Peer-reviewed version available at *PeerJ* **2020**, *8*, e9712; doi:10.7717/peerj.9712

On the Cognitive Bases of Illusionism: An Untapped Tool for Brain and Behavioral Research

Jordi Camí[1]*, Alex Gomez-Marin[2] and Luis M. Martínez[3]

[1] *Universitat Pompeu Fabra, Barcelona*
[2] *Behavior of Organisms Laboratory, Instituto de Neurociencias CSIC-UMH, Alicante*
[3] *Visual Analogy Laboratory, Instituto de Neurociencias CSIC-UMH, Alicante*

* *Correspondence: jordi.cami@upf.edu*

Abstract

Cognitive scientists have paid very little attention to magic as a distinctly human activity capable of creating situations or events that are considered impossible because they violate expectations and conclude with the apparent transgression of well-established cognitive and natural laws. And even though magic techniques appeal to all known cognitive processes from sensing, attention and perception to memory and decision making, the relation between science and magic has so far been mostly unidirectional, with the primary goal of unraveling how magic works. Building up from the deconstruction of a classic magic trick, we provide here a cognitive foundation for the use of magic as a unique and largely untapped research tool to dissect cognitive processes in tasks arguably more natural than those usually exploited in artificial laboratory settings. Magicians can submerge every spectator into the precise experimental protocol they have previously designed, accounting with ease for both circumstantial and social contexts. Magicians do not base the success of their experiments in statistical measures that smear out the individual in favor of an average spectator that we know never exists in the real world. They target each and everyone in the audience and, often, with a complete accomplishment. Magicians deliver their cognitive manipulations in real-time, in tight closed-loop with the audience, and in a single trial (they cannot afford to repeat the trick if it fails). Magic has also an inherent and strong social component, merging the private cognitive processes of each spectator with the group dynamics. Finally, when combined with the wide range of precise measuring and wearable technologies available today, magic paves the way for a road not taken towards real-world cognitive science. We dare to speculate that some of the mysteries of how the brain works may be trapped in the split realities present in each magic effect.

Keywords: magic; cognition; real-world neuroscience

Introduction

Illusionism is a millenary art whose social context has evolved substantially over time. Currently it is an artistic expression, a pure form of entertainment; but there was a time when it was related to the activities of the priests, the mediums, the sorcerers and witches (Scot 1584). Contemporary magic is unique in the sense that it is capable of provoking the wonderful experience of the impossible without the need for the audience to actually believe that what they observe is real (we use "magic" and

"illusionism" as interchangeable concepts). With that in mind, illusionists have mastered a myriad of methods and techniques which have withstood the test of time. These techniques have been perfected using purely empirical means, just by trial-and-error, and have been preserved and, up until now, transmitted with discretion amongst the pundits. The wisdom of magicians is such that it encompasses many scientific disciplines, including physics -especially optics-, mechanics, electronics, new materials, mathematics, and, above all and mainly, cognitive neuroscience.

Our goal is to offer an unexplored perspective on the cognitive mechanisms that explain the efficacy of magic tricks and how this knowledge can, in return, feedback into cognitive neuroscience research. We refer here to the effects that illusionists perform to create situations or events that are considered impossible because they violate expectations and conclude with the apparent transgression of natural laws. In fact, to be considered as such, magic tricks should induce in the audience a sort of cognitive dissonance, the so-called "illusion of impossibility", resulting from the blatant conflict between the expectations created during the presentation of the effect and its outcome. This tension comes with an initial surprise that is followed by other reactions, which can range from admiration to unease, through enchantment. Not surprisingly, the few neuroimaging experiments that have so far measured changes in brain dynamics during the observation of magic effects have found that the same brain areas previously reported during problem solving and conflict monitoring tasks light up when the illusion of impossibility is experienced (Parris et al. 2009; Danek et al. 2015). But magic is, perhaps rather uniquely, a social, relational process. Magicians do not react to the observation of their own effects (Danek et al. 2015). In other words, magicians are probably the only artists who cannot trick themselves. Musicians can enjoy their own performance, and even a soccer game can be played in an empty stadium without affecting the result; for magic to exist, for the illusion of impossibility to occur, however, it is imperative that there be at least one spectator.

Related to this magic does not work the same in laboratory conditions and during real live sessions. In fact, the few experiments that, to date, compared the same effects by the same magician in both situations yielded quite different results (Shalom et al., 2015). And the same is true when other aspects of human cognition, such as the perception of beauty and artistic expression are judged directly in a museum and not in the aseptic laboratory environment (Leder and Nadal, 2014). The problem is that it is all too common for experiments outside the laboratory to sacrifice precision, accuracy and control for ecological relevance, making the comparisons difficult. However, magic, as we shall see, offers a very promising and virtually unexplored solution. With their ancient tradition, magicians have developed very controlled, perfectly repeatable routines that work for practically one hundred percent of their audience, without exception. Their effects interfere, either in isolation or concurrently, with almost all the cognitive processes studied in the laboratory, from attention and memory to perception and decision making (Figure 1). And they do it without sacrificing control for ecological relevance. Since the nineteenth century, most researchers have approached magic trying to understand its foundations from the postulates and techniques of psychology and cognitive science. The time is ripe to make the path in the opposite direction and take advantage of the enormous resources that magic offers to understand cognitive

processes using less reductionist and more integrative approaches and with great ecological and behavioral significance.

While new magic effects, compatible with current technological developments, are constantly being introduced, classic tricks have survived our own cultural and technical evolution and continue to be made as they were centuries ago with equal success, simply because they touch upon very relevant and universal cognitive mechanisms. Cups and balls, for instance, a magic trick already described by Seneca two-thousand years ago is very different from the 19th century Robert-Houdin's effect in which he simultaneously lit thousands of candles in the theater. While the former works because it depends exclusively on our perceptual and motor priors (evolutionary ingrained), the latter depends on our ignorance of the existence of electricity (culturally assimilated). The former continuous to amaze us today, the second is no longer included in magic shows.

Thus, we propose that the magic techniques that generate the illusion of impossibility are successful only because they take advantage of the strategies that we use to overcome our important limitations of capacity, extended processing time and relatively large energy requirements. As we will show, these techniques interfere with the basic mechanisms of sensory processing, attention, perception, memories as well as those of instinctive, learned and/or innate, decisions and behaviors. They take advantage of our strong unconscious biases and expose the automatisms and predispositions that characterize the functioning of our brains. They influence even our simple interactions with the physical and social world; and they do it very efficiently, unlike most of our cognitive experiments in the lab, they work in every show and virtually for every spectator in the audience.

However, the potential of harnessing these powerful magic techniques in research, especially in designing experiments with great ecological relevance, has been very scarcely exploited, probably due to a great mutual ignorance, and even suspicion, between the two fields. In this article we try to build bridges that help alleviate this gap by identifying cognitive processes that could be studied using magic techniques in more ecological and behaviorally relevant conditions.

The structure of a magic effect

A magical effect may tap into practically all the cognitive processes studied in the laboratory. In general, every magic effect has the following structure: a presentation or demonstration of an expository nature -with or without a plot or storyline- that ends with a climax or magic upshot. The duration of a magic effect can range from seconds to a few minutes. A magic game can contain one or more effects, and a magic routine consists of a set of effects or consecutive games. The magic effects that are the subject of this article are those that are performed live and produce the illusion of impossibility in the audience, in contrast to those seen on television and whose impact is generally much lower.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at *PeerJ* **2020**, *8*, e9712; doi:10.7717/peerj.9712

A central but seldom recognized conception in magic is that in every effect two different worlds coexist in parallel. According to the Spanish magician Arturo de Ascanio, the first world is called the "external life" of the effect and it consists of what the audience consciously experiences, sees, hears and touches. The second world, or the "internal life", includes everything that the magician secretly manipulates as the effect progresses (Etcheverry 2000) (Box 1). To achieve the illusion of impossibility it is necessary for the magician to coherently combine the obvious and patent actions of the "external life", with the concealments, secret maneuvers and the use of various gimmicks and gadgets, that live only in the "internal life".

Magic thus entails a complementary relationship between the magician and the audience; without spectators the magician cannot do magic. Through their actions, magicians create a new meaningful environment, an *umwelt* that provides a unique set of *affordances* (Von Uexkull 1926, Gibson 1979) that only they control, and that lead the audience to anticipate a solution which will, in the end, be frustrated by the great final surprise. Ascanio used to say that magicians need that all actions of the "external life" have, by themselves, a high degree of likelihood; they want them to follow logical and predictable sequences, without raising any suspicion, until the effect arrives at the magic finale, thus creating the maximum contrast between the initial situation and the outcome of the game. The most important aspect of the "external life" of the effect is that the structure and the elements of the presentation are all clear, obvious and coherent so that the public can follow them smoothly and be surprised when their expectations are violated at the end. The essence of the "inner life" is the skillful concealment of all secret manipulations. That is why magic is known as "the art of hiding the art (*ars artem celandi*)"; which has its maximum expression when, in the climax of an effect, the public expresses in amazement "no way, if s/he has done nothing!".

