A STUDY OF BEHAVIOURAL AND NEURAL SIGNATURES OF PERCEPTUAL AND COGNITIVE ILLUSIONS INDUCED BY MAGIC EFFECTS

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I dedicate this thesis to the loving memory of my
grandfather, Jose Arturo Codoni.

He was a good man with a bright mind, that has passed me his passion and love
for Art and Science. God bless him.

‘A Study of Behavioural and Neural Signatures of Perceptual And Cognitive Illusions Induced by Magic Effects’

Hugo A. Caffaratti

Abstract

For millennia magicians have entertained their audiences by manipulating perception, as well as other cognitive processes, such as attention, memory, and decision-making. In the past decade psychologists and neuroscientists have realized that this intuitive knowledge magicians have about the human mind can be used to further investigate some aspects of human perception and cognition, from a novel perspective. Whilst most of the research done in this field, to date, has been focused on subjects’ behavioural responses elicited by a magic trick, very little has used the unparalleled nature of the magic’s cognitive illusions to further study the neural bases of perception. It is within this context, that this thesis presents, in Chapter 2, two experiments, both of them, showing behavioural and evoked responses of subjects while watching an oddball sequence of continues, unedited videos of a magic trick known as Chop-Cup (where a ball appears ‘magically’ under a cup). Altogether, in both experiments, it was found that, on the one hand, subjects’ behavioural responses were strongly biased by the magic trick, and on the other, that the neural responses were modulated by the oddball sequence of stimulus presentation, as expected. In addition, in the second experiment it was found, that the same retinal stimulus, the ball (having appeared ‘magically’ or ‘naturally’) —elicited different brain responses. This novel paradigm, as well as paving the way for investigating perception and cognition under more natural conditions, required the development of a new set of technical approaches for its correct implementation, which are discussed in Chapter 1.

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List of Abbreviations

RM: Representational Momentum

IB: Innatentional Blindness

CB: Change Blindness

ChB: Choice Blindness

VBI: Vanishing Ball Illusion

DLPFC: Dorso-Lateral Prefrontal Cortex

VMPFC: Ventro-Medial Preforntal Cortex

ACC: Anterior Cingulate Cortex

CN: Caudate Nucleus

EEG: Electroencephalography

ERP: Evoked-Related Potencial

fMRI: functional Magnetic Resonance Image

MEG: Magneto Encephalography

ASD: Autism Spectrum Disorder

FC: Force Choice

ms: Milliseconds

μV: Microvolts

CNV: Contingent Negative Variation

RP: Readiness Potential

SPN: Stimulus Preceding Negativity

Publications

Caffaratti, H., Navajas, J., Rey, H. G., & Quian Quiroga, R. (2016). Where is the ball? behavioural and neural responses elicited by a magic trick. *Psychophysiology, 53*(9), 1441-1448.

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Invited Speaker:

- 2017: Biennial International Convention of Psychological Science (ICPS) held at the Austria Center Vienna in Vienna (Austria).
- 2016: First International Congress of Neuromagic at the Science and Cosmos Museum of Tenerife (Spain)
- 2016: British Society of Psychology at Cumberland Lodge. Windsor (United Kingdom)
- 2015: Liga Española Contra la Epilepsia (LECE). Medical School of Palma de Mallorca (Spain)
- 2015: Congress SABIENS 2015. Principality of Andorra
- 2015: De Montfort University. Leicester (United Kingdom)
- 2015: Human Robot Interaction Workshop. Aland (Finland)
- 2015: Brain Awareness Day at University of Leicester. Leicester (United Kingdom)
- 2015: Science of Magic. Faculty of Psychology, Goldsmith University of London (United Kingdom)
- 2014: Faculty of Psychology, University of Leicester. Leicester (United Kingdom)
- 2014: Brain Awareness Day at University of Leicester. Leicester (United Kingdom)
- 2014: Vision Laboratory at University of Leicester. Leicester (United Kingdom)

- 2013: 'III Aspects of Neuroscience' at University of Warsaw. Warsaw (Poland)

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National Newspapers:

'La Vanguardia' (Spain)

http://www.lavanguardia.com/local/canarias/20161027/411375165334/ciencia-y-magia-se-unen-en-un-festival-internacional-en-tenerife.html

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"*Magician and PhD student Hugo Caffaratti to analyse magic moments*"

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General Introduction

One of the questions to have intrigued scientists and philosophers for centuries is whether it is possible to visually perceive the outside world, as is presented in front of the viewer's eyes. Intuitively, considering everyday experiences, one would assume that, indeed, phenomenal (perceived) and physical objects are exactly the same. As the famous German physicist and psychologist Hermann von Helmholtz (1821-1894) wrote: '*we always believe that we see such objects as would, under conditions of normal vision, produce the retinal image of which we are actually conscious*' (Helmholtz, 1878a; Helmholtz, 1878b). However, Helmholtz, under the strong empiricist influence of Immanuel Kant, stated that it is not possible to have an objective knowledge of reality, (thing-in-itself) but rather a subjective representation, or symbols, of the real-world objects (Gregory, 1973; Gregory, 1997a). In this sense, Helmholtz referred to perception as a 'conclusion' or 'combination' of data given by the stimulus (i.e. sensory data), with information from past experiences stored in a subject's memory (i.e. higher-level cognitive processes). Helmholtz described the psychological processes by which this 'conclusion' or perception is achieved, as 'unconscious inference' (Helmholtz, 1878b) (the word 'unconscious' refers to the fact that, in a perception, it is not possible to consciously dissociate what is sensory data from stored experiences). This subjective representation of reality, achieved by inferences processes, constitutes the closest experience of the real world that can be reached (Gregory, 1973). Although this understanding of perception has a general consensus (Gregory, 1997b; Neisser, 1976; Vernon, 1962), it leads back to the initial question posed above, still unresolved: Are perceptions accurate representations of the real-world objects? Richard Gregory stated that: '*…depending on the sensory data available and the difficulty of the perceptual problem to be solved*', perceptions '*could be more or less likely to be true*', which means that some perceptions could be considered as merely a deviation of reality, or an ***illusion*** (Gregory, 1973).

Although illusions have originally been considered 'exceptions' or 'errors' of perception, they have long helped scientists to understand that this cognitive process is much more than '*...the pick up of information that is already available and specific...*' (Helmholtz, 1878b). In fact, during the past centuries, different forms of illusions – such as ambiguous or conflicting monocular figures (see Figure 1) – have been largely used to disentangle some of the neural mechanisms that underlie (visual) perception, and visual awareness (Alais & Blake, 2005; Logothetis, Leopold, & Sheinberg, 1996).

