Using Magic as a Vehicle to Elucidate Attention

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Attention, the awareness and selection of elements in our physical or mental environments, is a central concept in neuroscience. Michael I Posner and colleagues have proposed a three-network model of attention. 'Alerting' involves increased readiness for immanent stimuli, 'orienting' refers to selecting amid various stimuli; whereas 'executive attention' links attention to decision making, planning and other higher cognitive functions. Though ignorant of the neural mechanisms underlying human attention, magicians are skilled at exploiting human attention to achieve their effects. Recent interest in the neuroscience of magic has built bridges between the practice of magic and the study of attention. However, beyond illustrating how our attention systems can be tricked, magic can be employed in research to explore otherwise unachievable conditions. Such methods provide a unique opportunity to study atypical attention, providing important insights into the function of human attention and other key cognitive domains.

Introduction

Attention refers to the preparedness for and selection of certain aspects of our physical environment, such as objects, or some ideas in our mind which are stored in memory. As such, attention has many faces and has been a pivotal theme in psychological science. Cognitive neuroscientists increasingly construe attention as disparate control networks, which correlate with discrete neural circuitry and respond to focal brain injuries, specific drugs and mental states. It is possible to tease apart from these varieties of attention and elucidate their individual development and function. On the one hand, illuminating the neural correlates of attention exemplifies the links between brain and behaviour and binds psychology to the techniques of neuroscience. On the other hand, it shows how it is possible to illuminate different aspects of attention using disparate approaches. In this chapter we sketch how investigators and magicians interpret attention as an organ system and as a vehicle to an art form, respectively. The way a researcher and a magician approach attention provides complementary perspectives on the varieties of attention and serves to elucidate the correspondence between a psychological phenomenon and its neural underpinnings.

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Attention and Magic

'Everyone knows what attention is ...' wrote William James, the American father of modern psychology, in his seminal 1890 volume *Principles of Psychology*. He described attention as 'the taking possession by the mind in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought ... It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state'. James' account heavily joins attention with subjective experience. Moreover, James' effort to deal with both attention to objects and attention to 'trains of thought' is important for understanding current approaches to sensory orienting and executive control. Attention in the sense of orienting to sensory objects, however, can actually be involuntary and occur unconsciously. Furthermore, as any neophyte magician knows, paying attention is not the same as being aware.

According to another famous James – James Randi, an accomplished magician, writer-educator and a vociferous skeptic – magicians are 'honest liars', actors who use an arsenal of techniques, including attentional diversion, to accomplish their entertaining effects. Although, magicians have been exploiting the vagaries of attention to trick their audiences for thousands of years, scientists have been studying the psychology of attention and unravelling its underlying mechanisms for a little over a mere century.

The study of attention has turned into one of the oldest and most central issues in psychological science. Investigators have learned a great deal about what attention is, what it does and how it works. Attention refers to both external and internal information. Unlike William James, however, we are less sanguine today that '[e]veryone knows what attention is …' especially as the scientific literature grows exponentially and continues to unravel the neural and psychological substrates of attention. Both before and after William James, great scientists and philosophers have grappled with the study of attention, but he was probably one of the first to broach the concept of *attentional varieties*, challenging a monolithic conception of attention and recognizing the existence of different shades of attention rather than one unitary form.

Several researchers have followed in James' footsteps and suggested multiple components to describe attention. In this chapter, we will show how one of the most influential models in the field of attention illustrates the crosstalk between the science of attention and the art of magic.

Features of Attention

Before jumping into an in-depth description of any specific model of attention, it is helpful to appreciate a few of its gross characteristics. These qualities may seem intuitive, but intuition can be specious, especially when dealing with both attention and magic.

Attention can apply to various areas of the visual field and can change the detail with which we look at any given area. For example, you can look at this page and pay attention to its appearance as a whole, or you can zoom in on specific words and certain letters therein. If you are paying attention to single characters, you can glean a lot of information about punctuation marks, catch typos and even spot minute imperfections on the physical paper. But in that case, you may miss the main idea of a paragraph. Thus, we can change the location of attention as well as the size of the attention focus. Beware of using cliché appellations, such as 'zoom lens' or 'attention spotlight', to describe attention. These metaphors may be useful in that they relate to our common experience concerning the kind of attention we use (e.g. for reading versus proofreading), but they are just metaphors.

Attention can be either overt or covert. Overt attention involves looking directly at the scene of interest. We usually look straight at what we wish to attend. Sometimes, however, attending to a location different from fixation is advantageous. Covert attention is the ability to select visual information at a cued location, without moving the eyes to study it directly, and to grant such information priority in processing. For example, we often engage in covert attention in social situations when we want to examine a person without being overly conspicuous. Note, however, that covert attention is not the same as daydreaming. Thus, looking at something is not the same as paying attention to it.