Cognitive processes involved in magic effects

To explain how magic achieves the "illusion of impossibility", we dissect in different sections the main cognitive processes involved and provide some representative examples of magic effects whose effectiveness rely on them. Most magic techniques and procedures in use today can be assigned to at least one of the eight sections we present below (Figure 1).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at PeerJ 2020, 8, e9712; doi:10.7717/peerj.9712

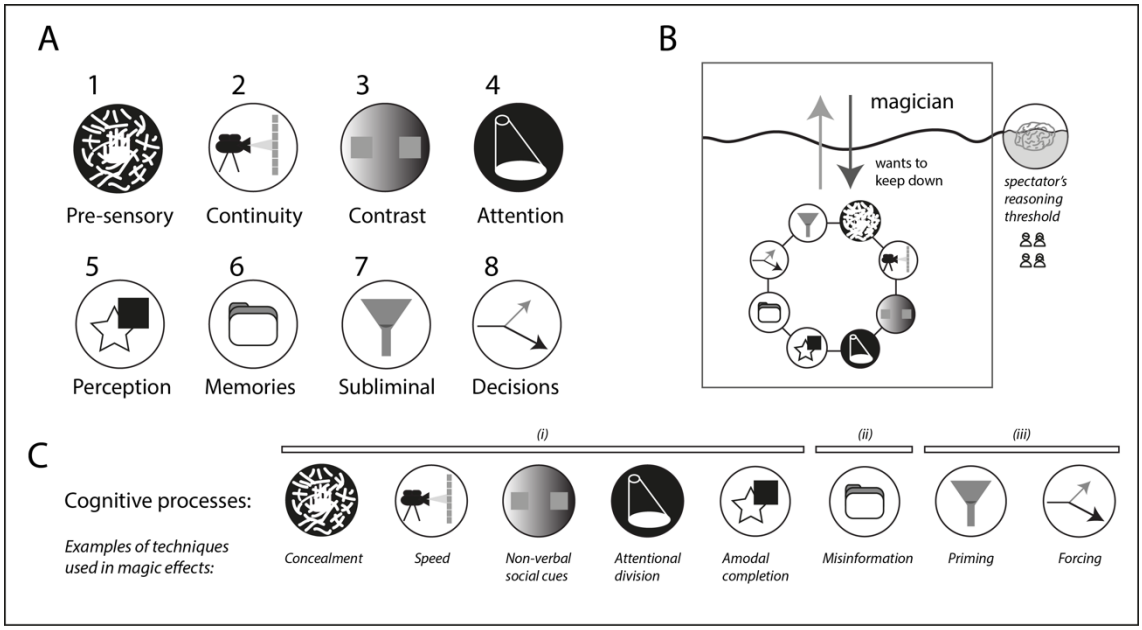

Figure 1. Cognitive processes involved in magic effects. (**A**) We sustain that every magic trick hijacks one or several of these, but only these, cognitive processes. (**B**) In the dynamics between the spectator and the magician, the magician tries to keep all these cognitive processes under the spectator's reasoning threshold. (**C**) Examples of techniques used in magic effects that correspond to the cognitive processes in (A), which can be grouped by the following sequence: (i) sensation, attention, and perception, (ii) episodic memories and (iii) judgement and decision-making.

1. Pre-sensory manipulations

A great deal of materials and methods that are used in magic effects involve the concealment or interference with the objects in a scene at a pre-sensory stage, i.e. prior to the activation of brain neurons and sense organs. Magic uses concealment very often and does so through very different techniques, such as direct physical covers, optical manipulations, disguise or camouflages. Simple examples of camouflage would be Black Theater or the use of decks of cards with the black back on a black mat in close-up magic. These pre-sensory manipulations are often combined with visual or cognitive illusions (Macknik et al., 2008) such as when a magician appears to bend a spoon effortlessly simply by rubbing it between the tips of his fingers. Sometimes magician's resort to the use of auditory masks, such as a certain musical score or a timely sharp noise to cover the sound of a secret contraption at any given time. In the large settings that characterize some "Grand illusions" (stage-magic with large displays), optical tricks are widely used, created through the presentation of black spaces, mirrors and other gadgets, allowing magicians to conceal or distort volumes at a certain distance. In addition to these optical manipulations, "Grand illusions" also benefits from the use of pre-sensory manipulations and visual and cognitive illusions, for instance when the perception of depth is concurrently altered using illusory perspectives.

2. Illusion of continuity

The challenges we face when interpreting even the simplest of scenes are daunting: from the inherently ambiguous information we collect filtered through the veil of our

sensory systems, to the relative slowness of our nerve circuits and their characteristically noisy nature, all these make it very difficult to integrate the rapid and continuous flow of information we receive into a coherent, seamless string of percepts and actions. By way of convention, we group under the concept of "illusion of continuity" those cognitive mechanisms that allow us to have a continuous and complete experience, both in space and time. In the case of vision, these include the phenomena of change blindness, our difficulty in perceiving detail at fast presentation speeds, and the processes that contribute to image fusion linked to iconic or sensory memories (Sperling 1960).

Some magic effects take advantage of the fusion or filling in mechanisms supported by iconic memory. This is the principle underlying Dani DaOrtiz's rendition of a famous trick by the nineteenth-century Peruvian magician "L'Homme Masqué" (DaOrtiz 2014). In that effect, the magician riffles in front of a spectator a deck of cards that contains the whole suit of hearts, with the particularity that the Queen of Hearts has been replaced by the Queen of Diamonds. Due to an effect of retinal persistence, this subtle change in symbol, red diamond instead of red heart, at the exposed upper corner of the card is imperceptible for the spectator as the entire red suit is riffled through at a relatively high speed. Magic also takes advantage of the existence of sensory persistence in other modalities, such as touch; that is the mechanism that allows a pickpocket to remove the watch from a spectator without her noticing. The artist, before and while undoing the strap, exercises light pressure against the wrist of the spectator, thus generating a brief "post-sensation" of still wearing the watch that prevents the astonished victim to realize that, in fact, this has already been stolen.

Magic effects also take advantage of those situations in which change blindness occurs (Rensink, O'Regan and Clark, 1997). [Change blindness is our inability to perceive even very obvious changes in a scene when they are introduced very slowly or after a brief visual interruption]. An example of change blindness in magic is the classic "Princess Card Trick", an effect that is found on the web in countless versions (we suggest that of Lance Burton in https://youtu.be/8CvwvskFhTY). In this effect, short-term memory and attention limits prevent the audience to consciously compare and realize that the first and second set of cards are all different. Another popular example in card manipulation is the Elmsley Count, a technique in which four different cards are apparently shown, but in reality two of them are the same, something that always goes unnoticed. A viral video of the magician and psychologist Richard Wiseman, published in 2012, the "Color Changing Card Trick", includes many examples of changes that go unnoticed by those who see it for the first time. As the author himself says at the end of the video, the presentation is not actually a card trick, but a very powerful demonstration of change blindness (https://youtu.be/v3iPrBrGSJM). John Henderson and Tim Smith, researchers at the University of Edinburgh, analyzed with an eye tracker the spectators' gaze and fixations while they were watching Wiseman's video (https://youtu.be/8wxbeEuGW00). Those who saw the video for the first time and did not notice the changes moved their eyes and explored the same parts of the scene as those who had already seen it and, therefore, already detected them. This confirms that what prevents naive observers from detecting the changes is not concealment or physical distraction, but the limits of

attention and short-term memory that normally operate when we observe any natural scene.

A third phenomenon related to the illusion of continuity gave rise to the classic magic concept of sleight-of-hand. Centuries ago the magicians discovered empirically that "the hand is faster than the eye", that is, manipulating speed could make their maneuvers invisible. This is how, sometimes, cards, coins, balls and other gadgets are hidden or concealed in front of the eyes of the audience without them noticing. The speed of movements in magic was studied scientifically for the first time in 1893, thanks to the support of the newly founded French Association of Prestidigitators presided by the magician and director of theater and cinema Georges Méliès. Méliès facilitated that two reputed magicians of the time, Arnould, a great professional mnemonic, and Raynaly, a stage magician, collaborate in the experiments of the psychologist Alfred Binet. Binet studied the magicians' maneuvers with a novel development (chronophotography) that allowed him to take about 10-15 photographs per second, and concluded that the effectiveness of many magic effects laid not only in the precision of the movements, but also in their speed, due to the inability of sight to perceive such rapid changes (Binet 1894; Thomas et al. 2016).

3. Fluency and contrast

"If the audience feels impelled to analyze why you did something, you've already lost the battle" (Ortiz, 2006). What we have already experienced in the past is easier to process in the present. It is said that it has more fluency (Alter & Oppenheimer, 2009). And on the contrary it is also true, things that are easier to process, those that are more fluent, generate an illusory sense of familiarity, even if we have never experienced them before (Whittlesea, 1993). Processing fluency biases our perceptions and judgments. We are more likely to judge easy-to-read statements as true (Reber and Schwarz, 1999). Even jokes written in a more readable font seem funnier (Topolinski, 2014). And art works that are easier to understand seem more aesthetically pleasing (Reber et al., 2004; Leder and Nadal, 2014). In sum, high perceptual fluency increases the experience of positive affect; and, as a consequence, greatly influences how we interact with others and with our surroundings (Reber et al., 1998).

The flip side of processing fluency is contrast. Brain circuits are very sensitive to contrast, i.e. the differences that emerge when comparing similar objects. A classic example in vision is the degree of difference between the lightest and darkest parts of a picture that drive On- and Off-center cells in the early visual pathway (Hirsch et al., 2015). This capacity to preferentially process relative differences has been extensively used in art to capture attention and engage the audience; for instance, when juxtaposing dissimilar properties, such as color or tone in a painting, or when introducing sudden emotional shifts or unexpected turns in the plot of a movie, a novel or a play.

