by Earthwatch Institute (Europe) and the Natural History Museum (London, UK) in association with the Earthworm Society of Britain. "Earthworm Watch" was launched for a first instalment to run through April and May, but it will continue each autumn and spring, which is the time when the worms are most active, as Dr Jenny Cousins from Earthwatch Institute explains. She and her colleagues have already registered several hundred participants, and the data collected will be analysed and disseminated in a range of publications and outreach events over the next three years. The project pack provides instructions and materials for lay participants of all ages to conduct a detailed survey of worms on two small plots in their gardens — or any other place where they can get permission to dig two holes (http://earthwormwatch.org/).

The instruction booklet (also downloadable as a PDF file) suggests to survey two 20 cm x 20 cm plots that either represent different types of habitat (e.g. lawn or flowerbed) or that have been treated in different ways (e.g. with and without fertiliser use). For each of these, volunteers should dig up the soil to 10 cm depth, recover the worms from the soil, and then pour in mustard water to encourage worms from deeper layers of the soil to come up.

Tables and helpful advice are provided to further characterise the worms that show up and to describe their soil environment. Participants learn to distinguish between adult and juvenile worms, as well as between deep-living, surface-feeding and soil-feeding worms. A simple acid test using vinegar clarifies if the soil contains carbonates.

Thus, anybody with access to a patch of land can now follow in the footsteps of Charles Darwin and contribute to our knowledge about those helpful worms that enable the soil to provide our food. Rather than taking them indoors and playing piano for them, however, Earthworm Watch suggests to return them to the hole and to fill up the soil.

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Essay

Magic and cognitive neuroscience

Rodrigo Quian Quiroga

In recent years, neuroscientists have shown an increasing interest in magic. One reason for this is the parallels that can be drawn between concepts that have long been discussed in magic theory, particularly misdirection, and those that are routinely studied in cognitive neuroscience, such as attention and, as argued in this essay, different forms of memory. A second and perhaps more attractive justification for this growing interest is that magic tricks offer novel experimental approaches to cognitive neuroscience. In fact, magicians continuously demonstrate in very engaging ways one of the most basic principles of brain function — how the brain constructs a subjective reality using assumptions based on relatively little and ambiguous information.

There appears to be a fundamental rule in magic: never perform the same trick twice. It is indeed common that, when an observer left wondering in amazement asks, or rather demands, that the magician repeats a trick, he will very politely decline and move on to something else. Harry Houdini, one of the most renowned magicians of all time, used to debunk the so-called psychics and other conjurors. About a century ago, he posed the challenge that, if shown any trick three times in a row, he should be able to figure out how it is done. On February 1922, during the Society of American Magicians convention in Chicago, Dai Vernon — at the time a young unknown magician who would later become a father figure of close-up magic and would be known as "The Professor" or "The man who fooled Houdini" — happily obliged. He asked Houdini to pick a card and sign it with his initials. He then lost the card in the deck and "Abracadabra", the card appeared on top. He proceeded to lose the card again and, once more, the card ended up on top of the deck. He repeated the trick a third time and, at Houdini's request, who remained clueless, he continued to do so up to seven times.

In fact, Vernon could have repeated what is now known as the "Ambitious Card Trick" the whole day long and Houdini would have never figured it out. For, as famous as he was as a remarkable escapologist, Houdini was only a novice magician. What he did not realize was that Vernon kept changing the method he used to make the card appear on top (for a detailed description, see [1]). That was Houdini's failure: he could not avoid making the perfectly sensible assumption that Vernon was always repeating the same trick. Thus, to refine the initial statement, the general rule for the magician is to never repeat the same trick using the same method (but see [2] for exceptions).

Repetition is a very powerful tool for conjurers. As psychologist Norman Triplett put it in a very comprehensive review at the turn of the 19th century [3]: *"First actually do what the spectators are to be led to believe you do… make a genuine experiment several times, then, when the association has been formed by repetition, a pretended experiment is made and the subject by reason of the suggestion responds as before"* (pp. 489 and 491). Triplett illustrates this principle with the "Vanishing Ball Illusion", in which a ball (or some other object) is thrown vertically a number of times and then, upon the final throw, it magically vanishes while in the air (pp. 492). The trick is no more sophisticated than the one we use to fool a dog running baffled after a stick he cannot find, which, instead of been thrown, remains concealed behind our backs. The first set of repetitions imprint a cause–effect association. The magician performs the movement of throwing the ball and it follows that the ball is then in the air, time after time, until he makes the same movement but keeps the ball concealed in his hand and it seems to have disappeared.