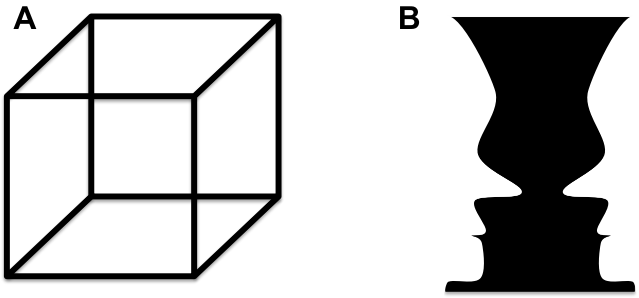

Figure 1. Reversible images. A, B, are examples of ambiguous figures. A) (Necker cube, (Necker, 1832) is a bistable image, which ambiguity is solved by reference frame realignment. B) (Rubin's vase, (Rubin, 1915)) is bistable image which ambiguity is resolved by reconstruction of meaning.

The aforementioned figures have the invaluable condition of generating two different—and 'rival'—perceptions without changing its physical nature. Thus, they have helped to study, in general terms, how the brain interprets and routinely resolves the ambiguity present in the retinal image (Long & Toppino, 2004). Although the mechanisms of 'Monocular' and 'Binocular' rivalry are out of the scope of this thesis, it is important to note that there is a big bulk of scientific evidence demonstrating that these 'perceptual illusions' are produced by a combination of low and high-level brain processes, meaning that the sensory data processed in early visual areas are influenced by inferences based on expectations and knowledge from past experiences (Alais & Blake, 2005; Logothetis et al., 1996; Long & Toppino, 2004).

There exists an argument, however, that multistable stimuli are rarely observed in natural environments, concluding that 'monocular' and 'binocular' rivalry, and its offshoots such as flash suppression (Wolfe, 1984), are just mere laboratory artifacts, or, in other words, a result of a 'visual trickery' (Alais & Blake, 2005; Gibson, 1966). These phenomena have been studied for centuries, and continue to be today. It is interesting, however, that none of the perceptual scientists, until a decade ago, had moved their view towards another type of illusion which has demonstrated, for millennia, to (strongly) manipulate perceptions among other cognitive processes: 'The Art of Magic'. Magic is a very complex form of art which, as Richard Gregory mentioned in his book 'Illusions in Nature and Art' (Gregory, 1973), bases most of its illusions in breaking, or violating, the expectations (and inferences) that humans have of the physical world. Although it is a different kind of perceptual illusion than the ones produced by reversible figures, magic offers an innovative approach to study the role of inferences and past experiences in human's perception, but in a more natural context than the sets used to investigate 'Monocular' or 'Binocular' rivalry. In this regard, within the past decade, neuroscientists and psychologists started to pay more and more attention to this ancient form of deception, in order to use it as a tool to disentangle not only some of the still unknown mechanisms of perception, but also of other cognitive processes such as attention, memory, reasoning, and decision making (Martinez-Conde & Macknik, 2008). Although the bulk of research using magic has been growing in the past decade, most of them have been focused on behavioural and oculomotor studies (Cui, Otero-Millan, Macknik, King, & Martinez-Conde, 2011; Johansson, Hall, Sikstrom, & Olsson, 2005; Kuhn, Caffaratti, Teszka, & Rensink, 2014; Kuhn & Land, 2006b; Kuhn & Findlay, 2010; Lamont & Wiseman, 2005; Macknik, King, Randi, & Robbins, 2008; Martinez-Conde & Macknik, 2008; Olson, Amlani, & Rensink, 2012; Otero-Millan, Macknik, Robbins, & Martinez-Conde, 2011; Parris, Kuhn, Mizon, Benattayallah, & Hodgson, 2009; Rieiro, Martinez-Conde, & Macknik, 2013; Shalom et al., 2013) and only a few have presented physiological recordings of magic perception (both of them using fMRI) (Danek, Öllinger, Fraps, Grothe, & Flanagin, 2015; Parris et al., 2009). However, Susana Martinez-Conde, co-author of the book '*Sleight of Mind*', (Macknik, Martinez-Conde, & Blakeslee, 2010a) pointed out the importance of understanding the neural mechanisms that underlie magic illusions since they '*...may provide fresh new insights into the brain mechanisms of perception and cognition*'.

This statement has inspired the work presented in Chapter 2 of this thesis; which consisted of electroencephalography (EEG) recordings of subjects while perceiving non-edited videos of magic tricks, embedded in an oddball sequence of trials. As will be explained in detail in Chapter 2, the use of videos represents a novel and significant step forward in the study of perception under control conditions. Videos present stimuli on a natural and continuous fashion, as they appear in real life, in contrast to the discrete presentation of stimuli, normally used in classical cognitive set ups. The results of these experiments include, among other interesting effects, differential event related potentials (ERP) responses elicited by the same visual stimulus (having appeared 'magically' or 'naturally'). In general terms, this work not only offers a new perspective in the field of Neuroscience of Magic (*Neuromagic)*, being the first EEG study of magic perception, but also it demonstrates that ERP studies of cognitive processes (such as perception), can be carried out under more natural (realistic) conditions, compared to classic evoked responses paradigms (see 'Introduction to Chapter 2', in which classic oddball paradigms are reviewed). This novel method is challenging, and required overcoming several technical difficulties to fully exploit the advantages it offers. All these technical issues, and the way they were sorted out, are listed and explained in Chapter 1. The work described in Chapter 2 has been recently published in the scientific journal, *'Psychophysiology'*, under the title *'Where is the ball? Behavioural and neural responses elicited by a magic trick'* (Caffaratti, Navajas, Rey, & Quian Quiroga, 2016). This chapter is a contribution not only to the field of *Neuromagic*, but also for Cognitive Neuroscience in general. It demonstrates how magic can be used as an innovative research tool for neuroscientists and psychologists, in order to create new, or to improve existing paradigms with which to study cognition. In this sense, the experiments presented in this thesis add to a growing number of research studies using magic illusions to study not only perception, but also other high-level processes such as attention, memory, and decision-making. These works are reviewed in the following pages, which all together constitute the 'Literature Review' of this thesis.

Literature Review

The cognitive study of magic illusions is not new. In fact, it was started more than a century ago, by three psychologists from the late 1800s who were interested in addressing the study of perception from the outstanding perspective offered by the ancient Art of Magic (Binet & Nichols, 1896; Jastrow, 1897; Triplett, 1900). The, aforementioned psychologists were the first in understanding that magicians have a large, although intuitive, knowledge of human cognition (since they have been 'manipulating' and 'playing' these processes for millennia) that can be used by cognitive scientists in the study of the mechanisms behind attention, memory, reasoning, decision-making, and visual perception et cetera.

Surprisingly, and for reasons unknown, after the work published by Binnet and his colleagues in the 1800s, the cognitive study of magic was abandoned – until recently in 2005, when a psychologist and magician Gustav Kuhn published '*Magic and fixation: Now you don't see it, now you do'* (Kuhn & Tatler, 2005). In this work, Dr. Kuhn et al. studied visual perception of subjects that were watching a magic trick being performed live in front of them. These results, which are explained later in this introduction, mark a renewing point in a promising line of research that is providing a growing number of interesting studies, published in journals and books.