Fluency and contrast are also very relevant in magic because they modulate the attentional state of the audience. When processing fluency is high and contrast at its minimum, we pay little attention and analyze situations only superficially, as long as our interactions with the environment continue to progress smoothly. On the contrary,

when processing fluency is low, contrasting situations abound and our interactions with the environment require more effort. We become more aware of the circumstances, pay more attention and tend to be more analytical to solve any problem that may arise (Alter et al., 2007; Song & Schwarz, 2008; Winkielman et al., 2003). As we will expose in the next cognitive process, during a magic effect, magicians must manage the attention of the audience at all times to be able to guide them inadvertently and without suspicion towards the impossible outcome. Occasionally, this might require to intentionally create a significant contrast between different elements of the game, be them physical or argumentative, to capture attention during key instants of the expositive phase. But more often than not, magicians need to work in the opposite direction, actively preventing the secret maneuvers of the inner life from attracting attention, effectively increasing processing fluency and avoiding contrast with the external life so that the games progress smoothly until their shocking ending.

This absence or avoidance of contrast is crucial to strengthen a presentation of the magic effect that the public considers logical and predictable. Neglecting these aspects causes low quality effects with a high risk of ruining the magic outcome. This is so because, under these conditions, processing fluency is very low, the audience loses the thread of the presentation and begins to ask themselves questions. In a magic effect, if what the public observes happens according to what is predictable, processing fluency is high, attention is relaxed and everything supposedly superfluous is discarded.

Magic theorists such as Darwin Ortiz or Arturo de Ascanio have written reference treaties exposing the rules and conditions to optimize this necessary avoidance of contrast in the presentation of magic effects (Ortiz 1999, Etcheverry 2000). In the presentation of an effect, theorists emphasize the importance of clarity both in the structure of the game and in the argument or plot of the presentation. At the same time, they highlight the importance of naturalness in everything that the magician explains and does. For this reason, for example, in magic with ropes the magicians strive to make the knots as anyone would. Along with clarity and naturalness, the importance of coherence and justification of all actions and movements involved is also stressed, since both confusion and unjustified movements raise suspicions and make the presentation thread lose. They also refer to the "economy" of the actions, in the sense of avoiding steps or movements that are superfluous. Finally, theorists emphasize the timing of the maneuvers and procedures –adequate synchronization to do everything at the right time– as well as the rhythm (cadence of the acts), all with the goal in mind of maintaining control over the audience's attention. Every action is in service of a common goal: not creating contrast and increasing processing fluency to not raise suspicions, and leading the audience smoothly towards the impossible outcome without asking questions. In sum, creating a plausible "external life".

Magicians have devised concrete techniques to avoid contrast and contribute to the logic and predictability of the presentation of the magic effect. These techniques include the use of ruses and feints, illusory correlations and the concept of familiarization or "conditioned naturalness." The use of feints or illusory correlations is very frequent in magic with coins. For example, some techniques of false deposit of coins begin with false maneuvers, when the magician passes a coin from one hand to another, first they do

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at PeerJ 2020, 8, e9712; doi:10.7717/peerj.9712

the action without cheating, which is the pre-conditioning phase, and then, when repeating the action, the trick, the false deposit, which leads to the "disappearance" of the coin is inadvertently added. As for illusory correlations, for example, when the magician needs to reinforce that in one hand or in another place there is more than one coin (especially when this is not true) the magician manages to produce the noise of the supposed coins entering into contact. "Familiarization", a concept already described by Dessoir at the end of the 19th century or "conditioned naturalness", as Ascanio later coined, refers to a special form of fluency, a kind of conditioning in a short space of time, where it is sought to normalize, always by priming and repetition, something that in any other context would attract attention (Dessoir 1983, Etcheverry 2000). For example, when magicians need to grab the deck of cards in a rare or unusual way at a given time, they prefer to condition the public already from the beginning of the effect with this uncommon grip.

Finally, it must be considered that contrast is not detached from context, therefore the circumstances through which the minimization of contrast is structured in magic always depend on the context of the presentations. The setting, the atmosphere and the type of public are decisive. It is not the same to do magic in the street than in a closed place, in a noisy or silent environment. In short, the same outcome can be very magic or completely anodyne depending on the scenario. Context is thus constitutive not just enabling (Gomez-Marin and Ghazanfar 2019).

4. Attention

Magicians have adopted the term "misdirection" from military to refer to one of their best tools: the control of attention. This term was consolidated in magic reference texts at the beginnings of the 20th century, like those of the legendary John Nevil Maskelyne (1911) and Harlan Tarbell (1927). In fact, magicians are true specialists in the subject. They have developed diverse techniques to control the spatial and temporal aspects of attention, including not only where we focus our attentional resources in space and time, but also how to deviate and divide them (Wonder 1994).

Let's start with the spatial capture of attention that is usually followed by its overt deviation. Magicians use their gestures and gaze to direct the public's attention to a particular place or focus away from the method. The aim of the deviation in magic is to create new areas of attention in order to perform some maneuver outside these areas of interest. In this sense there are several procedures for attentional exogenous capture (passive or bottom-up) and subsequent overt deviation (known among magicians as "physical misdirection"), such as the introduction of contrasting stimuli, the so-called “priority movements”, and the use of social cues.

The most used contrasting stimuli for exogenous attention capture are sounds (such as rhythms, changes in tempo or other musical scores), and surprising appearances, such as the production of some striking object in contrast to the main storyline. Beyond the trick itself, this is also the result, for example, of the classic rabbit that comes out of a hat, the visual impact of the igneous flash paper, or the sudden change in color of a handkerchief or the back of a deck of cards.

Magicians have also learned empirically that not all movements have the same attentional valence. A large movement can cover a small change (Suchow and Alvarez, 2011), and this, in the magic jargon, has been translated as “priority movement”, a concept that includes either the first movement that is performed or the movement that has greater amplitude. The study of movements in magic effects has received significant recent attention. In particular, it has been experimentally tested whether curved movements capture more attention than rectilinear ones (Otero-Millan et al. 2011, Tachibana and Gyoba 2015), if some locations and directions of movement in space are more salient (Stone, 2011), or the influence of relative speed in simultaneous trajectories (Hergovich et al. 2011).

Both for the recruitment and for the control of attention, social cues are a strategic resource often used in magic effects. Among the different aspects of nonverbal communication, the magician’s gaze plays a central role to such an extent that, in many magic effects, the control of attention depends almost exclusively on gaze control, always with the reinforcement of an appropriate body language. One of the most celebrated "misdirection" techniques is the "crossing of gazes" introduced by the magician Tony Slydini. This technique is based on using interacting gaze movements to deviate attention from the existence and handling of a small object in one hand (Tamariz 1981). Experimentally, it has been reported that social cues, beyond gaze location, can manipulate the audience’s attention effectively (Kuhn and Tatler 2005, Kuhn et al. 2008a and 2008b). In general, social cues strengthen the effectiveness of the magic effects, can be imposed on explicit instructions and allow manipulating the audience’s expectations (Cui et al. 2011, Hergovich and Oberfichtner 2016, Kuhn and Land 2006, Kuhn et al. 2009, Kuhn et al. 2016, Kuhn and Rensink 2016, Thomas and Didierjean 2016a and 2016b, Tompkins et al. 2016).

In contrast to exogenous capture, endogenous capture of attention (active or top-down) is linked to covert deviation (or "psychic misdirection" in magic). The covert deviation is achieved when the focus of attention of the audience shifts away to another place or thought, without necessarily having to mediate a change in gaze ("you look, but you do not see"). This covert deviation of attention is very important in some close-up magic effects and, in most cases, it is achieved through the use of dividing techniques. Divided attention, and its adverse consequences, such as inattentional blindness (Simons and Chabris 1999), is an increasingly current phenomenon, since human beings have adopted the use of mobile phone and other portable and wearable devices. Accidents associated to distractions related to the use of phones, texting or consulting the GPS while driving a car, or even while crossing busy streets, are now a issues of social concern. Magicians have acquired a secular experience with the cognitive limitations derived from dividing attention. Magicians use the division of attention both to hide methods and to hinder the reconstruction of the effect by the audience. With divided attention everything is a little easier for the magician, the spectators cannot assimilate everything that is happening on the scene, nor do they find out about certain maneuvers necessary for the method. In magic, the most used techniques to divide attention are the introduction of sudden distractions and demanding tasks.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at PeerJ 2020, 8, e9712; doi:10.7717/peerj.9712

Sudden distractions are achieved, for example, by asking extemporaneous questions. The magician Ascanio coined the concept of "obnubilant question", to describe these techniques of attentional interruption that are used to perform necessary maneuvers that need to go unnoticed, and that under normal conditions would have been very evident (Etcheverry 2000). Alfred Binet described them with the following example: "Suddenly I ask the spectator sitting in front of me: Do you know how to count to sixty? The spectator looks at me, self-conscious, not knowing how to answer the question; the others look at him with a smile; it only lasts a second, which is enough to peek at the card" (Binet, 1894). The introduction of demanding tasks is also a common feature of magic shows, especially use with those spectators invited to participate in effects. For example, if a spectator is asked to find a specific card in a deck, checking his cards one by one, and then counting its position from the beginning, the situation is demanding enough that most of us would not realize that the cards are sorted in a certain way or repeated, for example.

We have mentioned that the temporal control or continuous direction of attention is as important as its spatial control. The attention of the audience fluctuates throughout a show. Spectators spontaneously look for moments of relief and can be easily distracted. The goal of the magician is to temporarily capture attention, control it during the entire expository phase of the effect, and make ensure that during this period the spectators' trains of thought do not proceed on their own. Temporal control of attention is a goal in itself during a magic effect, not only to prevent the audience from discovering the method, but also to ensure that they understand the entire expository phase so that no undesired contrast occurs and processing fluency remains high. Beyond naturalness and clarity, timing and rhythm of the maneuvers are key for the continuous direction of attention since they create different attention hotspots and areas of interest in the service of the magical effect (Barnhart et al. 2018). If the temporal control of attention fails, the audience is distracted, does not follow the magician, and the magic is ruined.