Con artists use the same principle in the "Three Card Monte" game: they place three slightly combed cards face down on the table, one of which is, for example, a Queen of Hearts that the audience has to follow; then they quickly rearrange the cards and whoever feels audacious enough to try his odds has to

place money on the one he believes is the Queen. The power of the deception is, however, not due to the intricate manoeuvres performed by the con artist — after all, it is not that difficult to follow — but due to the fact that he has an associate who appears to keep losing money by making obviously wrong choices. The observer then believes it is trivial to follow the card, as he is always getting it right while the associate is betting, but once he decides to bet himself, with a simple sleight of hand the con artist changes the method and he will lose time after time without ever realising why.

To the naïve observer, magic relies on myths such as "the hand is quicker than the eye" or on the fact that the magician diverts the audience's gaze and, while they are distracted looking at a glamorous assistant, he performs the trick out of sight. This is, however, far from truth. The way magic is achieved is actually much more interesting. In the late 19th century, the philosopher and amateur magician Max Dessoir observed: *"Apparatus and instructions do not reveal the kernel of modern magic… That which makes prestidigitation an art of deception, is not its technical appliances, but its psychological kernel. The working out in the realm of the senses of certain capacities of the soul is something incomparably more difficult than any finger-skill or machinery."* [4].

So, with very few exceptions, like the initial manoeuvre of the "Three Card Monte", or the "Snap Change" and the "Shape Shifter" sleight, in which one card changes to another in front of your eyes, the vast majority of close-up magic tricks do not require blink-of-an-eye fast sleight of hand. The secret magical moves can be performed relatively slowly and you will still fail to perceive them. Second, diverting attention by making you look to the side while the trick is performed is considered low class magic. It ruins the magic effect. There is a perfectly reasonable explanation: the trick was done while you looked away. With good magic, you should end up with the feeling of having absolutely no clue how the trick could have been performed. You are puzzled and amazed, and as Juan Tamariz, one of the most renowned close-up magicians put it [1], a good trick should leave you with one possible explanation: it has to be magic.

So, the key ingredient of modern magic is neither fast hand dexterity nor forcing the audience to look away. On the contrary, to a large extent it is based on what Vernon used to fool Houdini: playing with our relatively limited ability to attend to all incoming data (and to later recall it), which is compensated for by unconscious, unavoidable assumptions. Vernon made use of a very simple assumption, whose roots go back to the thoughts of 18th century philosopher David Hume: if an effect is repeated over and over again, it is difficult to avoid inferring that it always has the same cause. This is when magic gets interesting to cognitive neuroscientists; when a two-thousand-year-old art form shows different aspects of how the brain constantly uses inferences to make sense of the world around us, and how magicians break these inferences at will to let us believe what seems to be impossible.

Repetition is, however, just one of a large repertoire of tools that conjurers use to play with your assumptions at will. In general, the idea is quite simple: you cannot possibly process all the information that is presented to you; you need to select a few facts and infer the rest, but, unbeknown to you, the magician, with his apparently casual movements, posture, patter, timing, gaze and so on, will influence the facts that you unconsciously process and the ones that you leave aside. This is the cornerstone of magic: the concept of misdirection.

Misdirection

It has long been recognised that the success of a magic trick critically depends upon subtly deviating the spectator's focus away from 'the method' [3–6] — the actual technique used to cause the magic effect. I will not attempt to give a precise description or classification of misdirection techniques, as these have been largely covered elsewhere [7–9]. But I will focus on three main forms of misdirection, because they are tightly linked to cognitive neuroscience and, particularly, to memory processes, as I will argue in the next section.