In the following pages are reviewed some of the most important works that have, with different methods and perspectives, used magic (perceptual) illusions to study how expectations and inferences based on knowledge of past experiences shape and influence (visual) perception. As will be noticed, most of the studies done in this field have been focused on the behavioural and oculomotor responses elicited by different magic tricks, whereas very few have tried to disentangle the neural concomitants that underlie the perception of the ancient art.

Although some research based on magic has been published between 2005 and 2008, it is important to start this review with an esteemed article, published in

2008. Dr. Kuhn, together with Alym A. Amlani and Ronald A. Rensink, took a crucial step forward in the cognitive study of magic, with their article: *'Towards a science of magic'* (Kuhn, Amlani, & Rensink, 2008). In this article, the authors tried to pave the path in this field, proposing different ways of how to apply the knowledge that magicians have to psychological research. In this regard, they '*...believe that **this knowledge can be systematized** and used as a source of insight into mechanisms that are central to human perception and cognition...*', calling the study of the scientific basis behind magic the **'Science of Magic'**. Kuhn et al. summarise the scope of the 'Science of Magic' '*...in three sets of issues...'*:

1. *The nature of the magical experience*
2. *How individual magic tricks create this (magical) experience*
3. *Organizing knowledge of the set of known tricks in a more comprehensive way.*

A lot of research has been done (and published) addressing each of these three statements. The first 'issue' was studied by Eugene Subbotsky, whose work addressed the magical experience in children and adults – a study that has been compiled in books like '*Magic and the Mind: Mechanisms, functions, and development of magical thinking and behaviour'* (Subbotsky, 2010). The large bulk of research, however, is focused on the second point proposed by the 'Science of Magic', studying different aspects of general and particular magic tricks in order to describe cognitive mechanisms involved in the magic experience that these tricks create. Examples of these are in the research done by Kuhn et al. in '*Magic and fixation: Now you don't see it, now you do*' (Kuhn & Tatler, 2005) in which they study the relationship between eye movements and visual attention using a well-known magic trick, popularised by the famous magician Slydini, in which a cigar and a lighter disappear in a movement that is performed in view of the subject. In this case, Kuhn and Tatler found that most of the participants that detected the secret method were not looking directly at the place were the secret action was carried, indicating that subjects used covert attention strategies to detect the vanishing of the cigarette and lighter. Kuhn et al. carried a second version of this experiment, in 2008, in which participants were shown videos corresponding to the previous (live) trick (Kuhn, Tatler, Findlay, & Cole, 2008). In this case, the detection rate of the secret method was higher than before (perhaps because social cues did not work as expected). However, once again they found that detecting (or not) the cigarette disappearance was independent of the participants' visual eccentricity, replicating the previous results: the detection of the secret method involved covert attention. In this case, the authors also reported that there was a correlation between the post-disappearance eye's movements and the detection of the secret method, pointing out the importance of analysing the whole scan path of participants rather than focusing on the instant of the event of interest. These studies are good examples that show how magic can be used to investigate an open question in visual perception, which is the relation between eye movements and covert attention (Awh, Armstrong, & Moore, 2006).

In 2006, Kuhn and Land presented a simple but remarkable study that, in a way, was the continuity of the work published by Tripplet almost a century ago. In *'There's more to magic than meets the eye'* (Kuhn & Land, 2006b) subjects were shown videos of the first author performing a classic magic trick consisting of throwing a ball several times up in the air before it 'vanishes' in the last throw (in actuality, the magician retains the ball in the same hand with which he was throwing it). The effect is that the ball seems to have disappeared up in the air. With this trick – named the 'vanishing ball illusion' (VBI) – the researchers wanted to study how magicians can change or distort subjects' visual perceptions. They hypothesised that the effectiveness of the illusion created will highly depend on the magician's social cues (his gaze, head movement, facial expression, et cetera). With this in mind, they used two different conditions consisting of two separate videos, in which the magician used different social cues during the last throw. The first one was called 'pro-illusion', in which Kuhn, for the last throw, followed—with his head and gaze—an imaginary ball while the real ball was actually retained in his hand. The second condition was 'anti-illusion', in which the first author, for the last throw, looked directly at the hand that retained the ball. They found that significantly more subjects were sensitive of the illusion in the 'pro-illusion' condition compared to the 'anti-illusion', concluding that a magician's social cues, (i.e. depending where he was looking while making the ball disappear) were determinant to create the effect that the ball had vanished in the air. However, the eye-tracker data showed that for the last throw, there were no significant differences in the fixations between the subjects that perceived the illusion (i.e. reported having seen the ball up disappearing up in the air for the last time) and those that did not (i.e. reported that the ball was retained in the magician's hand). Kuhn and Land concluded that these results demonstrate dissociation between oculomotor system and perception. While the latter was 'fooled' by the expectations created by the magician's social cues, the former was not.

As will be exposed in this literature review, the VBI experiment laid down the foundation for further research that already gave very interesting results, and has helped, for example, in knowing more about social attention difficulties in autism-spectrum-disorder (ASD) children, as is reviewed in the following lines.

In 2010, Gustav Kuhn et al. published one of the most remarkable studies done in relation with the second statement of the 'Science of Magic': '*How magic changes our expectations about autism*' (Kuhn, Kourkoulou, & Leekam, 2010). The authors investigate—using the aforementioned 'vanishing ball illusion' (VBI) trick—how children with autism spectrum disorder (ASD) perceive social cues and '*…the difficulties…*' these children have '*…in rapidly allocating attention toward both people and moving objects*.' As explained before, the magician throws the ball up in the air several times before he finally retains it in his hand, while his gaze still follows an imaginary ball moving upward – thus producing the effect that the ball had disappeared up in the air. Due to previous evidence of the social-attention difficulties (i.e. gaze avoidance) that ASD children have, the authors expected that these children would not follow magicians' misdirecting social cues, and so would be less susceptible to the vanishing ball illusion. Surprisingly, Kuhn et al. found exactly the opposite; ASD children spent similar time looking at the magician's face and eyes than did the TD (Typical Developing) children, and so ASD were even more susceptible to the presented illusion, showing typical attention to social cues. In the current year, and continuing with this line of research using the VBI, Cyril Thomas et al. gave a turn to the interpretation of Kuhn's et al. previous results in the article *'No need for a social cue! A masked magician can also trick the audience* *in the vanishing ball illusion'* (Thomas & Didierjean, 2016b)*.* They hypothesised that the previous findings of subjects, that saw the 'pro-illusion' videos were significantly more sensitive to the illusion (i.e. they saw the ball vanishing somewhere up in the air) than the ones that watched the 'anti-illusion' video, were not due to the magician's social cues, but rather to the fact that in the anti-illusion condition Kuhn looked at the hand that hides the ball, priming the secret of the trick to the participants. Cyril et al. reproduced Kuhn's videos but added two no-social-cue conditions. In one of them, the magician appears with his head totally covered by a black mask, and in the other he is looking stationary to the front (towards the subject) while performing the trick. In this context, the authors did not find significant differences in the sensitivity of the VBI between the group that watched the social-cue condition videos (the magician follows the trajectory of the ball with his head and gaze until it 'disappears' up in the air) and those who watched either of the no-social-cue performance. They also replicated the previous findings of Kuhn et al 2006 (Kuhn & Land, 2006b) though in this case, the anti-illusion condition was split in two: in one, the magician looked at his hand only on the last throw; in the other, the magician looked at the hand that throws the ball throughout the whole performance. In both cases, they found that the experience of the VBI significantly decreased compared to the pro-illusion condition. These findings altogether led Cyril et al. to conclude that the VBI is not mediated by magician's social cues, since the expectations created by the illusion itself (independently of social-cues) are strong enough to alter participants' perception of the ball in the last 'fake' throw (after which most participants reported to having seen the ball up in the air for the last time). These findings may alter Kuhn's conclusions made in '*How magic changes our expectations about autism'* (described above) since, apparently, the VBI is not mediated by the magician's social cues. Although the work of Cyril et al. added some interesting evidence about how expectations play a role in the vanishing ball perceptual illusion, the psychological mechanisms involved in the VBI are still unknown.