Attention often involves selection. For example, think of when multiple people talk simultaneously and you try to hone in on one of these streams of conversation, to follow it in detail (e.g. at a party). You can do it based on the location of the person by visually orienting towards her or locking on her frequency of voice – it is easier to separate a female voice from a male voice than it is to separate two male voices – or you may follow by content. When we attend to one input stream, the unattended information goes into the background; although present, it rarely receives the same focal analysis.

The brain processes unattended information in subtle and complicated ways. Unattended information can suddenly get interesting because your name or another particularly charged word is present, or because something happens that is related to the conversation you are following, and you find yourself orienting to the new information. Experimental psychologists have studied these phenomena in great detail and have elucidated some of the mechanisms subserving them as well as the computations that such data receive.

Attention can also influence perception and mental processes. For example, an individual reading an engrossing book may fail to identify certain environmental cues. Similarly, attention can aid perception. Improvement in perception, however, is not synonymous with altered thresholds for detection, better performance or faster reaction times. Cognitive scientists draw a distinction between how attention may be useful for simple detection of events versus how performance can improve at those events.

Attention and perception interact in complicated ways. For example, visual attention can give priority to stimuli appearing at a specific physical location, but it cannot substitute for the acuity provided by the fovea. Although the fovea is critical for visual acuity, the costs in latency for an unexpected foveal stimulus are just as great as for an unexpected peripheral event. In other words, visual attention does not compensate for visual acuity. Although performance may improve on increased attention investment, controversy persists over what orienting attention to a sensory stimulus actually does. General agreement posits that attention provides priority, so that reaction time to the attended stimulus is usually faster. Thus, visual attention influences priority or processing preference. This characteristic of attention applies to other attention modalities such as hearing.

The neural basis of visual attention has been studied extensively. Single-unit recordings in monkey visual processing areas demonstrate how stimuli compete for attention in the visual modality (Duncan, 1998). Recent research describes the specific relationship between attention and activity of visual neurons in V1 (Chen *et al.*, 2008). Attention also modulates processing in later visual areas. For example, in area V4, attention differentially alters response to relevant and distracter stimuli by influencing centre-surround mechanisms (Sundberg *et al*., 2009). Primate studies have therefore been instructive regarding the specific effects of attention on neurons in visual cortexes. **See also**: Visual System

A Three-network Model of Attention

In line with William James' early notion of distinct attentional varieties, Michael I Posner and his colleagues have proposed a modern model of attention wherein at least three main functionally and anatomically distinct types of supramodal attention varieties cooperate and work closely together (see **Box 1**):

Alerting refers to the increase and maintenance of response readiness in preparation for an imminent stimulus (**Figure 1**). Roughly equivalent to sustained attention and vigilance, alerting is probably a more foundational form of attention on which other attentional functions rest. Without putting too fine a point on it, however, alerting is typically task-specific rather than a general cognitive control of arousal. Modern experimentalists have replaced the 'older' *vigilance tasks* by 'newer' *alerting tasks*, although some researchers argue that these two task-types tap different mechanisms. The relationship between alerting and arousal includes psychological variables such as stress that can further influence alerting, increasing or decreasing it as a function of specific context and task. In contrast to the in-depth studies of the other attention systems (i.e. orienting and executive control), alerting has been relatively understudied and attention research has yet to elucidate its neural substrates.

Orienting informs us where an important event is likely to occur (**Figure 2**). It is also the ability to select specific information among multiple sensory stimuli. Sometimes known as scanning or selection, it is the most studied attentional network. Whether overt or covert, orienting has traditionally been measured by reductions in reaction time to a target following a cue that gives information on the location, but not the timing, of an event. Scientists distinguish between exogenous orienting – when the flash of a cue automatically captures attention to a specific location – and endogenous orienting – when a central arrow points to one of the two lateralized target presentation locations.

A recent study elucidated the neural processes underlying scanning and reported that scanning tasks follow a 'grouping search algorithm' (Fan *et al*., 2008). Such

Box 1 Neuromodulators of Attention

Pharmacological findings relate each of the three attentional networks with specific chemical neuromodulators: the norepinepherine system, which arises in the locus coeruleus of the midbrain, functions in alerting; the cholinergic system, which arises in the basal forebrain, plays an important role in orienting through its effects in the parietal cortex, where it seems to reduce neural activity and reaction time cost associated with cueing to an invalid target; and the anterior cingulate cortex and lateral prefrontal cortex, involved in executive attention, are target areas of the mesocortical dopamine system. **See also**: Dopamine

Figure 1 Alerting. Adapted from Raz and Buhle (2006).

