Model of information process for neuromagic

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Abstract

In this work, I structure the magical knowledge around the neuroscientific literature. For that, I present a theoretical neuropsychological model to illustrate how magic tricks can interfere with different processes of the information flow. This model combines different memory stages, the perceptual pathway, the emergence of attention and the consciousness threshold to provide a holistic picture of how magic functions from the neuroscientific perspective. Following the model, I also present a misdirection definition and classification that is more accurate with the biological reality than the existing ones.

Introduction

Over the last few years, the field of neuroscience has developed a branch based on the combination of both magicians and neuroscientists knowledge—"neuromagic"- (Tompkins et al., 2016; Shalom et al., 2013; Kuhn et al., 2008; Rissanen et al., 2014; Lamont & Henderson, 2009; Olson et al., 2015; Rensink & Kuhn, 2015; Ekroll et al., 2017; Barak & Tsodyks, 2014; Kuhn, 2019). The goal of magicians is to surprise their audience and to do so, they create magic tricks that are increasingly impressive. In this process, they are inadvertently lighting a lot of processes underlying attention, perception and memory (Kuhn et al., 2016; Wiseman et al., 2016; Rieiro et al., 2013; Cui et al., 2011; Demacheva et al., 2012; Kuhn & Land, 2006). In this work, I propose a model to address the impact of magical techniques based on a neuroscientific framework of how the brain processes information.

The popular notion that magic works because “the magician makes us look elsewhere” has pushed the field to investigate attention through magic. Therefore, misdirection - roughly defined as the control of the spectator’s attention- is the most studied magical concept in neuromagic (Kuhn & Martinez, 2012; Hergovich & Oberfichtner, 2016; Kuhn et al., 2014; Smith, 2015; Tamura et al., 2016; Beth & Ekroll, 2014). To describe how misdirection works, neuroscientists have used attention-based models (Macknik et al., 2008). Although attention-based misdirection classifications can be extremely useful, they have problems when including some misdirection techniques that entail memory components. The classic attention-based misdirection classification is exclusively based upon the gaze location during the misdirection attempt. This division distinguishes between overt and covert misdirection. Overt misdirection is defined as actions that divert the spectator’s gaze away from the method behind the effect; covert misdirection refers to the instances in which attention is directed away from the method, irrespective of the position of the gaze. I consider this classification is isolated from other cognitive processes -mainly memory- that are necessary to explain and classify misdirection. Memory is essential for magic (Quiroga, 2016; Tamariz, 2016; DaOrtiz, 2015). However, nearly the entire “neuromagic” literature doesn’t address the different types of memory that interplay during a magic trick. The main exception is the work of Quiroga (Quiroga et al., 2016), where he introduces the idea of misdirection as the alteration of memory stages. In this work, Quiroga develops the idea that the ultimate role of misdirection is to prevent sensory memory reaching the working memory state. Although what I am proposing here coincides with Quiroga’s work, an exclusive memory-based misdirection has problems classifying the most basic forms of misdirection, where memory has a secondary role. Thus, an integration of both attention and memory models is required to get the whole picture of how magic and misdirection techniques are translated into brain processes.

Here, I will present a theoretical neuropsychological model based on the multistore model of memory (Atkinson & Shiffrin, 1968) that parsimoniously combines attention, perception, consciousness and memory to explain how information is processed during a magic trick. With this model, I aim to both provide a common framework to explain how magical techniques work and a misdirection classification that is more correct from the neuroscientific point of view.

Model

The different stages of the model are schematized in Figure 1. It consists of an input of internal and external information, a processing of the information where attention, perception and memory processes interplay to explain our experiences during a magic trick and an output which addresses both motor responses and how the attentional spotlight emerges.

Input

I have divided the input into two different modules. The first module is the *external information*, which entails all the stimuli perceived by our senses. The second module is the *internal information*, which refers to the set of interpretations, ideas and beliefs that are internally generated (Theeuwes, 1991).