A first form of misdirection deals with spatial and temporal attention — when and where the conjurer gets the spectator to focus his interest. This is far from the distraction of having the spectator looking away while the trick is performed. The deviation of attention should be subtle and remain unnoticed. The spectator should be left with the feeling that he has been carefully looking at the trick the whole time, which is the fuel that ignites his amazement when seeing the magical resolution. Therefore, rather than using distraction, the magician skilfully plays with bright and dark spots of attention.

Let us illustrate this with an example. Figure 1A shows a professional magician, Miguel Angel Gea, performing the well-known "Coin Vanishing Trick": he holds a coin in his right hand, then he tosses it to the left, holds it there, and then shows that it has disappeared. Of course, the coin remains concealed in the right hand. The figure shows the four main stages of this trick, with the points of fixation of several subjects (measured with an Eye-Tracker), while they watched a video of the performance. Note that he starts looking at the coin on his right hand, and this is where all subjects look at. Next, he momentarily looks at the (virtual) spectator while doing the false transfer manoeuvre, and most of the subjects who later claimed to not have seen how the trick was achieved (red crosses) looked at this face, while the others (green crosses) kept looking at the hand.

We note, in passing, that this effect is much stronger when the spectator observes the trick in person, because inherent social habits make it virtually impossible not to look back at a person who suddenly looks at you. When Gea apparently holds the coin in the left hand, he changes his gaze and body posture towards it. This sets the bright spot of attention, while the hand concealing the coin remains in the dark. All subjects inevitably focused their attention and gaze to the left hand until the resolution of the trick. Figure 1B shows exactly the same trick, but this time Gea kept looking at his hands (rather than at the observer) when performing the false transfer. In this case, most subjects looked at the manoeuvre and reported seeing how the trick was done.

The magician diverts attention away not only from the location but also from the time when the deceiving manoeuvre happens. Imagine that the magician now wants to repeat the coin vanishing trick. He starts with the coin on the table; he slides it to the border to pick