Also last year, 2016, Gustav Kuhn and Ronald Rensink published *'The Vanishing Ball Illusion: A new perspective on the perception of dynamic events'*, presenting new results of the VBI that led to a new perspective about the mechanisms that could be responsible for such an effect (Kuhn & Rensink, 2016). They studied whether a possible explanation behind the experience of this illusion is related to the top-down processes that influence our perceptions of real-world events. Once again, subjects were shown previous videos of Kuhn performing the VBI while eye movements were recorded. In order to study if immediate past knowledge could affect the perception of the present events, Kuhn et al. considered two different conditions. The first one, 'priming condition', consisted of the performance of the VBI, as was done in previous experiments, in which the magician threw the ball up in the air a few times before doing the fake throw (pretending to throw the ball while it is retained in his hand). The second condition consisted of doing the fake throw in the first movement, without previous priming. Although priming the fake movement had a significant effect in subject's experience of the illusion (i.e. subjects who watched the priming condition videos experienced the illusion more than the group that watched the no-priming videos), the authors found no significant differences in the fixations between participants that experienced the illusion and the ones that did not. Kuhn et al. concluded that there is a clear dissociation since whereas eye movements appear to be unaffected by priming, this has an effect on the '*conscious experience of the illusion*'. However, they found that even in the no-priming condition there were still an important number of participants (32%, although significantly lower than in the priming condition) that were sensitive to the illusion, meaning that the effect in the perception of the VBI was due by the long-term knowledge, either created by the observation of the previous movements (in the priming condition), or by the kinematics of the fake toss (in the no-priming condition).

One of the hypotheses that was also considered to be responsible of the sensitiveness of the VBI, as reported by Kuhn et al. in 2006 and again in the present article, was the representational momentum (RM), first discovered by Freyd & Finke, in 1984 (Freyd & Finke, 1984). The RM was described as the tendency that subjects have of perceiving the last point of a moving object's trajectory, ahead from where it really was. Although Kuhn et al. made some brief conclusions about RM as an explanation of the VBI, this hypothesis inspired Cyril Thomas and André Didierjean to carry a whole new experiment in order to find evidence that supports this idea. They published their results under the title *'The ball vanishes in the air: can we blame representational momentum?'* in 2016 (Thomas & Didierjean, 2016a). The authors listed some similarities between the effect produced by the VBI and the RM. Perhaps the most relevant one is that, in both cases, the moving object seems to be seen for the last time ahead from its real position. However, they also pointed out some main differences between these two phenomena; for example, in the RM, the object is actually moving, following a real trajectory, while the last throw of the VBI is fake, which means that the ball does not leave the magician's hand at all. With a clever experiment, however, consisting of presenting both RM and VBI to subjects in similar contexts (same magician, same ball), Cyril et al. found that subjects which were sensitive to the VBI did not show high RM scores as expected (were not sensitive to the RM effect) considering previous findings (Blättler, Ferrari, Didierjean, & Marmèche, 2011). The authors rule out these results, arguing that subjects could apply two different attentional strategies while observing both VBI and RM. Whereas the VBI is potentiated when the subject's focus of attention is directed towards the ball trajectory, in the RM, this attentional strategy, could decline the effect, as was first demonstrated by Hayes & Freyd (Hayes & Freyd, 2002). However, Cyril and André Didierjean, considered important to continue investigating in order to discard RM as a possible psychological explanation for the VBI.

Changing topic, but still related to the second statement of the 'Science of Magic', in 2010 Kuhn et al. published '*Misdirection, attention and awareness: Inattentional blindness reveals temporal relationship between eye movements and visual awareness'* (Kuhn & Findlay, 2010) in which they showed evidences that a paradigm based on magic illusions can be used to study the famous phenomenon described in 1998 by Mack, A., & Rock, I., *'Inattentional Blindness'* (Mack & Rock, 1998) (in which subjects fail to consciously perceive a salient, and task-irrelevant event, that was presented at fixation). In this study, Kuhn used a similar trick to the one used in previous experiments in which a lighter that was visibly dropped behind the table seems to have vanished when Kuhn, using proper visual misdirection, makes the movement apparently 'invisible'. Since subjects' eye movements were recorded with eye tracker while they were watching the performance of the magic trick, the authors could analyse the relationship between verbal reports given by participants at the end of the experiment, and their scan paths (fixations). The authors found that subjects' reports were actually a reflection of their conscious perception (i.e. subjects that reported having seen the drop of the lighter, they actually fixated the object at the time of the drop). Replicating previous findings (Kuhn & Tatler, 2005). Kuhn et al. found that the detection of the 'secret move' was independent of subjects' visual eccentricity. However, once again the differences between participants who detected the drop of the lighter and the ones that missed it were significant in subjects' scan paths (or fixation points) immediately after the secret movement. Participants who reported having detected the drop, moved their fixation significantly faster to the lighter hand, after the drop, than the ones that did not detect it, thus demonstrating a close temporal link between covert and overt attention. Also the fact that some of the participants who detected the drop did on average up to 3 saccades prior to fixating the hand which held the lighter, suggests, as Kuhn et al. concludes: '*…that covert attention is required for the planning of an eye movement'.*

Altogether, these studies are a clear example of how the perceptual illusions produced by magic provides a new opportunity to investigate, in a more naturalistic environment, how expectations and knowledge of past experiences shape visual perceptions. Magic illusions has also helped to better understand visual attention (differences between covert and overt attention) and to unravel which features of the environment drive humans' attentional selection mechanisms (Kuhn & Tatler, 2011; Moran & Brady, 2010).