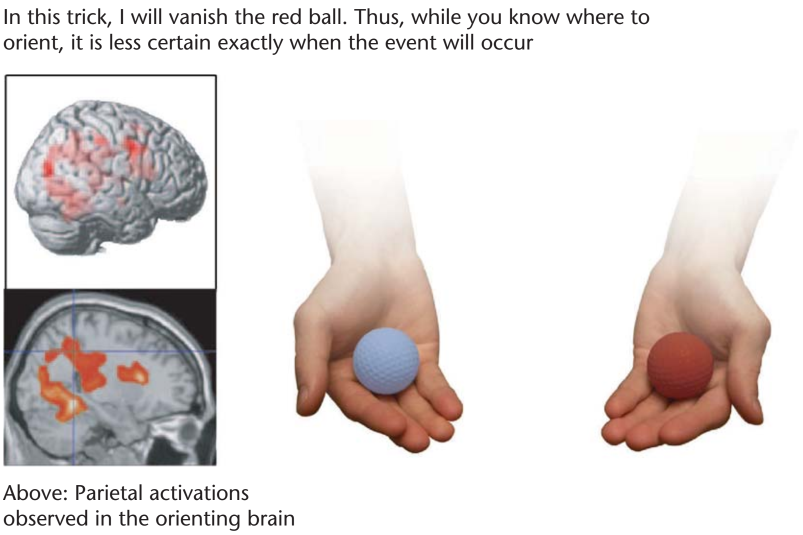

Figure 2 Orienting. Adapted from Raz and Buhle (2006).

processing putatively occurs involuntarily and unconsciously, with the end result being the conscious experiencing of an answer. Additional examination will likely further unlock which aspects of attention scanning are under one's control, and which are automatic processes.

Some researchers argue that at least part of the capacity subsumed by alerting is conceptualized as orienting in the temporal domain. The bulk of the evidence, however, supports the notion that orienting and alerting are largely controlled by different brain systems. Although most research in orienting has been conducted using the visual modality, neural activity increases in response to an orienting cue and concomitant performance enhancement have been demonstrated in most sensory systems. Some researchers suggest that orienting may encompass not only sensory, but also purely mental events, including memory. Recent work has shown an orienting effect for a variety of internal representations, including items stored in *working memory* and *long-term memory*.

It is possible to increase the efficiency of a specific attention network by focal training. For example, several rehabilitation programmes for patients with specific impairments of the orienting system involve expressly tailored attention exercises. Attention training has also been used in early child education to improve *self-regulation*. This form of attention operates in close coordination with working memory in many cognitive tasks (see www.teach-the-brain.org/learn/attention). Many studies have shown that children between the ages of approximately 3 and 7 develop a brain network that allows them to regulate their thoughts and emotions.

Executive attention typically relates to conflict of the kind you encounter when trying not to scratch a particularly itchy mosquito bite or when confronted with two police officers who demand that you comply with contrasting orders (**Figure 3**). In general, executive functions pertain to planning or decision making, error detection, novel or not well-learned responses, conditions judged to be difficult or dangerous, regulation of thoughts and feelings and overcoming habitual actions. Although some may consider any instance of *top-down control* as an executive attention, others construe it as the monitoring and resolution of conflict between computations in different neural areas. Executive attention is typically measured using experimental tasks where one is faced with an incompatibility between dimensions of the stimulus or response.

Whether and to what extent executive attention governs the other attentional networks remains unclear. A more successful effort has related concepts such as *emotion-regulation*, self-regulation, *effortful control* and *inhibitory control* to executive attention. These findings collectively reveal that attention is a strong modulator of emotion, cognition, thought and action. For example, recent findings elucidate several aspects of the influence of attention training on executive attention in young children, drawing on measures of brain activity, cognition and behaviour in children as early as four year of age. These measures include behavioural assessments of executive attention and intelligence, genotyping of dopamine-related genes, recording electrical activity at the scalp generated by neuronal function and parental questionnaires relating to the child's temperament. This training programme – adapted to be child-friendly from a method originally used to prepare macaque monkeys for space travel – was given for five days over a two- to three-week period and resulted in great attention improvements, including increase in IQ and better self-regulation of affect and cognition. This approach potentially opens a new vista for experiments in developmental cognitive neuroscience in which genetics, brain function and behaviour can be related through the study of individual differences and demonstrates that executive attention skills can be trained. In addition, these