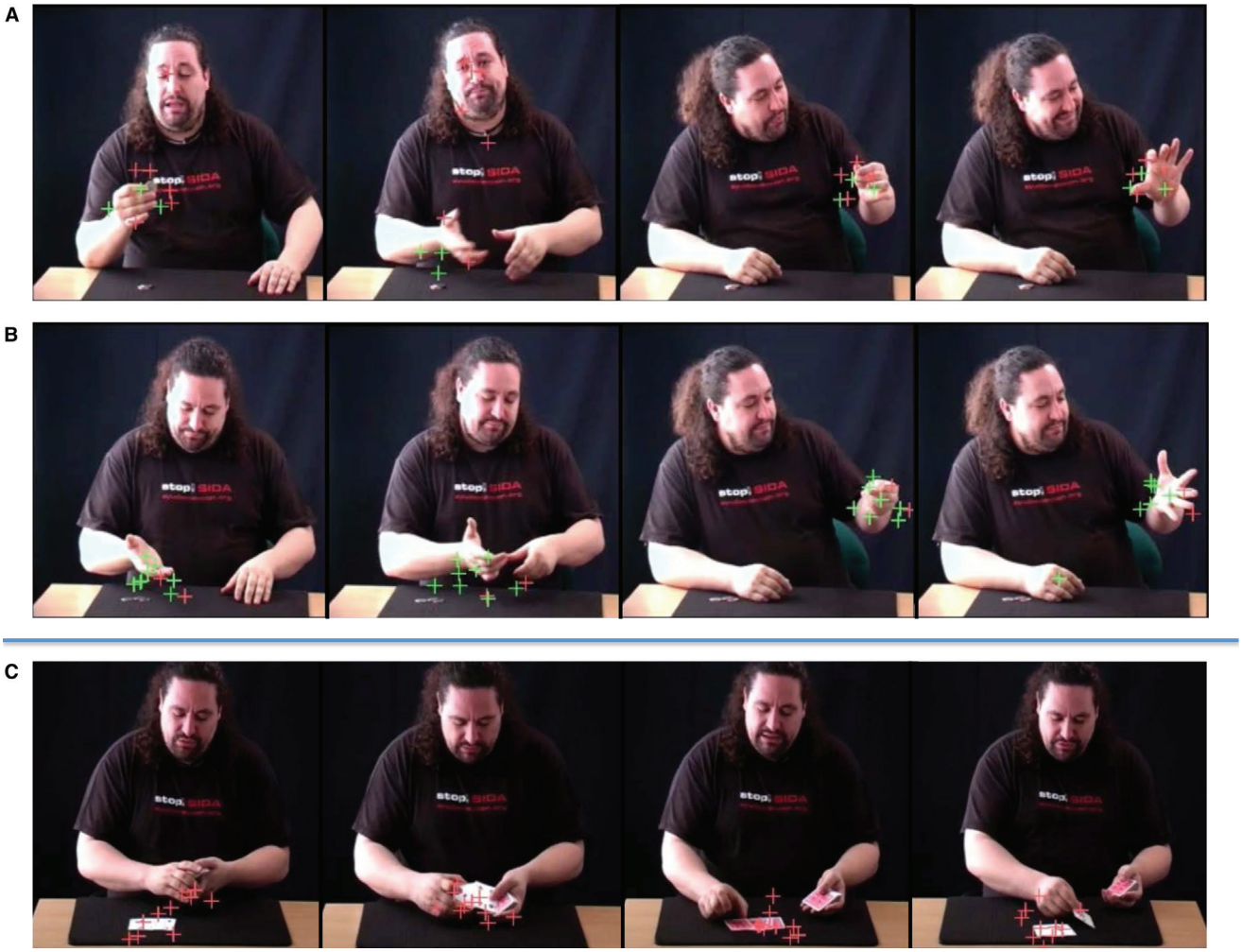

Figure 1. Illustration of misdirection.
(A) A magician performing the "Coin Vanishing Trick", in which a coin initially held in the right hand is passed to the left and then disappears. The green (red) crosses show the fixations of different subjects that watched a video of the performance and did (did not) recognise how the trick was done. (B) The same trick as (A), but with the magician looking at his hands (instead of looking to the front) at the time the trick was done (second frame from the left). In this case, most subjects recognised how the trick was achieved. (C) A "Card Changing Trick", in which the magician reinforces the attention and gaze of the subjects to remain at the cards.

it up and keeps it in his right hand; he then claims that he will repeat the trick one more time; he passes it to the left hand, as before, but now, after showing that the coin is no longer on the left, he also shows that it is not in the right hand either. The effect can be very strong and it is due, at least in part, to a 'false beginning': the trick was done before the magician says he will repeat the trick, as he has actually dropped it to his lap when picking it up from the table.

Magicians use a variety of strategies to manipulate when the audience pays attention. In general, they will always justify the actions involved in a deceiving manoeuvre to avoid raising suspicion (which would increase the audience's attention): in the example above, the magician is not just quickly dropping the coin in his lap, on the contrary, he does this movement naturally as he is allegedly picking it up. Other subtle manipulations of temporal attention are given by the magician's posture — a tense posture attracts more attention than a casual one, something that could be done just by leaning a bit forwards or backwards, respectively— his patter and intonation, the relaxation produced by a joke or the clapping by the audience or, as illustrated above, by giving the feeling that the trick has not yet started or that it has finished (in the latter case, leading to an unexpected and notable finale). Coming back to the statement at the beginning of this essay, the main reason not to repeat a trick is that the naïve spectator doesn't know beforehand when and where to focus his attention. If the same trick is shown again, the spectator will know what to look for.

A second form of misdirection, named covert misdirection [8], occurs when the gaze and attention remain on the place and time of the trick, but the spectator still fails to notice how it is done. It has long been recognised that we can only process a limited amount of information at a time [10,11]. Thus, the principle of covert misdirection is based on the fact that, although the spectator is seeing the trick being performed in front of his

eyes, he will be busy processing other information. Figure 1C illustrates this idea. In this case, Gea performs a trick in which the spectator freely chooses four cards; the cards are placed on top of the deck, then back on the table, to finally reveal that they have changed. Note that in this case the magician kept looking at the cards. This is exactly were the gaze of all subjects watching the video remained, but none of them could even guess how the trick was done. The misdirection was given by the fact that Gea asked the spectators to remember the four freely chosen cards and, while they were busy trying to remember them, he changed them with a simple sleight of hands in front of their eyes.

