest). In this case, the high interest is manipulated by three things: (i) surprise: the disappearance of the lighter automatically leads to interest, (ii) social cues: the magician looks at the hand that previously held the lighter and rotates his body in that direction, and (iii) movement and sound: at the time of the drop the magician snaps his fingers and waves his hand, thereby attracting attention (see supplementary video 1 for the clip of this trick).

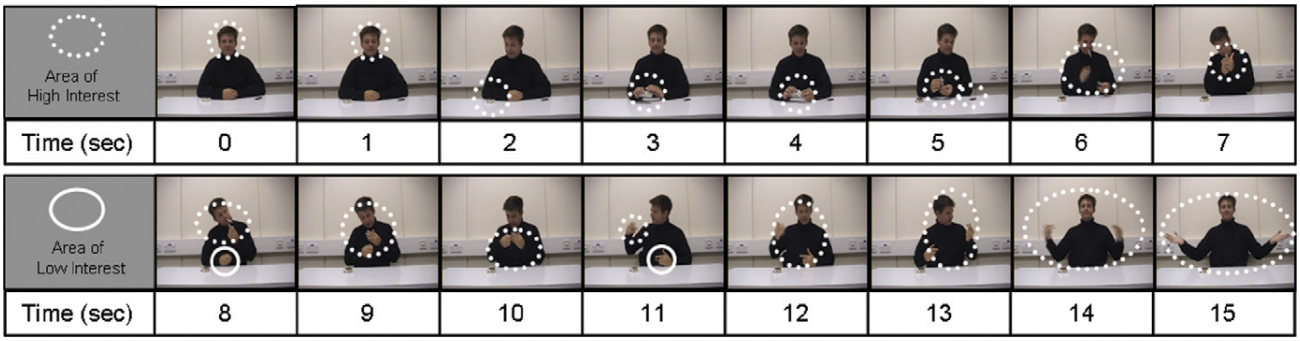

Figure I. A second by second breakdown of a misdirection trick.

on this form of attentional control could provide valuable insights into attentional modulation over time.

Psychological misdirection

Psychological misdirection controls spectators' attention by manipulating their expectations [8,9]; this is similar to the concept of endogenous control found in psychology, in which attentional orienting is determined by a person's goals and intentions [10,11]. The magician's aim is to reduce suspicion that a deceptive method has been used. For example, he could require a secret prop that needs to be hidden from view by putting it back into his pocket. If the action of putting his hand into his pocket seems normal and/or justified (e.g. he put his hand into his pocket on previous occasions), the action will cause far less suspicion and will therefore be far more likely to go unnoticed.

Another way of reducing suspicion is by keeping the audience in suspense as to what they are about to see. As long as the spectators do not know what to expect they will not know which aspects of the routine are important, and so will be unlikely to direct their attention to those aspects needed for the effect. Related to this, a key rule in magic states that magic tricks should never be repeated. Indeed, it has been shown that both repetition and prior knowledge about what the spectator will see increases the likelihood that the observer will detect the method [16,17].

Psychological misdirection can also be done via the false solution [18], which a magician will highlight in order to divert attention from the real solution. For example, a magician can pretend to have been caught out, so that the spectator will ignore all other less obvious solutions. Once the spectator has been sent down this garden path, this false solution can be revealed to be false. However, by this time, most of the tracks have been covered and he will find it difficult to discover the correct solution. This is probably related to the Einstellungs effect, the finding that once an idea comes to mind, alternatives are often not considered [19].

Illusion

Work in vision science has shown that much of vision is essentially a form of intelligent hallucination [20]. To perceive depth, for example, the visual system must recover the third dimension from the 2D image available on the retina. However, because multiple solutions are generally possible for a given image, the result must be obtained by applying assumptions of some kind. This approach, however, can sometimes lead to errors, which take the form of illusions. Two types of illusions are typically employed by magicians: optical, which involve physical factors, and cognitive, which involve psychological factors.

Optical illusions

Many conjuring tricks – especially those of the stage illusionist – involve optical illusions, which rely on tricks such

Box 3. Illusions

Several magical illusions rely on an impression of seeing something based on expectation rather than reality. Triplett [2] was the first psychologist to investigate this experimentally. In his vanishing ball illusion, the magician pretends to throw a ball in the air when in fact it remains concealed in his hand. Triplett performed this trick for school children; to his surprise, over half of them claimed to have seen the ball move up in the air and then disappear somewhere between the magician and the ceiling. As such, these children perceived an event simply because it was implied by the action.