Processing of information

Sensory integration: From Information to Perception.

The first step of the processing consists in the flow of information from the sensory areas to the brain. In this process there is an incredible loss of information. This loss is due to the compression systems necessary to send the information received in thousands of sensory cells through few axons to reach the sensory cortex. Therefore, just a piece of distorted information reaches the brain to be processed. The stimulation of the cells in

the nervous system generates a *sensory memory*, which lasts for only the time these cells remain excited.

A large amount of methods in magic do not generate this sensory memory, in other words, there is nothing regarding the methodology of the trick that can be perceived by the spectators. Magic that relies on electronic devices, black art, saccadic masking (Erdmann & Dodge, 1898), mathematics or concealed gimmicks do not generate a sensory memory, so spectators will never find out how the trick works by detecting the methodology (they will do it through reasoning and deductive thinking). I also include into this category invisible sight-of-hand techniques -those that, just when executed perfectly, do not generate any sensory evidence- such as the *paddle move* or *the invisible pass*.

To interpret this sensory information and therefore generate a *perception* of it, there are hierarchical pathways that integrate this low-level sensory information in increasing complexity (Goodale & Milner, 1992) and links it to memory (*significant memory*) to extract a lifetime experience meaning of it (Quiroga et al., 2005). At this stage, we will find the tricks which method relies on how the information is transformed in the visual pathway, so even the spectator guesses how the trick works, it will experience it anyway. This is the case of visual illusions -rarely used as tricks per se – or clever methods regarding colour reconstruction.

Once the integration of low-level information and the link to memory is done, we have a *perception*. In this model, I will refer to perception as something linked to consciousness, but it is well documented that unconscious information can bias our responses in primary stages of decision-making (Bargh & Morsella, 2008; Greenwald et al., 1995; Soon et al., 2008). Thus, I bypass the model at this point when the input does not reach a *consciousness threshold*. Regarding magic techniques which rely in this threshold, some psychological forces – the spectator thinks he made a free-choice when it is not the case - use subliminal information (DaOrtiz, 2009; Brown, 2000), although they are not 100% reliable.

Cognitive integration: From perception to the attentional output.

After the sensory integration, I implemented 4 different cognitive modules that interplay during a magic trick. The first one - *external tracking* – generates an internal representation of the external space, such as locations, lighting conditions or temperature. The second one - *internal tracking* - processes internally generated information, such as task rules and responses (Chun et al., 2011). The third module – *evoked memories*- gathers the reactivated memories both from the short and the long-term. In this module, I emphasize the submodule of the *emotional response*, which triggers those evoked memories with an emotional charge associated (e.g. fire-danger). The final module is the *WM-1*, which represents the memories that are still lingering from previous timepoints and provides us the sense of continuity. From the dynamic contribution of these modules, emerges the attentional output with a bias towards external or internal attention. For illustration, I represent the modules as a distribution with a certain amplitude and centre. The amplitude reflects the contribution of the module and a bias from the centre illustrates a change in the information processed by the module. If there is higher amplitude of the module responsible for external tracking compared to the internal, the attentional spotlight will emerge biased towards external information and vice versa. When presenting the classification of misdirection, I will provide specific examples of the role of each of the modules.

The mnemonic pathway.

At every timepoint, the response elicited from the processing of the incoming information will generate a specific working memory. This memory will be a key point in the process. First, it will allow the spectator to follow the procedures in the short-term in the subsequent timepoints (module *WM-1*). Second, it will determine whether memories are retained or not depending on the weight of the *emotional response* (Gold & Buskirk, 1975; Liang et al., 1986; Liang et al., 1990). Those memories that reach the threshold of emotional relevance will become *synaptic memories*. However, the majority will get lost