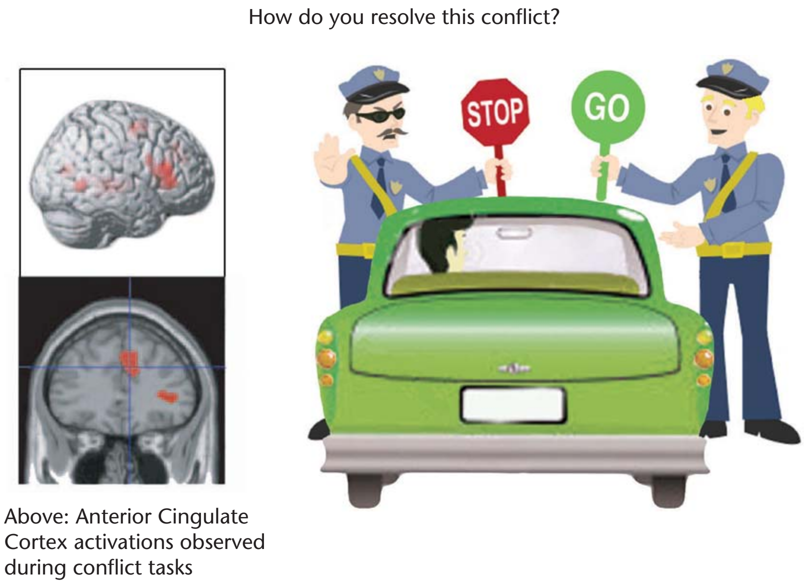

Figure 3 Conflict. Adapted from Raz and Buhle (2006).

findings could potentially lead to better intervention strategies for children with attention and other behavioural problems such as Attention-Deficit Hyperactivity Disorder (Raz, 2004) (**Box 2**).

Magicians as Clinicians

The arsenal of magic heavily draws on misdirection of attention (Lamont and Wiseman, 1999). Although, magicians have long been aware of ways to exploit the human visual system to affect illusions, scientists have recently uncovered the neural underpinnings of these processes. For example, differential responses in areas V1 and V5 can make a bouncing spoon appear to be bending (Macknik *et al*., 2008). In addition, after-images can provide magicians with a temporal window of approximately 100 ms to either vanish or produce objects (Martinez-Conde and Macknik, 2008).

Magic has been recruited as a lens to unravel diverse cognitive processes, including attention (Kuhn *et al*., 2008; Macknik *et al*., 2008). For centuries, magicians have been exploiting specific perceptual and cognitive processes to create remarkable effects. Furthermore, magicians have developed techniques which allow them to mask their methods in the minds of the audience (Sorensen, 2006). However, scientists have just begun to consider the art of magic as a foray into neurocognition. We highlight findings that illustrate this approach and sketch how studying magic can further pave the road to a more scientific understanding of attention.

Different taxonomies obfuscate the relationship between attention and magic. Disparate terminologies have surfaced as a function of the method (Kuhn *et al*., 2008), the effect obtained (Macknik *et al*., 2008) and the type of attention network (Raz, 2009). Misdirection can involve influencing the gaze of observers (i.e. overt attention) although magicians often achieve orienting effects without directing gaze (i.e. covert attention). A few scholars refer to controlling overt attention as 'physical misdirection' (Kuhn *et al*., 2008), whereas others call it 'overt misdirection' (Macknik *et al*., 2008); however, these two classifications are essentially one. In addition, Macknik *et al.* invoke the notion of 'bottom-up control of attention' intimating a form of physical misdirection. Kuhn *et al.* refer to the covert attention paradigm as 'psychological misdirection', whereas Macknik *et al.* call it 'covert misdirection'. It would be helpful, therefore, to have researchers work towards a common model of classification as this field moves forward.

Nascent research findings elucidate the neural correlates regulating overt attention in magic. Redirecting gaze exploits *change blindness*: the inability to notice differences in objects or scenes spanning short intervals (Simons and Levin, 1997, 1998). If change occurs during eye blinks, saccades or a brief lapse in scene viewing including interruption of gaze, observers typically claim to have neither seen nor experienced the difference that had transpired. Some researchers consider the way magicians exploit change blindness an instance of covert misdirection (Martinez-Conde and Macknik, 2008); however, interruption of gaze also disrupts overt attention. Indeed, interrupting attention in this way forces observers to compare two scenes. Richard Wiseman, for example, demonstrates this effect online (http://www.quirkology.com/USA/Video_ColourChangingTrick.shtml).

