Magic and the Brain. How Magicians "Trick" the Mind

By Susana Martinez-Conde and Stephen L. Macknik

The spotlight shines on the magician's assistant. The woman in the tiny white dress is a luminous beacon of beauty radiating from the stage to the audience. The Great Tomsoni announces he will change her dress from white to red. On the edge of their seats, the spectators strain to focus on the woman, burning her image deep into their retinas. Tomsoni claps his hands, and the spotlight dims ever so briefly before reflaring in a blaze of red. The woman is awash in a flood of redness.

Whoa, just a moment there! Switching color with the spotlight is not exactly what the audience had in mind. The magician stands at the side of the stage, looking pleased at his little joke. Yes, he admits, it was a cheap trick; his favorite kind, he explains devilishly. But you have to agree, he did turn her dress red—along with the rest of her. Please, indulge him and direct your attention once more to his beautiful assistant as he switches the lights back on for the next trick. He claps his hands, and the lights dim again; then the stage explodes in a supernova of whiteness. But wait! Her dress really has turned red. The Great Tomsoni has done it again!

The trick and its explanation by John Thompson (aka the Great Tomsoni) reveal a deep intuitive understanding of the neural processes taking place in the spectators' brains—the kind of understanding that we neuroscientists can appropriate for our own scientific benefit. Here's how the trick works. As Thompson introduces his assistant, her skintight white dress wordlessly lures the spectators into assuming that nothing—certainly not another dress—could possibly be hiding under the white one. That reasonable assumption, of course, is wrong. The attractive woman in her tight dress also helps to focus people's attention right where Thompson wants it—on the woman's body. The more they stare at her, the less they notice the hidden devices in the floor, and the better adapted their retinal neurons become to the brightness of the light and the color they perceive.

All during Thompson's patter after his little "joke," each spectator's visual system is undergoing a brain process called neural adaptation. The responsiveness of a neural system to a constant stimulus (as measured by the firing rate of the relevant neurons) decreases with time. It is as if neurons actively ignore a constant stimulus to save their strength for signaling that a stimulus is changing. When the constant stimulus is turned off, the adapted neurons fire a "rebound" response known as an afterdischarge.

In this case, the adapting stimulus is the red-lit dress, and Thompson knows that the spectators' retinal neurons will rebound for a fraction of a second after the lights are dimmed. The audience will continue to see a red afterimage in the shape of the woman. During that split second, a trap door in the stage opens briefly, and the white dress, held only lightly in place with Velcro and attached to invisible cables leading under the stage, is ripped from her body. Then the lights come back up.

Two other factors help to make the trick work. First, the lighting is so bright just before the dress comes off that when it dims, the spectators cannot see the rapid motions of the cables and the white dress as they disappear underneath the stage. The same temporary blindness can overtake you when you walk from a sunny street into a dimly lit shop. Second, Thompson performs the real trick only after the audience thinks it is already over. That gains him an important cognitive advantage—the spectators are not looking for a trick at the critical moment, and so they slightly relax their scrutiny.

The New Science of Neuromagic

Thompson's trick nicely illustrates the essence of stage magic. Magicians are, first and foremost, artists of attention and awareness. They manipulate the focus and intensity of human attention, controlling, at any given instant, what we are aware of and what we are not. They do so in part by employing bewildering combinations of visual illusions (such as afterimages), optical illusions (smoke and mirrors), special effects (explosions, fake gunshots, precisely timed lighting controls), sleight of hand, secret devices and mechanical artifacts ("gimmicks").

But the most versatile instrument in their bag of tricks may be the ability to create cognitive illusions. Like visual illusions, cognitive illusions mask the perception of physical reality. Yet unlike visual illusions, cognitive illusions are not sensory in nature. Rather they involve high-level functions such as attention, memory and causal inference. With all those tools at their disposal, well-practiced magicians make it virtually impossible to follow the physics of what is actually happening—leaving the impression that the only explanation for the events is magic.