The results published in 2010, discussed above, lead Kuhn et al. to describe a close relationship between the phenomena of 'Inattentional Blindness' (IB) and the most important component of the Art of Magic — 'Misdirecton' (which makes reference to the act of directing the spectator's attention far from the secret method). Some researchers have, however, already argued about Kuhn's conclusions; such is the case of Memmert, who has published an article pointing out at least four clear differences, or as he refers to them, 'disconnections', between these two paradigms (Memmert, 2010), very briefly:

- *People's expectations about what is about to happen are different. In IB they do not expect to perceive the salient event whereas in Kuhn's experiment some of the subjects are told about what is going to happen (the disappearance of the cigarette)*
- *In Misdirection paradigms there are not any control tasks to prove that the unexpected event is visible.*
- *In IB paradigms, there is a primary task that prevents subjects to perceive the unexpected event, whereas in Kuhn's experiments there is no concurrent task to be performed.*
- *In IB the unexpected event is task irrelevant, but in the Misdirection paradigms used by Kuhn et al. the salient event is relevant (e.g. the lighter drop, if visible is relevant, because is the essence of the trick)*

Kuhn and Tatler reply consistently to Memmert's 'disconnections' in '*Misdirected by the gap: The relationship between inattentional blindness and attentional misdirection'* (Kuhn & Tatler, 2011) undermining each of the aforementioned differences found between IB and Misdirection arguing that Memmert misunderstood the aims stated in Kuhn's experiments, and thus ending the controversy. However among the disagreement raised by the comparison between these two paradigms (IB and Misdirection) it is important to mention the one stated by Peter Lamont and colleagues. In '*Where Science and Magic Meet: The Illusion of a 'Science of Magic*'' (Lamont, Henderson, & Smith, 2010)**.** Lamont et al. points out that the main difference between IB and Misdirection is that in the former, subjects remember that they were distracted with a primary task while the unexpected event was visible, whereas in a Misdirection paradigm subjects do not remember being distracted, while watching the magic trick, or they should not remember (in a good magic performance, spectators should not remember or realised they were distracted, in order to potentiate the magic illusion (Ascanio & Etcheverry, 2005).

Continuing with the second statement of the 'Science of Magic' there is the investigation done by Andreas Hergovich et al. in '*The paddle move commonly used in magic tricks as a means for analysing the perceptual limits of combined motion trajectories'.* This is another interesting study of visual perception using a classic trick known as the 'paddle move, with which the authors study'*... essential variables for the accurate perception of complex patterns of motion trajectories...'* (Hergovich, Grobl, & Carbon, 2011). Very briefly the 'paddle move' consists in the combination of two rotational movements happening at the same time in order to apparently show both sides of a paddle while it is only shown the same side two times, to study visual perception of combined movements. They used different shapes, sides, and angular velocity of the paddle in order to find which are the conditions that give the best magical effect. They conclude that the perception of this illusion is independent of the side and shape of the paddle if its angular velocity is fast enough.

Another interesting work is the one published by Flip Philips et al. '*Magically deceptive biological motion- the French Drop Sleight'* in which they study, using the magic technique known as a 'French Drop', the contribution of magicians movements in the perception of the 'impossible' (Phillips, Natter, & Egan, 2015). This study is one of the first focusing not only in how magic is perceived but also in '*...the contributions of the performer to the act of deception'*, i.e. how a trick has to be performed in order to create the illusion in the spectators mind.

Finally under the second category of the 'Science of Magic', it is important to consider an article published by Amir Raz et al. '*Using Magic as a Vehicle to Elucidate Attention'* that explain how magic is an important tool to study the attention mechanisms in general and the attention network proposed by Michael I Posner et al., in particular (Raz & Zigman, 2001). Raz et al. proposed that understanding how magic works, can give scientists a new way with which to approach the study of the different attentional networks and neural processes underlying atypical attention in healthy people. The authors believe that magic tricks allow playing with misdirection, expectations and suggestions, producing atypical attention in healthy individuals. Raz et al. also point out, as previous researchers have done before, that magic can help to design new paradigms with which to approach the study of many other cognitive processes such as short-term/working memory as well as long-term memory et cetera.

Under the last statement of the 'Science of Magic' is included the article published by Kuhn et al. in which they presented: '*A Psychologically-Based Taxonomy of Misdirection'* (Kuhn et al., 2014). In this paper the authors put in order all the complex relationships between the components that constitute the method of physical and psychological Misdirection, and explained how each of them can be used in psychological research. Different types of Misdirection are exemplified with some videos performed by the second author (Hugo Caffaratti), as well as with the series of studies that Kuhn and colleagues have carried, in previous years, about Misdirection, (which have been commented above in this introduction). Also, a good review of the scientific research done, and still to do, using misdirection is, the article published by Gustav Kuhn and Luis M. Martinez in '*Misdirection: past, present and future*' (Kuhn & Martinez, 2012).

Although the 'Science of Magic' is becoming more and more popular in cognitive psychology and neuroscience, it is not free of controversy. Some scientists have questioned the whole point of such a '*theory*'. In '*Where Science and Magic Meet: The Illusion of a 'Science of Magic'* (Lamont et al., 2010), Peter Lamont et al. argue that in order to systematize the magic knowledge that is used in psychological research, it '*…requires a reduction of the magic theory in a basic terms…*' such as Misdirection (physical and psychological), 'Forced Choice', 'False Solutions' (Tamariz, 1988), and other different methods, or techniques. They consider this a main problem since there are '*…so many ways of reducing magic to more basic elements* ', and so, '*it is hard to see how any unknown mechanisms might be discovered through a process of reduction and exclusion…*' and so being difficult to study point 3 by doing classifications as the one done by Kuhn et al in '*A Psychological-Based Taxonomy of Misdirection*' (Kuhn et al., 2014). Lamont et al. also argue about points 1 and 2, of the 'Science of Magic', saying that there is an endless '*variety*' of possibilities in which methods or techniques could be combined, each of them leading to different magic effects (and experiences) with a '*lack of clear boundaries'; a trick carried out in a slightly different way is a different entity*. At the same time they consider that a particular magic effect can be achieved by different combinations of a wide range of methods, which make difficult the study of point 2: *how a particular magic trick creates a magical experience*.