Without interrupting gaze, magicians often misdirect covert attention. Many effects exploit *inattentional blindness*, whereby individuals fail to perceive information in plain view because of a shift in the focus of attention

Box 2 Methods of Investigating Attention

Although attention had already been studied from a neurophysiological view in the 1890s, *mental chronometry* together with application of the subtraction method provided rich information on psychological processes. In the subtraction method, investigators compared reaction times in two experimental conditions, which allegedly differed only in that one was hypothesized to require an additional cognitive process. Differences in reaction time were then taken to support and index the putative additional process. By systemically varying cognitive processing, researchers developed intricate models of brain function, many of which were subsequently supported by neuroimaging studies. Reaction time assays were later combined with such mathematical formulations as formal information theory. However, because these methods were largely divorced from anatomical and neurobiological data, these approaches were deemed inadequate to elucidate the mechanisms whereby the human brain pays attention.

In the 1950s, the advent of microelectrode recordings of single neurons from laboratory animals, at first anesthetized but later awake, afforded examination of neurophysiological processes and supported the notion that the brain processes information in serial stages. Studies using awake monkeys revealed ‘control systems’ – the terminological precursor to ‘attention networks’ – where higher brain areas feed back their influence onto earlier processing stages. This *top-down effect* challenged the then-common view of a completely serial approach to information processing, and provided evidence for focal brain areas within the monkey parietal lobe that could be systematically related to processing operations involved in attention. These ideas were extended to humans and tested using reaction-time paradigms in neuropsychological patients.

The arrival of analogue and then digital computers in the 1960s initiated the field of neuroimaging by recording the average electrical *event-related potentials* (ERPs) from scalp electrodes. Electrophysiology became an ideal tool to explore the notion of ‘attention for action’, which is characterized by millisecond resolution, and ERP components were systematically related to sensory and motor stages of information processing. In the late 1980s, neuroimaging experiments made possible the examination of activity in localized brain areas — first through the use of injected radio-nuclides detected by *positron emission tomography (PET)* and later through the use of an externally imposed magnetic field in *functional magnetic resonance imaging (fMRI)*. Over the past decade, fMRI has improved in spatial and temporal resolution and can now provide accurate spatial information of focal brain areas that are involved in cognitive tasks such as attention. Recently, the inferences obtained from both ERPs and *magnetoencephalography (MEG)*, which probe perceptual processing with fine temporal detail, have been important complements to the millimeteric spatial resolution of fMRI. **See also**: Brain Imaging: Localization of Brain Functions; Brain Imaging: Observing Ongoing Neural Activity

Recently, neuroimaging technology has been joined by genomics. Over the past decade, the Human Genome Project has made great progress in identifying the 30 000 protean genes in the human genome as well as the approximately 1.7 million polymorphic sites scattered across the 6 billion base pair length of the human genome. These findings hold promising prospects for illuminating how genes can influence disease development and may aid in the association of genes with particular psychopathology. In addition, genomics has the potential to promote the discovery of new treatments and to afford new insights into behavioural genetics, such as the relationship between certain genetic configurations and manifest behaviour. Combining neuroimaging with genetics, recent exploratory assays endeavoured to noninvasively probe genes that have been shown to result in variation in protein levels or biochemical activity in the context of both typical and atypical attention (see **Box 3**). Such pooled research efforts promise to elucidate both the neural and genetic correlates of attention.

Findings from genetic and neuroimaging studies of attention have provided some converging results. Although, most neuroimaging studies yield a small number of widely distributed brain areas that must be orchestrated to carry out a cognitive task, it is often unclear what the unique contribution of each area might be. However, in the case of attention, as in the case for language, these mechanisms have been sufficiently elucidated by a careful teasing apart based on chronometry, neuroimaging and genetics. Attention, therefore, is a primary research domain, which exemplifies the links between brain and behaviour and binds psychology to the techniques of neuroscience.

(Simons and Chabris, 1999). Furthermore, direction of gaze scarcely determines whether observers can decipher the modus operandi of a trick (Kuhn and Tatler, 2005). Vanishing objects typically draw on orienting of attention; expectation is one such tool. For example, having thrown a ball upwards a number of times, a performer repeats these motions again without actually throwing the ball. His upward glance, however, suggests that the ball has risen into the air, leading spectators to report that a ball has risen and then vanished even if they did not track its trajectory (Kuhn and Land, 2006). In addition to modulating covert attention by utilizing such social cues, magicians commonly hide key actions behind seemingly normal movements or entice the audience to turn their attention onto an irrelevant action (Kuhn *et al*., 2008; Macknik *et al*., 2008).