More recently, Kuhn and Land [34] investigated this by recording participants' eye movements while they watched a video clip of the illusion. Two different versions were used. In one, the magician's gaze followed the imaginary ball towards the ceiling, whereas in the other he looked at his hand (Figure I). If effectiveness were mediated by social cues (i.e. where the magician was looking), more participants should recall seeing the ball move towards the top of the screen in the former condition. Indeed, results showed that, in this case, 68% of the observers claimed to have seen the ball moving towards the top of the screen, compared with only 32% in the other condition.

Note that, by investigating eye movements, we can also gain an online measure of the visual information being used [35]. Rather than merely looking at the ball, which was what most of the participants believed they were doing, eye recordings revealed that participants typically glanced at the face before fixating (the imaginary ball) at the top of the screen, thus demonstrating that the visual system itself made use of these social cues (see supplementary videos 2 and 3 for the clips of this trick).

Figure I. Two versions of the vanishing ball illusion. The magician throws a ball up in the air twice, after which he pretends to toss it, when in fact it remains secretly concealed in his hand. In the pro-illusion condition (top panel) the illusion is supported by the magician's social cues. In the anti-illusion condition (bottom panel), the illusion is not supported by the magician's social cues – instead of looking at the imaginary ball the magician stares at the hand concealing it.

as intricate mirror combinations and perspectives [8]. For example, by manipulating the perspective of an object, the true size of a box can be distorted, leaving plenty of room to hide an elephant inside [1]. Other techniques, such as Pepper's ghost illusion, use mirrors and special lighting to make an object appear and disappear in full view of the audience [1]. This effect can also be used to make one object seem to morph into another. Many of these illusions could be implemented as the basis for new forms of investigations into visual perception.

Cognitive illusions

Most sleight of hand magicians tend to rely on 'higher level' cognitive factors, rather than the 'smoke and mirrors' used by the stage illusionist. An example of this is the 'vanishing coin illusion'. Here, the spectator perceives the magician transferring a coin from one hand to the other, with the coin then vanishing. But in reality, the coin never changes hands – it is instead secretly concealed in the hand and so remains out of sight. The key to sleight of hand involves discovering the extent to which the 'false' action can be altered to make the spectators still feel they are seeing the 'real thing'. Interestingly, spectators often report having seen a 'real' event, even if it never took place (Box 3).

Why might such effects occur? The finite speed of neural transmission causes a delay of ~100 ms between stimulus arrival and conscious percept [21]. One way of compensating for this is to 'predict the present' [22] (i.e. predict the outcome of an event before it has been completely processed). This strategy is particularly useful in situations that require rapid response such as skilled driving [23] or sports [24]. But such predictions can also make us vulnerable to deception. Effects such as the vanishing coin illusion and the vanishing ball illusion (Box 3) are experienced whenever the available evidence is consistent with the prediction made by the spectator. Effects of this kind could serve as useful starting points for the empirical investigation of the subjective 'picture' experienced in visual perception.

Forcing

Imagine picking a card from a deck of playing cards. To your astonishment, you find that the magician has predicted your choice. Although you felt like your choice was free, in reality it was highly controlled. The process by which your choice can be systematically influenced is known as forcing. This process has interesting connections to recent work showing that observers often confabulate about the reasons for their choices [25].

Magicians have long known of this effect [1]. For example, they often construct a context that favours reflexive behaviour – for example, putting the spectator under considerable stress to act quickly. Once the spectator has committed to the forced choice, the stress is reduced, and the magician then emphasizes the freedom of the choice. Upon subsequent reflection, the spectator will generally 'remember' his or her choice as being completely free.

Magicians typically use two different types of force. The physical force influences a spectator's selection when asked to physically select an object, such as picking a card. The mental force influences the choice of a spectator who is instructed to think of an item. In both cases, the key is to create appropriate assumptions, and to avoid having the spectator become aware of the fact that his or her choice was controlled.

Physical force

When asked to physically select a card from a shuffled deck, spectators have various assumptions: the deck contains 52 distinct cards, all are equally available for selection, and the magician has no control over them. However, a magician could have a deck that contains several eight of spades, dramatically increasing the likelihood of that card being selected. The set of cards displayed could also be reduced, affecting the likelihood of selection. Finally, a practiced magician can use sleight of hand to control the order of the cards, enabling them to later be forced upon the spectator, who has assumed that they have been randomly shuffled.