Ronald A. Rensink and Gustav Kuhn replied to Lamont et al. in *'The possibility of a science of magic'* saying that a '*...Science of Magic Centers primarily around experimental effects, not tricks...*', (Rensink & Kuhn, 2015b) and so such a science is focused on the study of the experience of wonder created by a particular trick: '*...the scientific study of magic is not concerned with the nature of magic tricks themselves, but with the magical aspects of experience created by these tricks...*'. Thus, independently of the component methods it could be considered *'...equivalent those...'* magic effects *'...with little or no differences in how they are experienced...'* in order to avoid the problem of '*lack of clear boundaries*' of the magic effect. Referring to the '*variety*' in which the same component (method or technique) could be used to create different effects they maintain that *'...there's no problem if a component is used in different ways for different tricks, if its analysis is based on functional considerations...*'. In resume, Kuhn and Rensink proposed to group all different methods that led to a same type of magic experience, and to focus on all the aspects that they have in common '*...given that humans respond in roughly similar ways to a given stimulus, there are stable regularities in what results, once a particular method and context have been selected. And such regularities can be studied in a systematic way...*'. And they finally conclude that the 'Science of Magic' '*...appears to have some potential to help researchers use magic to better understand perception, memory, and reasoning. And it could equally well enable knowledge of perception, memory, and reasoning to help better understand magic...'*
With no doubt psychologists were the first in tending bridges between the art of conjuring and science, starting more than a hundred years ago with the above-mentioned works of Jastrow, Triplet, and Alfred Binet, and retaken more recently by Gustav Kuhn et al. with a study that is also considered the first physiological investigation of magic (Kuhn & Tatler, 2005). It has been few years after the publication of this research, when cognitive neuroscientists starting to apply magic

in the study of neural mechanisms that underlay some cognitive processes such as attention and awareness. Thus, two American neuroscientists, Susana Martinez-Conde and her husband S.L. Macknik published a book '*Sleights of Mind: what neuroscience of magic reveals about our everyday deceptions*' (Macknik et al., 2010a) in which they explain the advantages of applying magic theory to the research of cognitive neuroscience. In this sense they are considered the creators of a new field in the study of Neuroscience, which they called *Neuromagic*. The content of the book is an extension of the previous review '*Attention and Awareness in stage magic: turning tricks into research*', published in Nature Reviews Neuroscience in 2008 (Macknik et al., 2008b). Martinez-Conde and Macknik explained that magic as a cognitive illusion can contribute to the study and understanding of different cognitive processes, in the same way that visual and optical illusions helped to reveal some of the neural mechanisms that underlie the visual system. They also point out, in the book, the importance of the intuitive knowledge that magicians have about the brain to be applied in laboratories, and they add that, if neuroscientists had looked earlier at the magicians knowledge, phenomena such as false memories (Loftus & Pickrell, 1995) inattentional blindness (Mack & Rock, 1998) and change blindness (Simons & Levin, 1997) among others, would have been described much earlier, since they are part of the backbone of magic theory, and magicians have been taking advantage of these phenomena for centuries. Martinez-Conde and Macknick give lots of specific examples showing how magic can help in the research of particular brain mechanisms of perception, as well as other cognitive processes. For instance the use of 'illusory correlation', by which magicians create impossible bonds between cause an effect apparently unrelated to produce the magic effect, could help neuroscientists to identify the neural mechanisms correlated with the perception and computation of cause and effect.

As mentioned previously in this review, another powerful tool that magicians use and in which are based all the illusions they create is the Misdirection. Susana and her husband reviewed in their book some of the work, done by Kuhn et al. (previously presented in this review) about the use of this technique in the research of cognitive psychology. They also mention that the different types of

Misdirection can be used to generate new laboratory techniques for studying attention and awareness. Magicians often use novel or unusual objects in their shows that capture spectators' exogenous attention. These, together with objects moving at the same time (in which case the larger movement is the more salient one and so it would catch more attention) could be used to study bottom-up attentional mechanisms such as contrast-gain control or adaptation. Another way that magicians have to accomplishing the purposed of directing attention out of the secret method, of the effect, is by giving to the spectator an implicit or explicit concurrent task in which he/she has to focus for a short period of time. This technique would capture endogenous attention, and could be applied in laboratories for the study of top-down attentional mechanisms. However it is important to notice that Misdirection is a very complex concept (which full description is out of the scope of this review) and it should be studied very carefully before its application to experimental research; otherwise the results could be misread.

In the past decade magic has also proved to be useful to describe a new phenomenon that was, until 2005, totally unknown. In 2005 neuroscientists from Lund University, Petter Johansson and Lars Hall, and colleagues, published a remarkable article '*Failure to detect mismatches between intention and outcome in a simple decision task'* (Johansson et al., 2005) in which they present the results of a very clever paradigm consisting in presenting to subjects a couple of pictures of human faces, and asking them to point to the preferred one, after a period of visual inspection. Once this was accomplished, the experimenter used a magic technique to secretly change the pictures and give to the subject the one that he did not choose. Immediately after, participants were asked to look at the given photo and explain the reasons of the selection. In 74% of the cases subjects did not notice the switch ('magic trick') and they confabulated to justify the (forced) outcome. Johansson and Hall called this new phenomenon '*Choice Blindness'* (ChB), and years after they replicated the results with different experiments in which participants were asked to choose the favourite jam, or to complete a form with questions about their favourite politic party (Hall, Johansson, Tärning, Sikström, & Deutgen, 2010; Hall et al., 2013). In these cases a similar percentage of participants did not notice the change done by the experimenter and so subjects end up giving 'good reasons' for a selection that they have never done. This phenomena represents another scientific prove of a method that magicians have been using for centuries, and it is known as 'force choice' (FC). Now, thanks to the *Neuromagic* research, it is revealed to scientists. Using this technique (FC), magicians can create the illusion that a specific spectator's selection (of an object, picture, playing card, coin et cetera) has been freely done, when in fact the magician has forced this choice. In the magic literature there are countless of different methods, with which to force an object without the audience noticing. The above experiment is an example of how this method of the magic theory can help to understand how humans can confabulate about the subjective sense of a decision made.

In this line, Diego E. Shalom et al. published the work, *'Choosing in Freedom or Forced to Choose? Introspective Blindness to Psychological Forcing in Stage-Magic'* in which they investigate how (FC) are subjectively perceived by a group of participants (Shalom et al., 2013). A FC method classically used in card-magic performance was tested, which consists in riffling the deck of cards in front of subject's view in order to force a card either by exposition time (the forced card is the exposed for a longer time), or by position in the deck (i.e. the last cards of the deck are more sensitive to be selected). In this particular experiment, subjects were shown a video of the deck of cards being riffled and they have to 'freely' select one. The authors found that independently of the condition ('exposition time' or 'position in the deck') subjects fail to notice that the selection was forced, confabulating about how free they felt while choosing a card. These results, in a way, replicate the findings of Johanson et al. 2005 (Johansson et al., 2005). However Shalom et al. gave a further step trying to find physiological marks that could shed light on the dissociation found between the '*objective factors'* of the choice and subject's subjective reports. It is well known, through past experiments, that a tag of slow cognitive events involved in decision making, such as attention and memory, is pupil size. In this sense subjects pupil size was recorded while watching the videos of the FC. The study of subjects' pupil dynamics demonstrated differences when they were forced but they did not notice it, (in which case the curve of the pupil-size showed a '*dip*') compared to when they were not forced and again they felt free in the selection (in which case there was a small build-up of pupil-size curve). The authors conclude that this paradigm constitutes a good example to study the '*constructs of free will'*.