For the continuous direction of attention, magicians use all kinds of personal, plot and stage resources. Among personal resources, everything related to the character that is introduced, its appearance, outfits and its way of speaking and presenting are relevant. Plot resources, beyond the quality of the narrative that we have already highlighted, can be very varied. A common example is the introduction of expectations, even those of fake failure, which help to continuously increase curiosity as the effect progresses. And, as for the scenic resources, it is necessary to emphasize the importance of lighting and music in certain effects. Specially in magic of "Grand illusions" music is fundamental to synchronize the attention of the audience and to punctuate or highlight very specific moments along the way that enhance intermediate outcomes or the power of the final climax.

The continuous control of attention is a key requirement and probably a unique and characteristic feature of magic. The illusion of impossibility is never achieved if the spectator sees the effect halfway; one has to follow the presentation of the effect completely, from the beginning to the end. Magic, and perhaps cognition in general, are serial, not sequential, phenomena and this contrasts sharply with the way we design cognitive experiments in the lab based on a sequential accumulation of trials. Therefore,

magic is a very demanding task both for the magicians and spectators, and that is why magicians have become true experts in the collective control of attention, at once, in real time, and for everyone. However, since temporal control of attention is a function directly dependent on the very limited short-term memory, this continuous demand has other derivatives and the formation of memories of the magic show is subject to great stress. The demand for continuous attention, coupled with the excessive information that is generally provided during the exposure of various effects, drains and saturates the public, and may even affect the ability to correctly perceive a scene (Ling and Carrasco 2006). The father of modern magic, the legendary magician Robert-Houdin, already warned about this, prescribing that magic shows should have a limited duration (Robert-Houdin 1868).

Finally, moments of complete deactivation of attention (known as “off-beat” moments) are also very important for the purposes of magic. Magicians achieve a complete deactivation of attention, for example, when they induce collective laughter through humorous gags or collective clapping, including post-climax applause, that occurs during some games containing various effects. The complete deactivation allows the magician to make arrangements or manipulations (changes of decks, loads or downloads, etc.), often in plain view without the audience being aware of it.

5. Perception

Magic effects interfere with perceptual phenomena, understood here as the cognitive processes of close-loop inference and interpretation that emerge to compensate for the limitations of capacity and slowness of cerebral processing in highly dynamic environments (Ahissar and Assa, 2016; Friston, 2018). Perception operates generating adaptive predictions based on past experiences from memories (Clark 2013). The fact that the human brain anticipates the future is something that the world of magic has learned empirically and that considers in the production of magic effects.

Indeed, most magic effects rely on breaking expectations and have a totally unexpected outcome. When the audience is not in a position to anticipate what will immediately happen, the capacity of the magician to have a continuous control of attention is greatly increased. The brain is very good detecting novelty, when something is observed for the first time it captures attention very efficiently. Thus, magicians never reveal in advance the full nature of an effect, so that the spectator does not know where to focus attention. On the contrary, when the audience can predict what is going to happen next, they stop making the same effort, being able to turn attention inconveniently towards other details potentially ruining the effectiveness of the effect. This reduction of the attentional effort is consistent with the perceptual fluency heuristic mentioned above (Whittlesea and Leboe 2000).

There is a related precept in magic according to which it is necessary to avoid making effects always with the same method in the same presentation, or the same method more than once in the same effect. Indeed, there is a tendency to consider that things that are repeated over and over again have the same cause. A continuous repetition of methods encourages the audience to test any perceptual hypothesis that has been

raised before and be convinced that what is repeated is always done in the same way. If the audience sees exactly the same over and over, it will be progressively better able to anticipate what will happen next and it will be able to grasp inconvenient details. The magician will lose the ability to control the attention of the public and the effectiveness of the magic outcome will be jeopardized. For this reason, in effects in which actions are repeated, magicians tend to continually change method. Consistent with this, Kuhn and colleagues have experimentally confirmed that manipulation capacity is extinguished by repetition, and that, in general, prior information about the magic effect being performed significantly increases the probability that the participants detect the method (Kuhn and Tatler 2005, Kuhn et al. 2008a and 2009, Kuhn and Findlay 2010). Although some simple maneuvers, such as those based on the false deposit, seem to be more resilient to repetition (Cui et al. 2011, Otero-Millan 2011).

The inferential, automatic and unconscious nature of perceptual processes leads to consistent predictions that magicians can hijack to construct surprising effects. For example, when partially hidden objects are presented to an audience, the visual system automatically and immediately fills in the invisible parts of the objects, even when the information is very scarce, a phenomenon known as amodal completion (Kanizsa 1985). This phenomenon follows gestalt laws, it is difficult to master for a magician but it provides great advantage in certain effects, especially in the magic of ropes (Barnhart 2010), in that of bent spoons or in the Chinese rings. Also, in cardmagic, there is amodal completion in the effects of the “torn and restored card” or in those of “linking cards”. In all these cases, the magician's hand acts as a screen, partially covers the objects at certain times, in circumstances in which the public tends to interpret what is hidden in a very different way from reality. In Chinese rings, when the magician shows the ring by covering the small opening key, a complete ring is automatically perceived. What is behind the screen is never questioned, escapes conscious control, because the process of filling-in acts by default, never fails and it is immediate. The same effect can be repeated again and again. A very striking case is that of manipulating balls, where the illusory experience persists even when the spectator knows that semispherical shells are used instead. The three-dimensional curvature of the visible surface of the object is sufficient for it to be perceived as a sphere, the audience remains with this perceptual solution and no other alternative is explored (Ekroll et al. 2013, Ekroll and Wagemans 2016, Ekroll et al. 2016). This phenomenon, known as "attribute substitution," underlies many magic maneuvers, including those based on image sequences such as the "Flushtration Count," a misleading way of counting cards (Thomas et al. 2018).

In general, partial concealments in magic allow spectators to interpret incomplete information and automatically perform perceptual filling-in. Sometimes, this perceptual completion is based on assumptions constructed through experience in relation to environmental regularities. Barnhart believes that one of the assumptions most used by magic spectators is symmetry, both in static situations and in sequences of actions (Barnhart 2017). In addition, amodal perception resists repetition very well, unlike the capture and active deviation of attention, whose effectiveness decays very rapidly in successive passes (Ekroll et al. 2018). In magic, concealments based on amodal perception have the advantage that they invoke automatic assumptions of the visual system that are not suspicious, that do not induce the spectator to “rewind” or think

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at PeerJ 2020, 8, e9712; doi:10.7717/peerj.9712

about the method behind the effect, they do not contrast with the intended flow of the game. Ekroll and colleagues recently claimed that these automatic inferences are "cognitively impenetrable perceptual mechanisms", that do not reach the conscious level; and they go on to suggest they must play a central role in many magic effects that has been often ignored because of the disproportionate weight traditionally assigned to "misdirection" and other forms of attentional control (Van de Cruys et al. 2015, Ekroll and Wagemans 2016, Ekroll et al. 2017).

The flip side of amodal completion is amodal absence, the phenomenon by which what we do not see does not actually exist. This is the basis of many concealments, such as hiding coins in one hand, or the convincing illusion of empty space surrounding levitating objects and persons. Like amodal completion, amodal absence is also considered a perceptual, automatic and unconscious illusion (Andersen et al. 2017, Ekroll et al. 2017).

6. Episodic memories

The construction of magic effects includes techniques for manipulating episodic memories, either at the service of the effect itself or to prevent the public from reconstructing the method afterwards. Already in 1973, the renowned Spanish magician Juan Tamariz wrote: “The magician has to know how to cause gaps in the memory of the spectators to make them forget what we want for the magic effect, or make them believe they remember things that did not really exist...” (Tamariz 1988[1]). Accordingly, some magic techniques have been developed to distract, affecting the codification and consolidation of memories, misinform, hinder recall and promote forgetfulness.

For the promotion of forgetfulness, common techniques are related to the deviation and division of attention, and the so-called “time misdirection”. When a magician diverts attention during an effect, the rationale is that there is a weakening of the codification and consolidation of the information captured at that moment (Quian Quiroga 2016). One can also promote forgetting by dividing attention through highly distracting comic gags, or tone outings with extemporaneous questions. On the other hand, "time misdirection", the equivalent to Ascanio’s "parenthesis of forgetfulness", introduces a temporal (and sometimes spatial) distance or delay between the moment of the method and that of the effect resulting for that method (Etcheverry 2000, Fraps 2014). There is already some experimental evidence on the relationship between the time separating method and outcome and the potency of the magic effect (Beth and Ekroll 2015).

Misinformation can affect recapitulation by distorting long-term memory recall. Magic techniques take advantage of the fact that the entrance door to episodic memories, short-term memory, saturates easily. These techniques generally create overwhelming situations in which the audience is flooded with an excess of information. The magician Juan Tamariz is known for having developed a special ability to induce false memories in his audience, especially when recapitulating the game, as he makes a point of explicitly detailing having shuffle and cut the cards in a way that, in reality, was never done. The magician Dani DaOrtiz performs an effect, called "The One", in which, after

[1] This text was in circulation in a type-written copy 15 years earlier in a compilation called “Secretos de Magia Potagia”.

discreetly forcing a card to a spectator, he manages to get the audience to think that the card has been "thought" freely by the spectator (DaOrtiz 2011). It has not yet been investigated to what extent the memory errors induced by Tamariz or DaOrtiz are homologous to the false memories described in the scientific literature (Loftus 2003), what is indisputable is that their magical routines based on misinformation generate similar effects in a much shorter time span, the few seconds or minutes that a game lasts, and without the need for repetitions or reinforcements.