when working memory decays with time. We use the concept of *synaptic memory* as a synonym of synaptic consolidation or late-phase LTP (Bramham & Messaoudi, 2005). It refers to a hippocampal-dependent state of the memory before it consolidates as *long-term memory* by becoming more independent -although not completely (Nadel & Moscovitch, 1997) - from the hippocampus (Frankland & Bontempi, 2005; Squire & Álvarez, 1995; McGaugh, 2000; Dudai, 2004). To provide a temporal framework, this kind of memory would be the one we have a few hours or days after the event. At the final stage of the mnemonic pathway, we find the long-term memories. To reach this state, besides the emotional response, the repeated recall of this memory is essential. It is important to point out that this recall can be either conscious or unconscious - like when sleeping (Walker et al., 2005; Vertes, 2004). In day to day experience, we tend to recall “emotional memories” because they make an impact on our lives. However, magic tricks rarely have such an impact, so they are not evoked as frequently as other memories with similar emotional responses. To potentiate memory consolidation, magicians have developed strategies to anchor their effects to everyday things such as objects, presents or ordinary sentences, raising the likelihood to recall the memory.

Memories can be accessed both from the short and the long term. It is well documented that every time we remember, the memory is modified (Nadel & Hardt, 2011; Gräff et al., 2014; McKenzie & Eichenbaum, 2011). This happens because this evoked memory is susceptible to other information that one may be processing at the time of the recall. This phenomena, known as “false memories generation” (Loftus & Pickrell, 1995), is exploited by magicians both in the short and the long term. Neuroscientists use long-lasting procedures to generate false memories with reduced success while magicians create them in few minutes with high success through guided instructions and the correct attitude (Tamariz, 2016; DaOrtiz, 2009). They do so by activating memories stored in working memory and adding extra information that modifies them on the spot. To generate false memories in the long term, magicians tend to exaggerate their effects, so they become even more impossible after each recall. Juan Tamariz brilliantly describes

as the “Comet effect” the process of how a memory should evolve in the spectator’s mind after the show (Tamariz, 2016).

Output

The outputs of the model are the motor output - actions such as “*pick one card*” or “*say your birthdate*” - and the attentional output. I divide the attentional output in a similar way as the input (*external* and *internal*) to represent the resulting amount of attention allocated in each of the sources of incoming information. The external and internal attention is again illustrated as distributions with a certain amplitude and centre. To mirror attentional resources (Monsell, 2003; Ophir et al., 2009), the decrease of amplitude in one distribution will sometimes coincide with the increase of amplitude in the other. In this model, attention appears as an emergent effect instead of an independent module. I represented it that way based on modelling and neuroimaging studies which suggest that attention emerges from the dynamic evolution of the networks involved in different attentional tasks (Reynolds et al., 1999; Deco & Rolls, 2004).

Misdirection

Several magicians and neuroscientists have proposed their own definition of misdirection, my definition is the following: “*those actions of the external life of a magic trick which influence the attention of the spectators to conceal the method used*”. I will dissect my definition and link it to the model proposed. I start by saying: “*actions of the external life of the magic trick*”, this refers to Ascanio’s distinction between external and internal life of a magic trick – what is seen and what is not supposed to be seen by the spectator, respectively-. According to my definition, a misdirection technique must enter the processing stage of the model. With this preliminary step, I am excluding those methods that rely on not generating a sensory memory such as *the black art* or *invisible sleight of hand*. In my opinion, it is not fair to incorporate into misdirection -a term that is

oriented towards “attention” – methods that do not have an influence into the neural correlates of it. In line with the previous statement, the definition follows with “*influences the attention*”. During a magic trick, the magician must know what the spectators are attending at and plan his future moves according to it, that is why I prefer the term influence instead of *divert, guide, direct, etc.* as it is general enough to include all the possible attentional manipulations. Finally, the last part of the definition states “*to conceal the method used*”. During a magic trick, the magicians could try to control spectator’s attention for different reasons (e.g. music played during the intro to capture attention) but, for me, aiming to conceal the secret method is a requisite to end up inside my definition. As a summary, a misdirection technique must fulfil the following points:

- It is processed by the spectator.
- It influences the emergent attention.
- It contributes to conceal the method.