After the publication of the book '*Sleight of Mind',* more neuroscientific studies have been carried, however most of them, with similar approaches as the ones taken by cognitive psychologists. In this sense, Cui et al. presented results of an experiment consisting in subjects observing a magician performing a classic trick, (in which a coin that is transferred from one hand to another disappears), while their eye movements were recorded with an eye-tracker (Cui et al., 2011). Different conditions in which the magician performed the trick with his face covered or not, allowed Cui et al. to determine how social-misdirection (or social cues), and joint attention can influence and potentiate the perception of the effect of the magic trick. Another example in the same line, is the study of Jorge Otero-Millan '*Stronger misdirection in curved than in straight motion'*, in which it is proved that sleight of hand involving curvilinear motion are more effective misdirecting the focus of attention out of the secret method than the rectilinear ones, thus potentiating the magic effect (Otero-Millan et al., 2011). Curvilinear movements of the hands seem to be more salient, following a more unpredictable trajectory, than straight movement, both affecting differently the oculomotor behavior of observers.

Besides these first studies, the creators of *Neuromagic*, Steve Macknik and Susana Martinez-Conde, who were also involved in most of the above-mentioned experiments, proposed in '*Real magic: future studies of magic should be grounded in neuroscience'* (Macknik & Martinez-Conde, 2009) that in order to understand how magic works in the observers mind, it is important to know the neural mechanisms underlying its perception. They continued that this approach of the study of magic: *'…may provide fresh new insights into the brain mechanisms of perception and cognition'.* The authors believe that in contrast with psychologists' point of view, the study of magic has to be addressed from a neuroscientific perspective, in order to gain insights into the physiological processes that underlie magic perception.

So far, in the neuroscientific literature, there are a couple of articles published, both of them presenting fMRI recordings of magic perception. In the first one '*Imaging the impossible: An fMRI study of impossible causal relationships in magic tricks'*, Ben A. Parris et al. presented evidence of neural activity, registered with functional magnetic resonance of subjects, while watching videos of magic effects (Parris et al., 2009). Specifically they observed that this activity, which was greater in the left hemisphere, is correlated with the violation of causation produced by a magic trick. Dorso-lateral prefrontal cortex (DLPFC) and anterior cingulate cortex (ACC) seem to be the brain areas related to detecting and evaluating (respectively) violations of cause-effect associations, that are both long-established and that have been learnt through past experiences. Parris et al. found that the activity in these areas was greater in the left hemisphere than in the right, supporting the findings of Gazzaniga who proposed that the role of this part of the brain is '*interpreting complex events*' (Gazzaniga, 2000). Relating the results with previous findings (Van Veen & Carter, 2006) the authors could disentangle the aforementioned activity (in DLPFC and ACC), declaring that ACC is active during violations of expectancy in general, whereas the activation of DLPFC seems to be specific for the detection of violations of causality in particular, such as the ones produced by a magic effect. Parris et al. also added that although the causality violations produced surprise, the activity found in DLPFC is not correlated by surprising events, demonstrating that this area has a special role in causality processing (i.e. the causality violations produced by a magic effect, but not by the surprise that this generates).

In a later fMRI study carried by Amory H. Danek et al. in 2015, they could replicate the findings of Parris et al. Danek and colleagues recorded brain activity of subjects while they were watching videos of magic in the scanner (Danek et al., 2015). However the authors criticized the methodology used in the Parri's experiment, since they only recorded the brain activity that was locked/correlated to the instant of the execution of the magic effect (i.e. the time point of surprise) without considering the whole time window in which the magic trick was executed. Danek et al. argue that, it is during the observation of the execution of the whole sequence of movements, which are involved in the magic trick, when subjects' (or spectators') expectations, about the outcome of the actions, are built up. Then the surprise comes when these built expectations are violated. So Danek et al. proposed that in order to have a clear understanding of the brain regions that support the causality violations, produced by a magic trick, it has to be studied the whole time window in which the trick is performed, as well as the climax instant in which the surprise (or magical effect) is produced.

As was mentioned Danek et al. found activity in the DLPFC and ACC, as previously reported, however they also observed activity in the head of the caudate nucleus (CN), left inferior frontal gyrus and the left anterior insula, for the entire duration of the magic trick, except for the time point of the expectation violation (magic effect). This find made the authors conclude that CN is related to expectations rather than the incongruence produced by the violation of causality. These results support previous findings in which CN was active when the outcome of a task was related to the preceding action, however no CN activity was found when changes in the contingencies between initial actions and outcome was perceived (Grahn, Parkinson, & Owen, 2008; Tricomi, Delgado, & Fiez, 2004).

Summary

From this review – which attempts to summarize some of the most important research done in the field of *Neuromagic*, in which this thesis is based – it is evident that most of the works published have focused on the behavioural responses elicited by magic. As was shown in many of these studies, researchers registered eye movements of participants while watching either videos or live performances of magic tricks. Authors reported interesting findings about the relationship between eye movements and covert attention, as well as between covert and overt attention. However, in the twelve years since Kuhn first published '*Magic and fixation: Now you don't see it, now you do'* (Kuhn & Tatler, 2005) only the two aforementioned fMRI studies have been focused on the neural mechanisms underlying the perception of a magic illusion. This may be due in part to the fact that a magic effect is a complex stimulus to study, and so, many different things are going on at the same time in order to achieve the illusion. As in many other cases, the behavioural response produced by a magic effect (i.e. the climax of any magic trick) is the result, or *product,* of a chain of neural processes, overlapped, that precede it; some of them related with expectancy, others with surprise, and some others with suspense. In this sense, the magic effect is built in a specific context that its perception, altogether, leads to the emotion of 'mystery'. So, altogether the interpretation of neural activity correlated to the magic effect is not straightforward due to the mentioned complexity of the magic stimulus. That said, the research done by Parris et al. and Danek et al. are the first two clear examples which demonstrate that a neuroscientific investigation of magic perception is actually possible, and that the neural responses elicited by the cognitive illusions produced by magic can help in the understanding of the variety of neural mechanisms that underlie its perception, such as expectations, causality violations, surprise, attention, memory, et cetera.