When spectators grasp how magic works then they have a feeling similar of an “aha!” moment. Beyond the distinct frequency of "aha!" moments, it seems that these are correlated with the subsequent memorability of the magic effect (Danek et al. 2013, 2014a and 2014b, Hedne et al. 2016). It has been proposed that audiences are "biologically" impelled to discover the secret behind the method of a magic effect, seeking to regain the cognitive control that has been disrupted by the magician (Prevos 2013). Throughout this inevitable search for solutions, magicians are aware that the public has “aha!” moments when they believe they have deduced the method. Whether they are right or wrong does not really matter, these moments can either way ruin the magic effect at more than one level, even if they lead to the wrong deductions (Ortiz 1999). Although some spectators may realize the moment when the magician executes the method, this rarely helps them solve how the magic effect occurs (Demacheva et al. 2012). Still, when an idea-solution appears in mind as reasonable, it is very difficult to consider other alternatives, a phenomenon known as the Einstellung effect (Bilalić et al. 2010). Therefore, anything else that at this point the magicians presents to us will be likely filtered out, affecting the experience of the game. In addition, most naive spectators tend to overestimate the ability of other members of the audience to deduce the method behind the effect, especially if they themselves believe they have discovered it (Ortega et al. 2018). All this is relevant for a magician and in order to manage the “aha!” moments during their shows, magicians know that the first requirement is to avoid contrast, to increase perceptual fluency, making sure that nothing attracts abnormal attention throughout the presentation of the effect. To control the emergence of “aha!” moments and the audience’s intuitions, magician Juan Tamariz has proposed techniques to introduce “false clues” at relevant moments designed to create false expectations or to subtly suggest controlled wrong solutions (Tamariz 2011). So far, few studies have begun to experimentally validate these proposals (Thomas and Didierjean 2016, Thomas et al. 2018).

Juan Tamariz gives great importance to what the magician can do during the show to control the memories that the audience take home, both to distort and specially to magnify the magic experience (Tamariz 2016). We wonder if these magic memories are similar to those acquired in especially emotional circumstances (flashbulb memories), in which the vivid memory of the experience does not guarantee the trustworthiness of its details (Hirst et al. 2015). Along these lines, memorability studies on supposedly paranormal experiences (some published more than 130 years ago) show that memories are very unreliable, and that, depending on the circumstances, there is a propensity to remember events that have not happened (Hodgson and Davey, 1887, Besterman 1932, Wiseman and Morris 1995, Wilson and French 2014). Subjects are also susceptible to manipulation through suggestion and instructions (Wiseman et al. 2003, Wiseman and

Greening 2005, Wilson and French 2014). We believe that these studies can be a good reference to plan the necessary and non-existent studies on the subsequent memorability of magic shows, and it is tempting to speculate that only the emotional details of the magic experience are remembered.

7. Subliminal effects during magic tricks

The inner life of a magic effect, even when it is not consciously processed by the audience, might leave an unconscious, weak, and ephemeral trace ("sometimes the audience feels the trick even if they do not perceive it" in words of Spanish magician Miguel Angel Gea), that might end up having an impact on the experience of the magic effect, or even its potential reconstruction afterwards (Gea 2017, see also Kawakami and Miura 2017). This could explain why the same magic routine, performed by different magicians, does not necessarily achieve the same magic potential, even when it is always allegedly done in the same way, using the same techniques, and with the same procedures.

It is also well known that, through priming —a phenomenon related to implicit memories— there is the possibility of influencing attitudes, perceptions and choices unconsciously (Dehaenne et al. 1998). Magicians are masters conditioning responses and surprising the public by "predicting" the choices that a spectator will make. There are experienced magicians even capable of achieving primacy effects during the seconds or few minutes that the presentation of an effect would last, influencing the subsequent choice of the audience through direct or indirect cues (for example, color, suit, card value, etc., see next section). It is difficult to think of a more ideal scenario to investigate subliminal perception, and how subtle interpersonal differences can influence memory processes and conscious reasoning in ecological conditions.

8. Instinctive decisions [Forcing, manipulating decisions]

When magicians interact directly with the audience, especially when inviting spectators to participate in any of their effects, they often asked them to answer questions or make decisions. Magicians look for these responses to be as automatic and instinctive as possible. They don't want reflexive answers that can lead the audience to process relevant information for the subsequent reconstruction of the game. They just want to control the audience's attention and influence their decisions. Magicians have developed very robust techniques to induce choice and manipulate responses. In the magic slang they are called "forcings" and they seek to overwhelm the spectator by not giving them time to think or reflect, and controlling all the reactions of the spectator. The main characteristic of a good "forcing" is that the spectator always considers that they have made a free choice (Shalom et al. 2013, Olson et al. 2015, Olson et al. 2016). Even in those cases, when they subsequently rationalize the causes of their decisions, they end up justifying them using fallacious arguments, which the magician knows have not been part of the choice set, a situation that has been dubbed "choice blindness" (Johansson et al. 2005, Johansson et al. 2006).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at PeerJ 2020, 8, e9712; doi:10.7717/peerj.9712

There is a wide spectrum of forcings, from automatic techniques (which always lead to the desired result), to techniques that seek to obtain the most probable answers (the result of which is not sure a priori, and which are known in magic as "psychological forcings"). In cardmagic, many automatic techniques are based on mathematical methods. There are also more complex techniques, which depend on the skill of the magician, such as the so-called “magician forcing”, in which the artist controls and varies the type of questions he asks the spectator as he chooses between different options, always arriving to the solution originally designed by the magician. Some forcings are also based on the use of visual prominence; such as, for example, exposing a given card for a longer time in a subtle way, a subliminal influence that is also rarely noticed by participants (Shalom et al. 2013, Olson et al. 2015). In the field of riskier forcings, the reference in cardmagic is the so-called "classical forcing", a technique that has been practiced identically since at least the nineteenth century (Triplett 1900) and whose effectiveness, which can be of 100%, is totally dependent on the training and experience of the magician. It consists of inviting the spectator to choose “freely” a card from the deck offered by the magician after presenting all the cards in a fan. The selection appears to be free, although in reality it is a forced delivery. Essentially, the key to this forcing lies in the magician's control of the spectator's reaction time. One prominent variant that requires the use of social cues is DaOrtiz’s "forcing at the stop", in which spectators are invited to choose a set of cards as he sequentially leaves them face down on the table (DaOrtiz 2010 and 2011).

There are other techniques of "psychological forcing" where situations or questions arise in which the magician expects the spectator would have a very specific type of reaction or response. Since it is not possible of obtaining the expected response with 100% certainty, in these cases the magician always has a "way out" or plan B to solve the situation. In these forcings, sometimes a previous “priming” of the response is introduced. In others, the magician risks the spectator giving the most probable automatic response. If several cards or piles of cards are set up on a table, magicians know that right-handed people tend to choose the card or pile placed in second position counting from their right. Other authors have already described comparable behaviors of choice using everyday objects (Nisbett and Wilson, 1977).

In other instances, magicians seek to obtain specific verbal responses, always under pressure and creating very specific contexts. For example, frequent or prototypical word responses stored in semantic memory, such as "a canary is ... yellow." In this line, many magic effects have been designed based on asking the audience to name colors, numbers, geometric shapes, objects; it has even been described that some expected answers are different according to the genre or the context in which they are formulated, although none of it has been experimentally tested. Magicians usually go after prototypical or representative responses of a certain category or class. Among animals, a cat and a dog are more frequent or representative responses than a kangaroo, but magicians (like linguists) also know that the words characteristic of a given category vary widely in different cultural contexts. If in Spain we are asked about a vegetable, we may say lettuce or tomato, but we will almost never say carrots or pickles that are the vegetables that come first to the minds of Americans. This type of “psychological forcing” likely depends on the heuristic of availability (Tversky and Kahneman 1973).

When the magician asks a spectator to say a number between 5 and 10, or even between 1 and 10, the probability that the answer is number 7 is very high. This has been exploited in magic for centuries (Binet 1894, Kubovy and Psotka 1976). Olson et al. 2012, have experimentally studied the perceptual characteristics of the cards of the French deck, observing that some are visually more accessible, others are better remembered and some are chosen more often than others, being among the most appreciated the Ace of Hearts, the Queen of Hearts (mainly in men) and the King of Hearts (mainly in women). There are still no studies that have reproduced these observations, although they are compatible with the experiences available in the world of cardmagic. Beyond the search for the most likely answer, magicians have also empirically learned the importance of framing. Although they may seem similar instructions, the results of a card game vary surprisingly greatly depending on whether the magician instructs the spectator to think, choose, indicate, point, touch, or take a card.

Outlook: A road not taken towards real-world neuroscience

The relation between science and magic has so far been mostly unidirectional, based on the work of a few scientists doing research to unravel how magic works (Figure 2A). The first formal experiments date back to the end of the 19th century (Lachapelle 2008). Among them are the pioneering studies of psychologists such as Alfred Binet or Joseph Jastrow (Binet 1894, Jastrow 1896). At the beginning of the 20th century, scientific interest in magic declined completely in part as a result of the irruption and progressive popularity of cinema. It has not been until very recently that the scientific community has regained the interest for illusionism. The leadership is of psychologists that are also magicians, among them Gustav Kuhn and colleagues stands out. He was the author of one of the first experimental studies on the perception of a magic effect and divided attention (Kuhn and Tatler 2005) and of a recent extended review on the “Science of magic” topic (Kuhn 2019).