Psychological science binds attention and memory. Although typically directed outward, attention can also be turned inward to ideas or memories. Executive attention, for example, constitutes a form of working memory (Raz and Buhle, 2006) and attention training overlaps with working memory training (Klingberg *et al*., 2005; Rueda *et al*., 2005). Furthermore, the orienting network and working memory share genetic codes for similar

Box 3 Atypical Attention

A number of human practices, such as drug ingestion, meditation and hypnosis, can dramatically influence attention. Cognitive neuroscientists are beginning to unlock the ways these routines influence the human brain and how such effects alter common information processing. It is possible to test the limits of attentional functions by examining healthy individuals under atypical conditions. That more notice should be given to the investigation of healthy individuals driven towards the neuropsychological domain is evident in light of the contributions of social psychology to cognitive science, exploratory assays of evanescent attention deficits and the impact of reversible lesion research using *transcranial magnetic stimulation (TMS)*.

Cognitive neuroscientists generally agree that mental processes come in two varieties: controlled and automatic. Some processes are thought to be innately automatic; others become automatic through practice. General accounts posit that once automatized, these processes are initiated unintentionally, effortlessly, even ballistically and cannot be easily interrupted or prevented. For example, the *Stroop effect* suggests that reading words is an automatic process for a proficient reader. The standard account posits that words are processed automatically to the semantic level and that the Stroop effect is the 'gold standard' of automated performance. Although cognitive scientists have focused on the processes that lead to automatization with over 4000 citations to Stroop's original work alone, the question of whether it is possible to regain control over an automatic process is unanswered, and mostly unasked. However, mounting evidence from assays of atypical attention show that deautomatization is possible. A few meditative practices claim to achieve deautomatization with some sparse evidence of reduced Stroop interference. The most compelling findings addressing this issue recently showed that a specific *posthypnotic* suggestion reduced and even removed Stroop interference in highly hypnotizable individuals. Reduction of the Stroop effect occurred following reduction in anterior cingulated cortex activation and altered processing in an occipito-parietal location that might be related to the chunking of visual letters into words. Independent accounts under typical conditions also challenge the robustness of the Stroop effect. Although critiqued, interpretation of these and other results supports the idea that attention may be employed to derail automatic processes. Clinicians are often interested in this 'deautomatization' as a way to unlearn or free one from undesired habits. Such derailment of automaticity may also occur spontaneously in extreme situations (e.g. in combat individuals might not realize that they have been hurt until much later).

Other demonstrations of top-down modulation and deautomatization showed that following hypnotic instruction to view a coloured picture as greyscale, highly hypnotizable individuals demonstrated reduced activity in colour areas of the prestriate cortex. These studies show that atypical attention can influence at least executive attention and possibly some of the other attentional networks. Exploratory assays using other forms of atypical attention may further elucidate the malleability of attentional networks. For example, meditation training may be a way to induce a long-term baseline change in attentional function permitting individuals to achieve better, more effective self-regulation.

neurotransmitters (Fan *et al*., 2003; Raja *et al*., 2005). Thus, controlling attention can have powerful effects on memory and related processes.

Choices appear to result from planned cogitations, but *choice blindness* suggests that the retroactive construction of events is also a potent factor in decision making experiences (Johansson *et al*., 2008). Experimenters use sleight of hand to sometimes change choices that participants make when selecting one of the two choices. In such cases, the participants typically own the false 'choice', and provide motivations for it (Johansson *et al*., 2008; Moore and Haggard, 2008). Magicians often exploit this phenomenon by forcing various choices. This paradigm shift elucidates both how such tricks are possible and how researchers can use magic as an experimental tool. Utilizing magic as a vehicle to enhance the researcher's arsenal, therefore, can help reduce the cognitive processes involved in such tasks as decision making and authorship.

Atypical Attention and Magic

Scientists and magicians approach their trades differently. Although scientists focus on controlled condition and replication, magicians employ various techniques to achieve a single effect and will rarely repeat the same trick for a given audience. Scientists wish to uncover the underlying order and causal sequence of events. Magicians aim to conceal the true underlying causality. Inherent in each trade is an attitude towards the public. Scientists strive to inform; consumers of scientific information take what they read at face value. Conversely, magicians are all about deception. If we take what the magician shows us at face value, we will believe in the supernatural. Therefore, as scientists investigate the techniques of magic, we must not be naïve about deception.

As aforementioned, magicians and researchers also approach attention very differently. Consider a person who desires to understand the meaning of time. Consulting with a watchmaker is probably not the best way to go. Rather, speaking to a physicist or a philosopher would likely be a better choice. Although watchmakers are knowledgeable about the mechanics of keeping time and fix timepieces, they are unlikely to be experts on time itself. Similarly, magicians are the watchmakers of attention – they are experts at hoodwinking their audience's perceptual or cognitive system, without necessarily having keen insights into the underlying mechanisms. Years of practice reveal the right procedures that successfully achieve an effect; how it works, however, is a different story. Scientists strive to