Mental force

In the case of mental force, the spectator is asked to simply think of a card; the magician then manipulates the presentation of the cards so as to favour a particular choice. Traditionally, this is accomplished by giving a certain card in the deck a longer exposure. A strong relationship between the likelihood of card being chosen and the length of its exposure has been found (A. Amlani *et al.*, unpublished).

The mechanisms underlying mental force are currently unclear. This type of effect resembles the way an observer's behaviour can be influenced by subliminally presented stimuli. But, whereas the field of subliminal perception is plagued with small effects [26], the magician's force is generally quite powerful and robust. As such, it could suggest a better way to investigate nonconscious perception.

Successful forcing is achieved not only by providing the spectator with assumptions but also by taking care that the spectator is subsequently given no evidence that these have been violated. Magicians exploit the formation of false memories by providing the spectator with false information. For example, a magician could falsely indicate that the cards were shuffled by the spectator rather than the magician, enhancing the impression that the selection was truly fair. Such effects could have potential for investigating the formation and distortion of human memory [27].

Potential developments

In this article we have argued that there is a shared interest between magicians and cognitive scientists in understanding human perception and cognition. It should be kept in mind that the effects discussed here are only a fraction of those available. For example, in the 'cut and restored rope trick', a rope is cut in half, after which the two ends are magically combined. Other tricks involve extraordinary mental feats such as vast memory capacities, or rapid mental calculation. To date, few of these effects have been explored scientifically, and few of the mechanisms involved are well understood.

More generally, rather than argue that researchers consider only the particular examples discussed here, we argue that they take seriously the general practice of

Box 4. Outstanding questions

- Misdirection relies on combining various cues to enable an extremely powerful way to control attention. How do these cues work, both in isolation and when interacting with one another?
- Magicians tend to stage-manage the performance environment so as to enhance the effectiveness of their illusions, such as using special lighting or exceptional cognitive demands. Why do these manipulations work? Do the principles involved apply only to high-level processes, or to more low-level processes as well?
- Magicians can convince us that they are doing one thing when in fact they are doing something entirely different. In the vanishing coin illusion, for example, the magician pretends to pick up the coin while it actually remains in the other hand. How is it possible for magicians to deceive us so convincingly? What are the mechanisms involved?
- Could the ability to fall for a magic trick give us insight as to the cognitive style or attentional capacity of an observer? For example, if there was a trick that is usually caught when seen a second time, what would this indicate about someone who was still fooled by this trick? If the method for one trick is discovered, to what extent does it affect the perception of related tricks?
- A science of magic could highlight those effects that cannot be completely explained in terms of known perceptual and cognitive mechanisms. What are these? What could be said about the possible mechanisms involved?

magic. Both magic and psychology could learn much from each other. Ideally, this could be done via a 'science of magic', which would explain all known magic effects in terms of known perceptual and cognitive mechanisms. Such a science might be able to reduce all known magic effects to a set of basic operations (such as physical and psychological misdirection), which are relatively well understood; any effects not reducible this way would indicate the existence of an unknown perceptual or cognitive mechanism (Box 4). Conversely, such a development might also suggest new kinds of magic effects, based on perceptual mechanisms different from those normally drawn upon.

The development of a science of magic could also have important practical applications. For example, human–computer interactions might be made easier and more transparent if the users' attention is guided so that they effortlessly 'do the right thing'. Most of the methods used for attentional misdirection have been shown to stand up in the real world, influencing spectators of all genders, ages and cultures. It is, therefore, likely that some of these methods could be harnessed for this purpose. In particular, the techniques of psychological misdirection used in showmanship could be useful for this [28], as could the techniques of physical misdirection, forming the basis of 'coercive graphics' that would make a user simply see (or not see) particular aspects of a display [29,30].

Likewise, what is learned about forcing a spectator's choice could have applications to decision making [31]. For example, the concept of choice lies at the heart of the advertising industry. Many of the techniques used in advertising and political propaganda resemble the methods of the magician. Because there will always be motives for manipulating our choice, an important challenge for the future will be to understand these techniques sufficiently to ensure our free will. A magician's force relies on the spectator being unaware that his or her choice is being manipulated. A science of magic could provide us with valuable ammunition in this regard.

One last point. Magic is one of the oldest art forms, and relies on people's ignorance of its methods. Although these methods can prove valuable to the scientist, care should be taken in using these techniques as a way of investigating the mind without destroying the necessary mysteries and secrets that give us so much joy.

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Supplementary data

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