We propose to take a different but complementary route, reversing the direction of the explanatory work. Rather than using brain and behavioral sciences to study magic we want to emphasize the opportunity to use of magic to study brain and behavior (Figure 2B). To that end, in the present manuscript we have proposed a comprehensive taxonomy of the phenomenon of magic based on eight main cognitive processes. This is in contrast with previous efforts that have been centered on the magic effects themselves, drawing from cognitive sciences in order to explain them (Lamont and Wiseman 1999, Kuhn et al. 2014, Macknik et al., 2008). Thus, we propose to update and revisit the powerful arsenal that ancient magic techniques provide as a unique, and we believe untapped, tool to improve our research strategies.

The different cognitive processes involved in magic effects we analyzed here suggest untrodden areas of research for which magic could contribute to a better understanding of human cognition. Let us mention a few. The lack of knowledge about the components of the cognitive dissonance that the illusion of impossibility entails stands out.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at PeerJ 2020, 8, e9712; doi:10.7717/peerj.9712

Moreover, there are huge differences in the experience of magic depending on the context in which it is performed. This extends to the cultural background of the spectators. Inter-individual differences in the reactions of the magic audience can also be large. In particular, it is well known that magic is very different if it is directed at adults, children or magicians. Children, unlike adults, often detect many details of the methods behind the effects that have been designed for more mature audiences. Magicians rarely experience the illusion of impossibility because they are well versed in the art, but enjoy the technical abilities and conceptual innovations of their peers. Last, the low popularity of magic (compared to cinema or fiction series) and the potentially negative implications associated with the consequences of magic effects (arguably unattractive to humans from an evolutionary stand point), are all surprisingly still open questions.

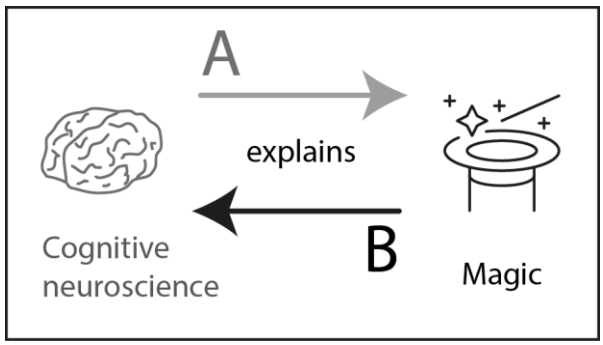

Figure 2. The dual relationship between the art of magic and cognitive neuroscience. One can use (A) cognitive science to explain magic or (B) magic effects to study cognition. Here we propose to explore and exploit the second untrodden path.

Beyond the variety of questions that emerge when considering cognition under the lens of illusionism, there is an over-arching challenge to which magic can help make a fundamental contribution: the move towards a real-world neuroscience. Brain and behavioral sciences thrive in laboratory conditions. And yet, we wonder ourselves if the processes we measure in such artificial contexts accurately capture the phenomena as they occur in the real world. Actually, the very experience of the effectiveness of magic in real situations, when compared to that of studies done in the laboratory, invites to re-examine many paradigms in cognitive science that have eluded an ecological approach. Moreover, most of the extant few investigations have been carried out in extreme laboratory conditions, with a very limited number of participants, presenting the effects of magic on video rather than live, and performing the experiments almost always without a representative audience. Note that, while in these laboratory contexts it is generally considered a success when 60% of positive results are achieved, in a live magic session in front of an audience the magician cannot settle for less than 100 percent of his audience experiencing the illusion of impossibility, no exceptions!

In ending, let us point out how the art of magic can provide tangible opportunities to pressing challenges in cognitive science. In a way, what we are proposing here is that the scientist adopts the role of the magician. First, a simple magic trick can integrate many different cognitive processes at once. Conversely, one can design magic effects

that target a particular cognitive process. This allows the experimental dissection of cognition in tasks arguably more natural than those usually exploited in artificial laboratory settings. Second, note that when bringing participants in the lab, one may assume that getting rid of context implies that there is none. And yet, as in a party without a dress code, everyone brings their own. Not falling prey to this fallacious assumption, magicians excel at submerging every spectator into the precise experimental protocol they have previously designed. This can be of great help to scientists studying human and non-human cognition in their struggle to have a cognitive task that really works. Third, magicians do not base the success of their experiments in statistical measures that smear out the individual in favor of an average spectator that never exists in the real world. They target each and everyone in the audience and, often, with a complete accomplishment. Fourth, it is remarkable that magicians deliver their cognitive manipulations in real-time, in tight closed closed-loop with the audience, and in a single trial (they cannot afford to repeat the trick if it fails). Finally, magic offers a subject-centric approach to cognition that integrates first, second- and third-person perspectives, thus allowing for neuro-phenomenological approaches. All of these vital scientific points are thus feasible and encapsulated in the nature of the magic effect. Combined with the wide range of precise measuring technologies available today (such as video tracking based on computer vision and deep learning, eye tracking devices, wearables quantifying different physiological states, EEG recordings, etc.), they pave the way for a road not taken towards real-world cognitive science.

Illusions are also interesting from a normative perspective, since they defy the notion of optimality in perception and decision making. Beyond the individual behavior, magic has also an inherent and strong social component, naturally merging the private cognitive processes of each spectator with the group dynamics that spontaneously emerges from cues such as applauses or laughter. As mentioned above, magic also offers a scientifically untapped angle to study cognition from a developmental point of view, reflecting how cognition morphs from children to teenagers to adults. In addition, magic provides cognitive sciences with a rich pool of subtle and unexpected differences when it comes to populations, including magicians versus profanes, as well as cultural backgrounds. Beyond cognitivism, the role of enaction and embodiment theories in the understanding of the illusion of impossibility remains to be worked out. Finally, the cognitive study of illusionism represents a true field of integration between scientific and artistic practices.

Drawing the analogy between science and magic further also reveals uncharted conceptual territory. Consider the existence of the two realities that coexist in the magic effects, the internal and the external life. It is not far-fetched that magicians conceive and perform their magical effects in a comparable way as to how nature operates. Thus, in trying to disentangle the secrets of nature, scientists may be comparable to the spectators of a magic trick, impelled to decipher how it works from their own particular and limited point of view. We dare to speculate that the some of the mysteries of how the brain works may be trapped in the same split realities as that of the magic effect.

In sum, for neuroscience to benefit from the polished methodology, overwhelming successes, and unique perspective of magic, it is essential that the joint work between magicians and scientists continues. This is a cross-disciplinary area of research for which

there is an immeasurable pending journey. Indeed, since the end of the 19th century to date, the actual experimental articles (excluding revisions and editorial works) in which magic effects have been used either as a resource or as a research goal do not reach a hundred. It is a ridiculous figure from all points of view. One only needs to compare it with that of any other scientific area of study. Therefore, it would not be an exaggeration to claim that, when it comes to the relationship between magic and science, everything is virtually yet to be done. We hope that the work presented here contributes to arise greater interest in magic amongst neuroscientists (psychologists and cognitive scientists included). We believe that our dissection of the cognitive processes behind magic provides a valuable toolbox to expand our knowledge of how the cognition works. This is a unique opportunity that brain and behavioral sciences should not miss.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 January 2020 doi:10.20944/preprints202001.0011.v1

Peer-reviewed version available at *PeerJ* **2020**, *8*, e9712; doi:10.7717/peerj.9712

Box 1. Proposal to "deconstruct" a magic effect

Below are the details that contain a specific magic effect, exclusively in relation to the techniques and methods based on and with cognitive consequences. Although all magic effects may contain techniques and methods from many different disciplines, in this case the different cognitive mechanisms that it includes have been identified. They are not easily standardized exercises since many magic effects that give rise to the same outcome can be constructed and materialized in very different ways throughout one's internal life, using different materials and methods. That is, there are generally several apparently identical versions of the same effect, although they are not strictly the same because the methods used are different.

The game chosen for its deconstruction here is the "Homing Card" by the magician Francis Carlyle. It contains many maneuvers related to attention. As illustrated in Figure 3, the game takes place in three phases, each phase is an effect, that is, each phase has its own outcome or climax. The main feature is that a card freely chosen by the audience and then signed travels surprisingly from the deck to the magician's pocket. This happens in the first two phases. In the third phase, what travels to the magician's pocket is the entire deck except for the chosen card, which is the only one that remains in the magician's hand.

This game is based mainly (although not exclusively) on successive captures and deviations of attention. It depends as well as on several physical concealments, including some card palms and card manipulations, that must be well executed to prevent the generation of contrast. At the end of the third phase, when the magician only holds a single card in his hand, a phenomenon of amodal completion makes the audience consider that he actually holding the entire deck.