Neuroscientists are just beginning to catch up with the magician's facility in manipulating attention and cognition. Of course the aims of neuroscience are different from those of magic; the neuroscientist seeks to understand the brain and neuron underpinnings of cognitive functions, whereas the magician wants mainly to exploit cognitive weaknesses. Yet the techniques developed by magicians over centuries of stage magic could also be subtle and powerful probes in the hands of neuroscientists, supplementing and perhaps expanding the instruments already in experimental use.

Neuroscience is becoming familiar with the methods of magic by subjecting magic itself to scientific study—in some cases showing for the first time how some of its methods work in the brain. Many studies of magic conducted so far confirm what is known about cognition and attention from earlier work in experimental psychology. A cynic might dismiss such efforts: Why do yet another study that simply confirms what is already well known? But such criticism misses the importance and purpose of the studies. By investigating the techniques of magic, neuroscientists can familiarize themselves with methods that they can adapt to their own purposes. Indeed, we believe that cognitive neuroscience could have advanced faster had investigators probed magicians' intuitions earlier. Even today magicians may have a few tricks up their sleeves that neuroscientists have not yet adopted.

By applying the tools of magic, neuroscientists can hope to learn how to design more robust experiments and to create more effective cognitive and visual illusions for exploring the neural bases of attention and awareness. Such techniques could not only make experimental studies of cognition possible with clever and highly attentive subjects; they could also lead to diagnostic and treatment methods for patients suffering from specific cognitive deficits—such as attention deficits resulting from brain trauma, ADHD (attention-deficit hyperactivity disorder), Alzheimer's disease, and the like. The methods of magic might also be put to work in "tricking" patients to focus on the most important parts of their therapy, while suppressing distractions that cause confusion and disorientation.

Magicians use the general term "misdirection" to refer to the practice of diverting the spectator's attention away from a secret action. In the lingo of magic, misdirection draws the audience's attention toward the "effect" and away from the "method," the secret behind the effect. Borrowing some terms from cognitive psychology, we have classified misdirection as "overt" and "covert." The misdirection is overt if the magician redirects the spectator's gaze away from the method—perhaps simply by asking the audience to look at a particular object. When the Great Tomsoni introduces his lovely assistant, for instance, he ensures that all eyes are on her.

"Covert" misdirection, in contrast, is a subtler technique; there, too, the magician draws the spectator's attentional spotlight—or focus of suspicion—away from the method, but without necessarily redirecting the spectator's gaze. Under the influence of covert misdirection, spectators may be looking directly at the method behind the trick yet be entirely unaware of it.

Cognitive neuroscience already recognizes at least two kinds of covert misdirection. In what is called change blindness, people fail to notice that something about a scene is different from the way it was before. The change may be expected or unexpected, but the key feature is that observers do not notice it by looking at the scene at any one instant in time. Instead the observer must compare the postchange state with the prechange state.

Many studies have shown that changes need not be subtle to cause change blindness. Even dramatic alterations in a visual scene go unnoticed if they take place during a transient interruption such as a blink, a saccadic eye movement (in which the eye quickly darts from one point to another) or a flicker of the scene. The "color-changing card trick" video by psychologist and magician Richard Wiseman of the University of Hertfordshire in England is a dramatic example of the phenomenon (the video is available online at www.youtube.com/watch?v=voAntzB7EwE). In Wiseman's demonstration—which you must see to appreciate—viewers fail to notice shifts in color that take place off camera. It is worth noting that despite its name, the color-changing card trick video does not use magic to make its point.

Inattentional blindness differs from change blindness in that there is no need to compare the current scene with a scene from memory. Instead people fail to notice an unexpected object that is fully visible directly in front of them. Psychologist Daniel J. Simons invented a classic example of the genre. Simons and psychologist Christopher F. Chabris, both then at Harvard University, asked observers to count how many times a "team" of three basketball players pass a ball to each other, while ignoring the passes made by three other players. While they concentrated on counting, half of the observers failed to notice that a person in a gorilla suit walks across the scene (the gorilla even stops briefly at the center of the scene and beats its chest!). No abrupt interruption or distraction was necessary to create this effect; the counting task was so absorbing that many observers who were looking directly at the gorilla nonetheless missed it.