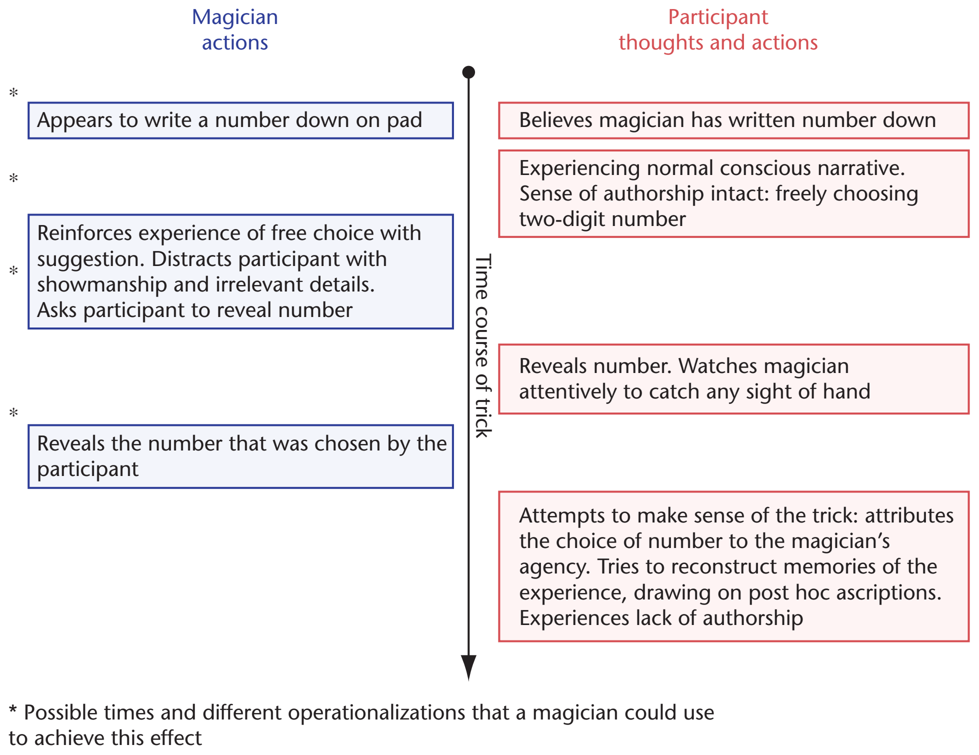

Figure 4 The number prediction trick.

understand the mechanisms and identify the processes that subserve attention. Yet, much as the philosopher of time might not be qualified to fix a watch, most investigators of attention hardly ever are great magicians.

These different approaches to attention may appear disjoint but can actually be complementary, in the same way that social psychology and cognitive neuroscience, two largely separate disciplines, have been increasingly overlapping in recent time. Social psychologists have traditionally tried to push healthy individuals closer to the pathological spectrum by incorporating into their research arsenal techniques such as suggestion and deception. Cognitive neuroscientists, however, have shied away from this approach and attempted, instead, to understand brain function by studying patients with specific deficits and focal brain lesions, as well as healthy individuals. The marriage of the methods of social psychology with cognitive neuroscience created an opportunity to test the limits of attention by examining healthy individuals under atypical conditions including hypnosis, meditation and sleep deprivation. For example, self-deception is crucial in creating the reality defined by hypnotic responding. The respondent may produce evidence indicative of a hypnotic episode or immerse themselves in the perspective appropriate for experiencing certain actions and perceptions as involuntary (Gorassini, 1999). Similar to some social psychologists, magicians capitalize on exploring the limits of human processing and triumph in commanding ways to tap these pliable behavioural perimeters. In this way, the cognitive neuroscience of attention can benefit from the contributions of both social psychologists and magicians.
See also: Cognitive Neuroscience

A specific genre of magic gives the appearance of psychological and even psychical effects (**Figure 4**). These 'mental' tricks, which still rely on misdirection, deception and expectation, make for some of the most impressive and insidious feats. The lay public often views mentalists as anywhere from pseudo-psychics all the way to genuine exemplars of the paranormal; regretfully, only few mentalists judiciously represent their performances for what they really are and dutifully steer clear of claims of the paranormal. Importantly, thinking of magic in this way allows us to move beyond visual attention and the neuroscience of illusions, to investigate attention as a window to belief formation, attribution and authorship processes.