We present the deconstruction similar to the original, made by the magician Tino Call (see Figure 3 and details of the effect in https://youtu.be/BVvmtv2D8MU)

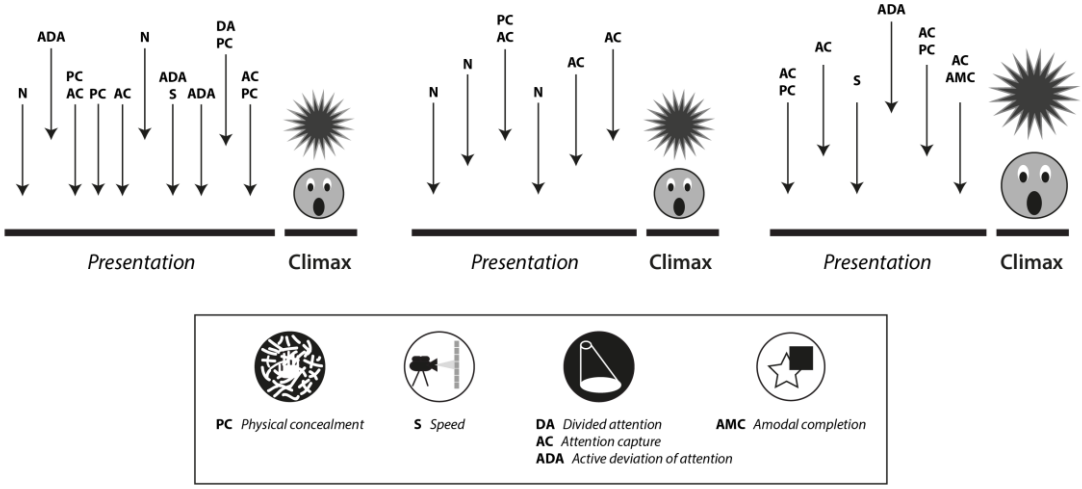

Figure 3. "Deconstruction" of the "Homing Card" effect by Francis Carlyle according to the version of Tino Call. The figure depicts that the game takes place in three phases, each with its own climax. In the internal life of each phase there are several maneuvers of attention control and concealment. Note that no phase is identical to each other (although apparently the same things happen in the first two).

References

- Alter AL, Oppenheimer, DM. Uniting the Tribes of Fluency to Form a Metacognitive Nation. Pers Soc Psychol Rev. 2009;13:219-35.

- Alter AL, Oppenheimer DM, Epley N, Eyre RN. Overcoming intuition: Metacognitive difficulty activates analytic reasoning. J Exp Psychol Gen. 2007;136:569-76.

- Ahissar E, Assa E. Perception as a closed-loop convergence process. eLife. 2016;5:e12830.

- Andersen S, Ring A, Svalebjørg, Ekroll V. The role of perceptual mechanisms in creating the illusion of levitation. [Abstract]. Science of Magic Association Meeting, SOMA 17. Goldsmiths University of London, 2017.

- Barnhart AS, Ehlert MJ, Goldinger SD, Mackey AD. Cross-modal attentional entrainment: Insights from magicians. Atten Percept Psychophys. 2018;80:1240-9.

- Barnhart AS. The exploitation of Gestalt principles by magicians. Perception. 2010;39:1286-9.

- Barnhart AS. The symmetry of deception: Predictability reduces attention toward symmetrical actions. [Abstract]. Science of Magic Association Meeting, SOMA 17. Goldsmiths University of London, 2017.

- Besterman T. The psychology of testimony in relation to paraphysical phenomena: Report of an experiment. Proceedings of the Society for Psychical Research. 1932;40:363-87.

- Beth T, Ekroll V. The curious influence of timing on the magic experience evoked by conjuring tricks involving false transfer: Decay of amodal object permanence?. Psychol Res. 2015;79:513-22.

- Bilalić M, McLeod P, Gobet F. The mechanism of the Einstellung (set) effect: a pervasive source of cognitive bias. Curr Dir Psychol Sci. 2010;19:111-5.

- Binet A. La Psychologie de la Prestidigitation. Rev Deux Mondes. 1894;125:903-22.

- Clark A. Whatever next? Predictive brains, situated agents, and the future of cognitive science. Behav Brain Sci. 2013;36:181-204.

- Cui, J, Otero-Millan J, Macknik SL, King M, Martinez-Conde S. Social misdirection fails to enhance a magic illusion. Front Hum Neurosci. 2011;5(103):1-10.

- Danek AH, Fraps T, von Müller A, Grothe B, Öllinger M. Aha! Experiences leave a mark: Facilitated recall of insight solutions. Psychol Res. 2013;77:659–69.

- Danek AH, Fraps T, von Müller A, Grothe B, Öllinger M. Working Wonders? Investigating insight with magic tricks. Cognition. 2014a;130:174-85.

- Danek AH, Fraps T, von Müller A, Grothe, B, Öllinger M. It's a kind of magic—what self-reports can reveal about the phenomenology of insight problem solving. Front Psychol. 2014b;5:1408.

- Danek AH, Öllinger M, Fraps T, Grothe B, Flanagin VL. An fMRI investigation of expectation violation in magic tricks. Front Psychol. 2015;6(84):1-11.

- DaOrtiz D. Libertad de expresión: el forzaje psicológico y psicología en el forzaje. Málaga: Grupo Kaps; 2010.

- DaOrtiz D. Utopía [DVD]. Essential Magic Collection. Luis de Matos, editor; 2011.

- Dehaene S, Naccache L, Le Clec'H G, Koechlin E, Mueller M, Dehaene-Lambertz G, van de Moortele PF, Le Bihan D. Imaging unconscious semantic priming. Nature. 1998;385:597-600.

- Demacheva I, Ladouceur M, Steinberg E, Pogossova G, Raz A. The Applied Cognitive Psychology of Attention: A Step Closer to Understanding Magic Tricks. Appl Cogn Psychol. 2012;26:541-9.

- Dessoir M. The psychology of legerdemain. The Open Court. 1893;12:599-606.

- Ekroll V, De Bruyckere E, Vanwezemael L, Wagemans J. Never Repeat the Same Trick Twice – Unless It Is Cognitively Impenetrable. Iperception. 2018;9(6):1–14.

- Ekroll V, Sayim B, Van der Hallen R, Wagemans J. Illusory visual completion of an object's invisible backside can make your finger feel Shorter. Curr Biol. 2016;26:1029-33.

- Ekroll V, Sayim B, Wagemans J. Against better knowledge: The magic force of a modal volume completion. Iperception. 2013;4:511-5.

- Ekroll V, Sayim B, Wagemans J. The Other Side of Magic: The Psychology of Perceiving Hidden Things. Perspect Psychol Sci. 2017;12:91-106.

- Ekroll V, Wagemans J. Conjuring Deceptions: Fooling the Eye or Fooling the Mind? Trends Cogn Sci. 2016;20:486-9.

- Etcheverry J. Concepción Estructural de la Magia. Su pensamiento teórico-mágico. En: La Magia de Ascanio Vol.1. Madrid: Editorial Páginas; 2000. English version in Hermetic Press Inc, 2005.

- Fraps T. Time and magic—Manipulating subjective temporality. En: Arstila V, Lloyd D, editores. Subjective time: The philosophy, psychology, and neuroscience of temporality. Cambridge, MA: MIT Press; 2014. p. 263-86.

- Friston K. Does predictive coding have a future?. Nature Neurosci; 2018;21:1019-21.

- Gea MA. Numismagia & percepción. Madrid:Taranco Producciones; 2018.

- Gomez-Marin A, Ghazanfar AA. The Life of Behavior. Neuron. 2019;104:25-36.

- Hedne MR, Norman E, Metcalfe J. Intuitive feelings of warmth and confidence in insight and noninsight problem solving of magic tricks. Front Psychol. 2016;7(1314):1-13.

- Hergovich A, Gröbl K, Carbon CC. The paddle move commonly used in magic tricks as a means for analysing the perceptual limits of combined motion trajectories. Perception. 2011;40:358-66.

- Hirsch JA, Wang X, Sommer FT, Martinez LM. How inhibitory circuits in thalamus serve vision. Annu Rev Neurosci. 2015;38:309-29.

- Hirst W, Phelps EA, Meksin R, Vaidya CJ, Johnson MK, Mitchell KJ, et al. A ten-year follow-up of a study of memory for the attack of September 11, 2001: Flashbulb memories and memories for flashbulb events. J Exp Psychol Gen. 2015;144:604-23.

- Hodgson R, Davy SJ. The possibilities of mal-observation and lapse of memory from a practical point of view. Proceedings of the Society for Psychical Research. 1887;4:381-495.

- Jastrow J. Psychological notes upon sleight-of-hand experts. Science. 1896;3:685-9.

- Johansson P, Hall L, Sikström S, Olsson, A. Failure to detect mismatches between intention and outcome in a simple decision task. Science. 2005;310:116-9.

- Johansson P, Hall L, Sikström S, Tärning B, Lind A. How something can be said about telling more than we can know: On choice blindness and introspection. Conscious Cogn. 2006;15(4):673–92.

- Kanizsa G. Seeing and thinking. Acta Psychol (Amst). 1985;59: 23–33.

- Kawakami N, Miura EE. Can magic deception be detected at an unconscious level? Perception. 2017;46:698-708.

- Kubovy M, Psotka J. The predominance of seven and the apparent spontaneity of numerical choices. J Exp Psychol Hum Percept Perform. 1976;2:291-4.

- Kuhn G, Amlani AA, Rensink RA. Towards a science of magic. Trends Cogn Sci. 2008b;12:349-54.

- Kuhn G, Caffaratti HA, Teszka R, Rensink RA. A psychologically-based taxonomy of misdirection. Front Psychol. 2014;5(1392):1-14.

- Kuhn G, Findley JM. Misdirection, attention and awareness: Inattentional blindness reveals temporal relationship between eye. Q J Exp Psychol. 2010;63:136-46.

- Kuhn G, Land MF. There's more to magic than meets the eye. Curr Biol. 2006;16(22):R950-1.

- Kuhn G, Rensink RA. The vanishing ball illusion: A new perspective on the perception of dynamic events. Cognition. 2016;148:64-70.

- Kuhn G, Tatler B, Cole GG. You look where I look! Effect of gaze cues on overt and covert attention in misdirection. Vis cogn. 2009;17:925-44.