Arturo de Ascanio — a magician who had a large influence on Tamariz, who was in turn the mentor of Gea — introduced the concept of the 'bewildering question': the magician asks a seemingly innocent question to force the spectator to focus his thoughts on processing the question and elaborating an appropriate answer while the trick is done. This second and more elaborate form of misdirection thus relies on the fact that, even if looking at the right place and at the right time, it is impossible to process all the available information. Again, we have to choose what information we should pay attention to and what should be disregarded, eventually filling in the gaps based on reasonable assumptions.

Juan Tamariz introduced the notion of the 'false solution' [1]. The idea is quite simple: during the execution of the trick, he suggests in a very subtle way a possible explanation of how the trick is being performed, to eventually show at the very end that this explanation is in fact not possible. So, by forcing the spectators to pay attention to a particular method, he is at the same time forcing them to disregard many other possible ones.

Note that the two forms of misdirection described so far are not mutually exclusive. In fact, it is possible to deviate the attention of the spectators from both the time and place of the execution of the trick, and also to deviate their attention with other subtle but distracting tasks.

A third form of misdirection deals with the recapitulation, after a trick has been observed, of how it could have been performed. In this respect, a very basic principle is to separate in time the method (the execution of the deceiving manoeuvre) from the resolution of the magic trick — what Ascanio dubbed 'parenthesis of forgetfulness'. This idea simply follows the most basic observation about how memory decays with time [12]. Let us consider again the second version of the coin vanishing trick described above. In principle, the magician could show an empty hand after having allegedly picked up the coin from the table; however, the magic effect would then come shortly after the execution of the deceiving manoeuvre and the spectator would have no problem in inferring how the trick was done. Having a series of salient events following the coin drop, like stressing the (false) fact that the coin is in the right hand, passing it to the left, and then showing that it has disappeared, introduces enough delay and enough number of events between the method and the effect, so that it becomes very difficult to recapitulate all the events to eventually establish a causal link.

Note also that this second version of the coin vanishing trick has a much larger impact if preceded by the first version, where the coin remains in the right hand, thus reinforcing the idea that the coin should be concealed in one of the hands (indeed, one of Tamariz' false solutions). This form of misdirection complements the time misdirection described above, but in this case, instead of just having the spectator not paying attention at the moment in which the deceiving manoeuvre is executed, the magician also makes sure it will be difficult to recapitulate precisely what was done. In the first case, misdirection applies to the encoding of information and in the latter case to its recall.

The magician may also recapitulate what has been done before the magic revelation, but this will be a biased recall, as he will reinforce the events he wants the audience to remember and will ignore the ones he wants them to forget. The skilled conjurer will not only influence the events that are recalled, but will also alter the content of these memories. In cognitive neuroscience, there is striking evidence of how malleable memories are, and how the recollection of an event may be altered even by how the question used to evoke its recall is formulated [13]. These procedures are well known to magicians. For example, a magician may have shuffled (and deceivingly manipulated) the cards himself and then given the deck to a spectator to do a few final cuts (which have no consequence whatsoever). After some patter and distractions, he may then recapitulate what was done and say something like "the cards have been shuffled" while looking at the spectator holding the deck, thus reinforcing the idea that it was the spectator and not him who shuffled the cards. An explicit statement, like "it was him who shuffled the cards" would not be as effective because it would raise suspicion and force the audience to check the facts in their minds. On the contrary, an ambiguous statement with a subtle insinuation will reinforce a false memory, which will play a critical role in enhancing the magic effect (as it would be impossible for the magician to, for example, find a card in a deck shuffled by the spectator).

A memory framework of misdirection

Misdirection has been historically related to attention [3–9]. In this section, however, I would like to offer an alternative view of the three forms of misdirection discussed above within a memory context. I should highlight that it is not my intention to propose yet another taxonomy of misdirection. On the contrary, the goal of describing this new framework is to widen the parallels between magic theory and cognitive neuroscience beyond the realms of attention, eventually opening the opportunity for novel experimental approaches in memory research.