Misdirection classification

Many magicians have developed or contributed crucially to misdirection classification (Ascanio, 1964; Randal, 1976; Bruno, 1978; Sharpe, 1988; Houdin, 1877; Giobbi, 1999; Ganson, 1956; Ganson, 1980; Tamariz, 1987; Wonder, 1994; Hugard & Braue, 1944; Hugard, 1960). As magic theory is sometimes drawn from experience of its practical application, many of these classifications are based on features completely unrelated to neuroscience. Ascanio’s three grades of misdirection (Ascanio, 1964), for instance, gravitate around the degree of exposure of the technique: The first grade refers to an open competition between a secret and an innocuous stimulus, equally salient. In the second grade, the innocuous is more salient than the secret and, in the third grade, the secret is not noticeable. Misdirection can also be classified according to a magician’s manoeuvres. An example of it could be Sharpe’s classification (Sharpe, 1988), where

two different branches of misdirection are defined depending on whether they are *active* (based on a movement, sound...) or *passive* (based on mind's reaction to static stimulus).

There is no fixed model for classifying misdirection within the magic community. In the case that they want to use a classification, each magician will decide the one that fits best for him. However, from the neuroscientific perspective, not all misdirection classifications are equally correct when reflecting how the brain processes information during a magic trick. The classification I propose is inspired in the classifications of Joe Bruno (Bruno, 1978) and the exogenous-endogenous distinction of visual science (Posner, 1980; Theeuwes, 1991), - also used in Lamont & Wiseman, 1999 and Sharpe, 1988 -. My classification consists of two hierarchical levels (Figure. 2). Starting from the bottom, I will distinguish whether the misdirection technique affected the external tracking, the internal tracking or both. In the top level, I will distinguish whether the emergent attention is directed, divided or diminished compared to the same situation without misdirection (control).

Direction: Modify the focus of external/internal tracking.

- **External:** The magician wants to move the external attention from one spatial location to a different one. He could achieve this through a salient movement (*"move the hand to reach something"*), a verbal instruction (*"look at here!"*) or a social cue (*"eye contact with the spectator"*) among others. In the model, there is an input biased towards the external tracking of a new region of the space. This is translated as a bias in the module responsible of tracking the external space (Fig. 3A). Due to this unbalanced new state of the module, attention will emerge biased to track the new spatial location.

The "parenthesis of forgetfulness" -temporal separation of the manoeuvre and the resolution of the effect (Etcheverry, 2000) is an example of direction-external with a longer timescale. In this case, the delay prevents the recovery of an

undesired memory (the tricky manoeuvre) from working memory. Thanks to that, an undesired position is not tracked (Fig. 3B)

- **Internal:** The magician wants to move spectator's frame from an internal expectation to another. The typical example is the one where the magician tells the audience he will perform a trick based in a mathematical principle when its method is something different. This would go inside what Tamariz calls "False Clues" (Tamariz, 1987). In the model, this is represented the same way as the direction-external with the difference that the biased modules in the processing and output is the one of the internal tracking (Fig. 3C).
- **External - Internal:** The magician wants to move spectator attention from the external to the internal tracking. An example would be the "bewildering question", which occurs when the magician asks a question when he wants to perform a tricky manoeuvre. In the model, it is represented as an input for the internal tracking that drives the emergent attention from the external to the internal-tracking (Fig. 3D).

Division: Increase the amount of external/internal tracking.

- **External.** The magician wants the spectator to attend to two simultaneous location at the same time, so they are unable to exclusively focus on one point. One example would be when the magician introduces both hands in his pockets when he wants to hide something in only one of them. In the model, this is represented as a double input in the external tracking. Tracking multiple independent targets compromises performance (Pylyshyn & Storm, 1988), this is represented as a dynamic attentional spotlight between both locations that consumes most of the attentional resources (Fig. 4A).