- Kuhn G, Tatler BW, Findlay JM, Cole GG. Misdirection in magic: implications for the relationship between eye gaze and attention. Vis Cogn. 2008a;16:391-405.

- Kuhn G, Tatler BW. Magic and fixation: now you don't see it, now you do. Perception. 2005; 34:1155-61.

- Kuhn G, Teszka R, Tenaw N, Kingstone A. Don't be fooled! Attentional responses to social cues in a face-to-face and video magic trick reveals greater top-down control for overt than covert attention. Cognition. 2016;146:136-42.

- Kuhn G, Teszka R. Attention and misdirection: How to use conjuring experience to study attentional processes. In: Fawcett JM, Risko EF & Kingstone A, editors. The Handbook of Attention. Cambridge, Massachusetts: MIT Press; 2015. p 503-25.

- Kuhn G. Experiencing the Impossible. The Science of Magic. Cambridge, MA: The MIT Press; 2019.

- Lachapelle S. From the stage to the laboratory: magicians, psychologists, and the science of illusion. J Hist Behav Sci. 2008;44:319-34.

- Lamont P, Wiseman R. Magic in Theory. Hartfield: Hermetic Press; 1999.

- Leder H, Nadal M. Ten years of a model of aesthetic appreciation and aesthetic judgments: The aesthetic episode—developments and challenges in empirical aesthetics. Br J Psychol. 2014;105:443–64.

- Ling S, Carrasco M. When sustained attention impairs perception. Nat Neurosci. 2006;9:1243-5.

- Loftus EF. Make-believe memories. Am Psychol. 2003;58(11): 867.

- Macknik S, King M, Randi J, Robbins A, Teller, Thompson J, Martinez-Conde S. Attention and awareness in stage magic: turning tricks into research. Nat Rev Neurosci. 2008;9:871-9.

- Maskelyne JN, Devant D. Our Magic. London: George Routledge & Sons Ltd., EP Dutton & Company; 1911.

- Nisbett RE, Wilson TD. Telling more than we can know: Verbal reports on mental processes. Psychol Rev. 1977;84:231-59.

- Olson JA, Amlani AA, Raz A, Rensink RA. Influencing choice without awareness. Conscious Cogn. 2015;37:225-36.

- Olson JA, Amlani AA, Rensink RA. Perceptual and cognitive characteristics of common playing cards. Perception. 2012;41:268-86.

- Olson JA, Landry M, Appourchaux K, Raz A. Simulated thought insertion: Influencing the sense of agency using deception and magic. Conscious Cogn. 2016;43:11-26.

- Ortega J, Montañes P, Barnhart A, Kuhn G. Exploiting failures in metacognition through magic: Visual awareness as a source of visual metacognition bias. Conscious Cogn. 2018;65:152-68.

- Ortiz D. La Buena Magia (Strong Magic, 1994). Madrid: Páginas Libros de Magia; 1999.

- Ortiz, D. Designing Miracles. El Dorado Hills CA: A-1 Magic Media; 2006.

- Otero-Millan J, Macknik SL, Robbins A, McCamy M, Martínez-Conde S. Stronger misdirection in curved than in straight motion. Front Hum Neurosci. 2011;5(133):1-4.

- Parris BA, Kuhn G, Mizon GA, Benattayallah A, Hodgson TL. Imaging the impossible: An fMRI study of impossible causal relationships in magic tricks. Neuroimage. 2009;45:1033-9.

- Prevos P. Perspectives on Magic. Scientific Views on Theatrical Magic. Kangaroo Flat, (Australia): Third Hemisphere Publishing; 2013.

- Quian Quiroga R. Magic and cognitive neuroscience. Curr Biol. 2016;26(10):R387-407.

- Reber R, Schwarz N. Effects of Perceptual Fluency on Judgments of Truth. Conscious Cogn. 1999;8(3):338–42.

- Reber R, Schwarz N, Winkielman P. Processing Fluency and Aesthetic Pleasure: Is Beauty in the Perceiver's Processing Experience?. Pers Soc Psychol Rev. 2004;8(4):364–82.

- Reber R, Winkielman P, Schwarz N. (1998). Effects of Perceptual Fluency on Affective Judgments. Psychol Sci. 1998;9:45–8.

- Rensink RA, O'Regan JK, Clark J. To see or not to see: The need for attention to perceive changes in scenes. Psychol Sci. 1997;8:368-73.

- Robert-Houdin, JE. Les secrets de la prestidigitation et de la magie. Paris: Michel Lévy Frères Editeurs; 1868.

- Scot, R. The discoverie of witchcraft. Wherein the lewde dealing of witches and witchmongers is notablie detected. London, 1584. See: https://en.wikipedia.org/wiki/The_Discoverie_of_Witchcraft.

- Shalom DE, de Sousa Serro MG, Giaconia M, Martínez LM, Rieznik A, Sigman M. Choosing in Freedom or Forced to Choose? Introspective blindness to psychological forcing in stage-magic. PLoS One. 2013;8(3)e58254.

- Simons DJ, Chabris CF. Gorillas in our midst: Sustained inattentional blindness for dynamic events. Perception. 1999;28:1059-74.

- Song H, Schwarz N. Fluency and the Detection of Misleading Questions: Low Processing Fluency Attenuates the Moses Illusion. Soc Cognition. 2008;26(6):791–9.

- Sperling G. The information available in brief visual presentations. Psychol Monog. 1960;74:1-29.

- Stone T. Vision & Velocity vectors. Genii. 2011;74(11):40-5.

- Suchow J, Alvarez G. Motion Silences Awareness of Visual Change. Curr Biol. 2011;21:140-3.

- Tachibana R, Gyoba J. Effects of different types of misdirection on attention and detection performance. Tohoku Psychol Folia. 2015;74:42-56.

- Tamariz J. El Arco Iris Mágico. Editorial MysticaGema Navarro, editora. Madrid: 2016.

- Tamariz J. La Vía Mágica. El método de las pistas falsas y la Vía Mágica. Madrid: Ed Frackson; 2011 (edición original de 1988 corregida y aumentada). English version in Hermetic Press Inc.

- Tamariz J. Los cinco puntos mágicos (1981). Madrid: Frakson; 2005. English version in Hermetic Press Inc.

- Tarbell H. The Tarbell Course in Magic, 8 volumes (1927). 15a ed. New York: D Robbins & Co Inc; 1999.

- Thomas C, Didierjean A, Kuhn G. It is magic! How impossible solutions prevent the discovery of obvious ones?. Q J Exp Psychol. 2018;71:2481-7.

- Thomas C, Didierjean A, Kuhn G. The Flushtration Count Illusion: Attribute substitution tricks our interpretation of a simple visual event sequence. Br J Psychol. 2018;109:850-61.

- Thomas C, Didierjean A, Nicolas S. Scientific Study of Magic: Binet's Pioneering Approach Based on Observations and Chronophotography. Amer J Psychol. 2016;129:315-8.

- Thomas C, Didierjean A. Magicians fix your mind: How unlikely solutions block obvious ones. Cognition. 2016c;154:169-73.

- Thomas C, Didierjean A. No need for a social cue! A masked magician can also trick the audience in the vanishing ball illusion. Atten Percept Psychophys. 2016a;78:21-9.

- Thomas C, Didierjean A. The ball vanishes in the air: can we blame representational momentum?. Psychon Bull Rev. 2016b;23:1810-7.

- Tompkins ML, Woods AT, Aimola Davies AM. Phantom vanish magic trick: Investigating the disappearance of a non-existent object in a dynamic scene. Front Psychol. 2016;7(950):1-15.

- Topolinski S. A processing fluency-account of funniness: Running gags and spoiling punchlines. Cognition Emotion. 2014;28(5):811–20.

- Triplett N. The psychology of conjuring deceptions. Amer J Psychol. 1900;11:439-510.

- Tversky A, Kahneman D. Availability: A heuristic for judging frequency and probability. Cogn Psychol. 1973;5:207-32.

- Van de Cruys S, Wagemans J, Ekroll V. The put-and-fetch ambiguity: How magicians exploit the principle of exclusive allocation of movements to intentions. Iperception. 2015;6(2):86-90.

- Von Uexküll J. Theoretical Biology. Oxford: Harcourt, Brace & Co; 1926.

- Whittlesea BWA, Leboe JP. The heuristic basis of remembering and classification: fluency, generation, and resemblance. J Exp Psychol Gen. 2000;129:84-106.

- Whittlesea BWA. Illusions of familiarity. J Exp Psychol Learn. 1993;19(6):1235–53.

- Wilson K, French CC. Magic and memory: Using conjuring to explore the effects of suggestion, social influence and paranormal belief on eyewitness testimony for an ostensibly paranormal event. Front Psychol. 2014;5(289):1-9.

- Winkielman P, Schwarz N, Reber R, Fazendeiro T. The hedonic marking of processing fluency: Implications for evaluative judgment. In: Musch, Jochen, Klauer, Karl, eds. The Psychology of Evaluation: Affective Processes in Cognition and Emotion. Mahwah, NJ: Lawrence Erlbaum Associates Publishers. 2003: 189–217.

- Wiseman R, Greening E, Smith M. Belief in the paranormal and suggestion in the seance room. Br J Psychol. 2003;94:285-97.

- Wiseman R, Greening E. 'It's still bending': Verbal suggestion and alleged psychokinetic ability. Br J Psychol. 2005;96:115-27.

- Wiseman RJ, Morris RL. Recalling pseudo-psychic demonstrations. Br J Psychol. 1995;86:113-25.

- Wonder T. The Books of Wonder. Vol. 1. Seattle: Hermetic Press, Inc; 1994.