Tricking the Eye or Tricking the Brain?

Magicians consider the covert form of misdirection more elegant than the overt form. But neuroscientists want to know what kinds of neural and brain mechanisms enable a trick to work. If the artistry of magic is to be adapted by neuroscience, neuroscientists must understand what kinds of cognitive processes that artistry is tapping into.

Perhaps the first study to correlate the perception of magic with a physiological measurement was published in 2005 by psychologists Gustav Kuhn of Durham University in England and Benjamin W. Tatler of the University of Dundee in Scotland. The two investigators measured the eye movements of observers while Kuhn, who is also a magician, made a cigarette "disappear" by dropping it below a table. One of their goals was to determine whether observers missed the trick because they were not looking in the right place at the right time or because they did not attend to it, no matter which direction they were looking. The results were clear: it made no difference where they were looking.

A similar study of another magic trick, the "vanishing-ball illusion," provides further evidence that the magician is manipulating the spectators' attention at a high cognitive level; the direction of their gaze is not critical to the effect. In the vanishing-ball illusion the magician begins by tossing a ball straight up and catching it several times without incident. Then, on the final toss, he only pretends to throw the ball. His head and eyes follow the upward trajectory of an imaginary ball, but instead of tossing the ball, he secretly palms it. What most spectators perceive, however, is that the (unthrown) ball ascends—and then vanishes in midair.

The year after his study with Tatler, Kuhn and neurobiologist Michael F. Land of the University of Sussex in England discovered that the spectators' gaze did not point to where they themselves claimed to have seen the ball vanish. The finding suggested the illusion did not fool the brain systems responsible for the spectators' eye motions. Instead, Kuhn and Land concluded, the magician's head and eye movements were critical to the illusion, because they covertly redirected the spectators' attentional focus (rather than their gaze) to the predicted position of the ball. The neurons that responded to the implied motion of the ball suggested by the magician's head and eye movements are found in the same visual areas of the brain as neurons that are sensitive to real motion. If implied and real motion activate similar neural circuits, perhaps it is no wonder that the illusion seems so realistic.

Kuhn and Land hypothesized that the vanishing ball may be an example of "representational momentum." The final position of a moving object that disappears is perceived to be farther along its path than its actual final position—as if the predicted position was extrapolated from the motion that had just gone before.

More Tools of the Trickery Trade

Spectators often try to reconstruct magic tricks to understand what happened during the show—after all, the more the observer tries (and fails) to understand the trick, the more it seems as if it is "magic." For their part, magicians often dare their audiences to discover their methods, say, by "proving" that a hat is empty or an assistant's dress is too tight to conceal a second dress underneath. Virtually everything done is done to make the reconstruction as hard as possible, via misdirection.

But change blindness and inattentional blindness are not the only kinds of cognitive illusions magicians can pull out of a hat. Suppose a magician needs to raise a hand to execute a trick. Teller, half of the renowned stage magic act known as Penn & Teller, explains that if he raises his hand for no apparent reason, he is more likely to draw suspicion than if he makes a hand gesture—such as adjusting his glasses or scratching his head—that seems natural or spontaneous. To magicians, such gestures are known as "informing the motion."

Unspoken assumptions and implied information are also important to both the perception of a trick and its subsequent reconstruction. Magician James Randi ("the Amaz!ng Randi") notes that spectators are more easily lulled into accepting suggestions and unspoken information than direct assertions. Hence, in the reconstruction the spectator may remember implied suggestions as if they were direct proof.

Psychologists Petter Johansson and Lars Hall, both at Lund University in Sweden, and their colleagues have applied this and other magic techniques in developing a completely novel way of addressing neuroscientific questions. They presented picture pairs of female faces to naive experimental subjects and asked the subjects to choose which face in each pair they found more attractive. On some trials the subjects were also asked to describe the reasons for their choice. Unknown to the subjects, the investigators occasionally used a sleight-of-hand technique, learned from a professional magician named Peter Rosengren, to switch one face for the other—after the subjects made their choice. Thus, for the pairs that were secretly manipulated, the result of the subject's choice became the opposite of his or her initial intention.