In the 19th century, psychologists like Ebbinghaus and James distinguished between two types of memory: short-term memory, which lasts seconds and is the one that supports our awareness of the flow of events of the present; and long-term memory, which lasts up to a lifetime and is the one we use to retrieve experiences from our past [12,14]. Later experiments showed that an initial form of 'sensory memory', which lasts a fraction of a second (in the case of visual stimuli), should be added to this classification [15]. A widely disseminated model by Atkinson and Shiffrin proposes how these three forms of memory interact [16]. Sensory memory is a short lasting buffer that provides the interface between perception and memory: only the information that is attended can be further processed and will give rise

to short-term memory. Facts that are not attended will not even enter our consciousness.

The first form of misdirection described above — when and where the spectator focuses his attention — is related to this process of transforming sensory memory into short-term memory. In turn, the main mechanism for converting short-term memories into long-term memories is by rehearsal — the facts that are revisited will be later remembered and the ones that are not will be only processed momentarily and will then be forgotten. The second form of misdirection disrupts this transfer: in this case, the spectator is looking at the right place and at the right time, and he may momentarily suspect that a deceiving manoeuvre is being performed. This information enters short-term memory (or, at least, has the potential to do so), but because of our relatively limited processing capacity, it is overridden by other cognitive tasks that the magician subtly enforces. Note that although the spectator may not realize how exactly the manoeuvre was performed, for the magician it is important to clear out any evidence or suspicion to reinforce the impact given by the resolution of the trick.

At the end of this hierarchy, long-term memories are highly dynamic and malleable, far from information set in stone. In order to persist, long-term memories should be periodically revisited — brought back to short-term memory and awareness — and they can be largely modified depending on how they are retrieved. The third form of misdirection aims at manipulating this process, as the magician will selectively highlight some events and disguise others. In this context, the notion of 'parenthesis of forgetfulness' is based on separating the method from the effect, so that the eventual visualization or suspicion of the use of a method is no longer stored in short-term memory and it does not consolidate into long-term memory either, because the magician reinforces a series of distracting events.

New approaches to cognitive neuroscience

One of the most basic principles of brain function is that the brain processes very little information and infers the rest based on assumptions [17]. In terms of perception, more than a century ago Herman von Helmholtz [18] argued that the information gathered by the eyes is relatively poor and, therefore, the brain uses unconscious inferences to make sense of what we see around us. Similarly, by evaluating how subjects remembered folk stories at different periods of time, Frederic Bartlett [19] reasoned that we do not remember objective facts, but rather personal schemas which we build up on the basis of our own subjective interpretations. It is mainly upon this principle that magicians hack the main feature underlying our intelligence and construct a biased interpretation in the spectator by using different forms of misdirection. The surprising resolution of a magic trick is, in this sense, comparable to the effect that can be produced by a visual illusion or by being suddenly aware of a false memory. In all these cases, unconscious assumptions have been broken.

Within this context, magic tricks offer new vistas in cognitive neuroscience. The main advantage is that they provide a new, orthogonal approach to study brain processes compared to standard experiments used in the laboratory. Moreover, magic tricks tend to work 100% of the time, which is a clear advantage compared to paradigms used in cognitive neuroscience, where it is sometimes hard to get behavioural performances above chance. Furthermore, magic tricks provide ecological and engaging scenarios, in the sense that attention can be manipulated by the magician's gaze or posture rather than by using, for example, a flashed cue or other standard attention engaging techniques.

Of course, the use of magic tricks also imposes some challenges. In particular, repetition is a gold standard in scientific experimentation to assess statistical significance, but we have already noted how repetition tends to be avoided in magic. Furthermore, ecological settings may, in principle, be very appealing, but it is hard to control and dissociate all the processes involved in a magic trick and match them to processes studied in cognitive neuroscience. In spite of these challenges, I would argue that magicians, with their tricks and their knowledge, can offer new insights to cognitive neuroscience. This interaction should ideally develop as a two-way road, as magicians may not only provide researchers with new experimental approaches, but also gather scientific knowledge that may have an impact on the way they perform their fascinating art of conjuring.

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