- **Internal:** The magician wants to “confuse” the spectator with multiple internal requirements. It is probably the less used form of misdirection as it intuitively goes against the clarity magicians want to have in their effects. An example of this type of misdirection would be when the magician gives several instructions to the spectator so he cannot track carefully the whole process (e.g. “*remember 2 different cards*”). In the model, this is represented as a double input in the internal tracking. As in the previous example, this generates transitions of the attentional spotlight between the different threads of internal information (Fig. 4B).
- **External-Internal:** In this case, the magician provides simultaneous external and internal information (e.g. “*Remember one card, make 3 piles of 7 cards each...*”). In the model, it is represented as incoming inputs from both the external and internal tracking, generating, as in the previous examples, the need to process a lot of information that prevents the spectator to process information regarding the method of the trick (Fig. 4C).

Diminishment: Modify the overall amount of attention allocated.

- **External:** The magician wants to reduce the spectator’s tracking of the external information. Usually, the magician generates relaxing moments through social cues (e.g. body relaxation). In the model, this process requires the recall of long-term memories to give sense to a stimulus that later reduces the amplitude of the external tracking (Fig. 5A). As in direction-external, by extending the timescale, I incorporate here those techniques that rely on adaptation, such as “naturalness conditioned”. In this situation, the spectator gets used to an innocuous gesture. When the same gesture is later repeated with the tricky manoeuvre, it captures less attention. In the model, this process requires an evocation of a previous working memory that influences the external tracking of information (Fig. 5B).

- **Internal:** The magician wants to reduce the tracking of internal information. This is what magicians refers as “shutting off the logical and analytic brain” and it is what every magician seeks when generating an appropriate “magical atmosphere” (Etcheverry, 2000; DaOrtiz, 2015). Thousands of pages are written about how the plot and magician’s attitude affect magic tricks (Miguel, 2012; Carrol, 1991; Giobbi, 1999). I consider that this “magical atmosphere” is translated as a recall of memories (from working memory, synaptic and long term) that reduce the internal tracking of the magic trick (Fig. 5C).
- **External-Internal:** The magician reaches both a relaxation of the external and the internal tracking. The classical examples for this process are the humour and the climax of the magical effect. In the model, it is represented as a decrease of amplitude in both external and internal tracking modules (Fig. 5D).

Final Remarks

With this model I have tried to provide a common background to interpret how magical principles and techniques work from a neuropsychological perspective. Moreover, I have classified misdirection based on this perspective, so magicians would be able to exploit different brain mechanisms to hide their methods in a more efficient way. As a neuropsychological nor a pure biological model, this model lacks the specific neural correlates that drive the information as well as the brain areas involved on each module. With this work I am aiming both to motivate neuroscientist and magicians to work together to push forward this art. On the one hand, neuroscientists should aim for more detailed models that explain, at the neural level, how magic techniques interfere with the default dynamics of the brain. On the other hand, magicians should provide neuroscientist the insight coming from years of experience and take advantage from the

evidence coming from the scientific investigation instead of just following subjective experience.

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Figures

Figure 1. Model of information process. This model addresses how incoming information is processed to provide a motor response and the emergence of the attentional spotlight. It includes different types of memory, the perceptual pathway and a consciousness threshold.

Figure 2. Misdirection classification. The first level distinguishes if the emergent attention is directed, divided or diminished while the second level addresses whether the misdirection technique affected the external tracking, the internal tracking or both.

Figure 3. Direction. **A)** Direction-external. **B)** Direction-external in the parenthesis of forgetfulness. **C)** Direction-internal. **D)** Direction-external-internal.

Figure 4. Division. **A)** Division-external. **B)** Division-internal. **C)** Division-external-internal.

Figure 5. Diminishment. **A)** Diminishment-external. **B)** Diminishment-external based on adaptation. **C)** Diminishment-internal. **D)** Diminishment-external-internal.

A

B

C

D