Intriguingly, the subjects noticed the switch in only 26 percent of all the manipulated pairs. But even more surprising, when the subjects were asked to state the reasons for their choice in a manipulated trial, they confabulated to justify the outcome—an outcome that was the opposite of their actual choice! Johansson and his colleagues call the phenomenon "choice blindness." By tacitly but strongly suggesting the subjects had already made a choice, the investigators were able to study how people justify their choices—even choices they do not actually make.

The Pickpocket Who Picks Your Brain

Misdirection techniques might also be developed out of the skills of the pickpocket. Such thieves, who often ply their trade in dense public spaces, rely heavily on socially based misdirection—gaze contact, body contact and invasion of the personal space of the victim, or "mark." Pickpockets may also move their hands in distinct ways, depending on their present purpose. They may sweep out a curved path if they want to attract the mark's attention to the entire path of motion, or they may trace a fast, linear path if they want to reduce attention to the path and quickly shift the mark's attention to the final position. The neuroscientific underpinnings of these maneuvers are unknown, but our research collaborator Apollo Robbins, a professional pickpocket, has emphasized that the two kinds of motions are essential to effectively misdirecting the mark. We have proposed several possible, testable explanations.

One proposal is that curved and straight hand motions activate two distinct control systems in the brain for moving the eyes. The "pursuit" system controls the eyes when they follow smoothly moving objects, whereas the "saccadic" system controls movements in which the eyes jump from one visual target to the next. So we have hypothesized that the pickpocket's curved hand motions may trigger eye control by the mark's pursuit system, whereas fast, straight motions may cause the saccadic system to take the lead. Then if the mark's pursuit system locks onto the curved trajectory of the pickpocket's hand, the center of the mark's vision may be drawn away from the location of a hidden theft. And if fast, straight motions engage the mark's saccadic system, the pickpocket gains the advantage that the mark's vision is suppressed while the eye darts from point to point. (The phenomenon is well known in the vision sciences as saccadic suppression.)

Another possible explanation for the distinct hand motions is that curved motions may be perceptually more salient than linear ones and hence attract stronger attention. If so, only the attentional system of the brain—not any control system for eye motions—may be affected by the pickpocket's manual misdirection. Our earlier studies have shown that the curves and corners of objects are more salient and generate stronger brain activity than straight edges. The reason is probably that sharp curves and corners are less predictable and redundant (and therefore more novel and informative) than straight edges. By the same token, curved trajectories may be less redundant, and therefore more salient, than straight ones.

Controlling Awareness in the Wired Brain

The possibilities of using magic as a source of cognitive illusion to help isolate the neural circuits responsible for specific cognitive functions seem endless. Neuroscientists recently borrowed a technique from magic that made volunteer subjects incorrectly link two events as cause and effect while images of the subjects' brains were recorded. When event A precedes event B, we often conclude, rightly or wrongly, that A causes B. The skilled magician takes advantage of that predisposition by making sure that event A (say, pouring water on a ball) always precedes event B (the ball disappearing). In fact, A does not cause B, but its prior appearance helps the magician make it seem so. Cognitive psychologists call this kind of effect illusory correlation.

In an unpublished study in 2006 Kuhn and cognitive neuroscientists Ben A. Parris and Tim L. Hodgson, both then at the University of Exeter in England, showed videos of magic tricks that involved apparent violations of cause and effect to subjects undergoing functional magnetic resonance imaging. The subjects' brain images were compared with those of a control group: people who watched videos showing no apparent causal violations. The investigators found greater activation in the anterior cingulate cortex among the subjects who were watching magic tricks than among the controls. The finding suggests that this brain area may be important for interpreting causal relationships.

The work of Kuhn and his colleagues only begins to suggest the power of the techniques of magic for manipulating attention and awareness while studying the physiology of the brain. If neuroscientists learn to use the methods of magic with the same skill as professional magicians, they, too, should be able to control awareness precisely and in real time. If they correlate the content of that awareness with the functioning of neurons, they will have the means to explore some of the mysteries of consciousness itself.

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