Figure 4 depicts a situation wherein a participant experiences the *illusion of lack of authorship*. Throughout the time when the participant was choosing a number, she was aware of her uninterrupted conscious thoughts and felt no different than usual. Yet, the magician managed to correctly predict the two digit number chosen. If the trick is successful, there will be doubt in the participant's mind regarding the freedom of the choice. The participant will have to provide some sort of explanation for the magician's feat, and the most intuitive one may be that the magician is somehow able to influence people's choices. This type of mental magic is a very personal and dramatic way to create the experience of a momentary lapse in authorship. But the powerful experience is merely the result of trickery; the participant freely chose the number. What the magician is able to do is to manipulate the participant's attention at key moments in the course of the trick, directing focus to specific events while concealing others. Misdirection may prevent the participant from accurately orienting their attention when the magician writes down the number. The magician may also manipulate the attention that the participant orients towards memories of thoughts or events occurring earlier in the trick. Finally, the magician may use jokes and other techniques to distract attention and influence alerting whereas the participant ignores possible actions during these interruptions.

The process of authorship bridges social psychology and neuroscience. Recent studies have unveiled which brain processes underlie action initiation, as well as what leads to our experience of authorship (Aarts, 2007; Blakemore and Decety, 2001; Frith, 2005; Wegner, 2003; Zhu, 2004). Deficits in normal authorship processing also characterize many neurological and psychological disorders, including schizophrenia, alien hand syndrome and dissociative disorders. In addition, creating order within random stimuli alleviates aversive feelings associated with experiencing a lack of control (Krummenacher *et al.*, 2002). Furthermore, sensing lack of control leads individuals to perceive patterns where none exist (Whitson and Galinsky, 2008). Sense of self, of which the experience of authorship is a vital component, decreases the need to perceive such illusory patterns. What magic tricks are able to do is create a situation, utilizing heightened attention, misdirection, expectation and suggestion, that pushes healthy persons towards atypical attention. In learning how magicians manipulate participants' attention, researchers cannot only glean information about the various attentional networks and the neural processes subserving atypical attention in healthy individuals, but use such knowledge as a window to study many other cognitive domains.

Conclusion

A three-network model of attention nicely illustrates how magic influences brain processing. Since its inception in the early 1970s, Posner's model has been revised and refined, but still retains its original tenor, namely that attention comprises a system of three disparate control networks (Posner and Rothbart, 2007). Experimental findings suggest that these attentional subsystems can modulate cognition, emotion, thought and action. Furthermore, these networks can influence early stages of neural processing concerning both the location and time of sensory information. Thus, an understanding of attention affords the overriding of perception, memory and affect. Magicians, the clinicians of attention, have exploited these aspects for years.

Individuals outside the magic fraternity often fail to appreciate that although performers may recast their tricks to gel with contemporary culture and employ modern technology, these variations are largely cosmetic and magicians continue to rely on age-old principles, mostly grounded in the psychology of attention and deception (Schiffman, 1997). The basic principles of conjuring comprise the subtleties of attention misdirection, the understanding of human perception – including the understanding of visual and psychological illusion – and good showmanship.

Inattentional and change blindness contextualize the relationship between attention and perception. For example, how much of our visual world do we perceive when we are not paying attention? As psychological research unravelled over a century, attention or lack thereof – directing attention away from a target object – plays a key role in perception. Although magicians can provide many practical demonstrations of these instances, it is up to researchers to unravel the neurocognitive substrates that subserve them.

Stage tricks aside, the way performers operationalize attention is fundamental to the study of human cognitive processes such as attribution, decision making, self-deception and authorship. In an effort to provide explanations, humans often seek patterns even where none exist. Choice blindness and the nature of post hoc ascriptions demonstrate how tenuous our cognitive thread is in disambiguating unsettling effects. Magic provides the ideal milieu to investigate the limits and bases of such cognitive processes because observers lack insight into the veridical modus operandi of the performer. Fostering atypical attention, magic is advantageous for examining the subtleties inherent in cognitive processes, especially those nuances less commonly salient.

Leveraging magic, not just as a context for an experiment but as an actual research tool, allows scientists to benefit from and fuse existing cognitive paradigms with those of social psychology. The essential feature of magic hinges on misdirecting attention to conceal pivotal actions (Kelley, 1980). Incorporating magic tricks into experiments permits crafting uncommon situations that would otherwise be difficult to probe. Although using such paradigms may kindle an incipient ethical conundrum (Hyman, 1989), findings from such experiments have been published in the best scientific journals, including *Science* (Johansson *et al.*, 2005). Indeed, this design provides participants with a sense of control while it leaves the experimenter to 'run the show'.

With more research tools becoming progressively available, understanding of attention is likely to yield innovations in education, the treatment of pathological conditions, rehabilitation, cognitive training and even the magical arts. It will also provide insights into cultural and individual differences and further integrate the psychological and brain sciences. Although, most research has been conducted with healthy or pathological individuals in the context of typical, waking attention, carefully designed experimentation in the plane of atypical attention may further accelerate the quest to elucidate human attention and perhaps even to the invention of new magical effects.

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