With this in mind, and due to the lack of research that still exists in line with these studies, in this thesis is presented work focused on the behavioural and neural responses elicited by magic illusion (see Chapter 2). As mentioned in both the General Introduction of this thesis and the fMRI studies referenced above, the perceptual illusion produced by a magic effect is based mostly on the incongruence caused by the violation of high-level processes, such as expectations. As will be explained in the next chapter, neural processes related to expectancy and surprise have largely been studied in ERP research since the early 1960s (although Pauline et al. in 1936, and Davis et al. in 1939 registered the first ERPs in humans). The discovery of the first cognitive brain potential by Grey Walter et al. related to expectancy events, known as the CNV (Contingent Negative Variation) (W. Walter, Cooper, Aldridge, McCallum, & Winter, 1964) together with Sutton's et al. publication one year after—in which they introduced P300, a potential also elicited by unexpected or surprising stimulus—set the beginning of a long path of research that reaches the present time with questions about expectancy and surprise still unresolved. Thus, on the one hand, the study of P300-like responses elicited by a magic illusion can give new insights about the understanding of how high-level processes, such as expectations and inferences based on knowledge from past experiences, influence visual perception. On the other hand, since expectations and surprise are part of the backbone of magic, this art can help in the ERP research to disentangle some of the neural mechanisms that manifest P300, but from a new perspective that involves the perception of violations of long-established causal relations in a more natural environment, than the one typically used (i.e. flashing images at the centre of a screen). In this sense, since magic is a performing art that has to be perceived live or through videos, it has forced the design of a new paradigm in which a series of non-edited videos, of magic tricks, were shown consecutively. This novel methodology has raised several technical issues, most of them related to the synchronisation of the shown videos with the EEG recording system. All of these challenges, and the way in which they were sorted out, are explained in Chapter 1 ('Methods'). This chapter can serve as a guide for future researchers wanting to carry ERP studies in a more ecological setting, as the one presented in Chapter 2. The work presented in Chapter 2 has been recently published in the scientific journal *Psychophysiology*, under the title: *'Where is the ball? Behavioural and neural responses elicited by a magic trick'* (Caffaratti et al., 2016).

Although Chapter 2 includes some relevant conclusions about the results presented in it, there will be general conclusions, at the end of this thesis, (see 'General Conclusions') about the work done in the field of *Neuromagic*, that, since its inception more than ten years ago, has demonstrated fruitful for the research of Neuroscience.

Chapter 1. Methods. Technical difficulties in the implementation of an ecological ERP paradigm.

1.1 Introduction to Chapter 1

As has been mentioned in the introduction of this thesis, magic is a very complex stimulus to be studied. Traditionally most of the ERPs studies consist of flashing images of different events, at the centre of the screen, to which point subjects are asked to maintain fixation, while performing either a discrimination or detection task (depending the paradigm). However, when it comes to study evoked potentials elicited by a magic stimulus, it would not make sense to present, to subjects, a picture or figure of a trick, since a prestige consists in a succession of acts or movements that, all together, lead to the illusion. In this sense, as Danek et al. and stated in their article (Danek et al., 2015; Parris et al., 2009): in order to understand the neural processes involved in the perception of magic, it is necessary to consider the whole sequence of steps that yield to the impossible effect. In order to achieve this, subjects have to, freely, observe a magic act either live (performance) or through the presentation of non-edited videos, (since otherwise subjects will notice the 'camera trick'). Inevitably, these requirement, force to readapt old paradigms, classically used in the ERP research, in order to measure evoked potentials elicited by a magic illusion. For the particular case of oddball paradigms, a live presentation of the magic trick would be difficult to control, mostly because of the high number of stimulus repetitions normally required in this type of paradigms (also it would be difficult to present the sequence with a predefined probability of the target/non-target stimulus). In this sense, for these cases, the use of non-edited videos offers a more controlled, and still natural, environment, with which to study evoked reponses. Is for this reason that, for both of the experiments explained in the next chapter, subjects were presented with an oddball sequence of videos of a particular magic trick, rather than life performance. However, this novel methodology raised several technical issues that needed to be sorted out in order to implement the two experiments presented in Chapter 2. In the following sections, of this chapter, are exposed some of the most important issues found, and how they were resolved.

1.2 Preparing the videos: Filming Process

In Chapter 2 of this thesis, two experiments are presented in which EEG recordings were carried out on subjects watching a sequence of videos embedded in an oddball paradigm. Hundreds of repetitions of the same stimulus were presented under different conditions (Conditions are defined and explain in detail in Chapter 2, see 'Paradigm'). However, due to the fact that this study was focused on the perception of magic, none of the videos used were edited, for two main reasons: i) it could not have been possible to create the cognitive dissonance elicited by the illusion; ii) subjects would not have performed a meaningful estimation of the probability of the trick's outcome (i.e. if the ball were going to appear under the cup or not). It was important, therefore, that each of the trials were unique and unedited, so subjects could perceive the whole sequence of movements performed "naturally" by the magician. This means that the same magic trick was performed 900 times (trials) in total (500 used in Experiment 1 and 400 used in Experiment 2, as explained in Chapter 2). For each experiment, different continuous videos were filmed one by one in blocks of 50 trials each (i.e. each continuous video contained 50 trials). This fact brought many technical difficulties. First of all, to find a magic trick that supported hundreds of repetitions without its secret being discovered was not straightforward. It is well known in magic theory that, in general terms, a magic effect should not be performed more than once in front of the same audience, otherwise the secret method could be guessed or unveiled. However, looking deeper into magic theory, there are some tricks (or movements) that have the potential to be adapted or changed in order to support several repetitions. Such is the case with the 'Chop-Cup' effect (Mark Wilson & Earl Nelson, 1979). This 'magical' cup has the ability to make any type of small object—such as a ball, appear or disappear under the magician's control. As described in Chapter 2, strong 'psychological Misdirection' (Kuhn et al., 2014) was applied, in the movement performed with the cup, in order to repeat the same prestige hundreds of times without exposing the method (none of the subjects could guess the secret method when asked at the end of the experiment).

Secondly, although it is humanly impossible to reproduce exactly the same movements hundreds of times, a lot of effort was required in order to keep all the trials as equal as possible, for two main reasons: subjects could observe an exact sequence of movements trial after trial, and so, any changes in the magician's performance could have been taken as a cue to guess the outcome of the trick (such as a strange gesture or movement that could cue the outcome), thus biasing subjects' decision. For these reasons, it was decided that the series of videos, needed for each of the experiments, had to be filmed in blocks of 50 trials, which were easier to control and to ensure all trials were "equal".

Third, the filming process itself was difficult, and required many repetitions in order to have each of the sequence of 50 movements/tricks as equal as possible. As the videos were not edited, if any of the 50 trials was wrongly performed or if a sudden and unexpected problem appeared, such as the ball falling and rolling on the floor or table, the whole sequence of 50 trials needed to be repeated from the beginning.

All the videos, used in both experiments, were filmed with a sampling frequency of 25 frames/sec., using a standard video camera mounted on a stable tripod.

1.3 Stimulus Onset

Another problem raised by the use of videos of complex events (such as magic), was the definition of the stimulus onset with which to lock the subjects' neural responses. As mentioned in Chapter 2, before the EEG experiments presented in this thesis, there have been two other physiological studies in magic perception. Both of them have used fMRI to record the brain activity of participants when watching videos of magic tricks, although in these cases all videos were different from each other (Danek et al., 2015; Parris et al., 2009). In order to set the stimulus onset, both groups of researchers proceeded as follows: a) they first presented the videos they were going to use to a group of subjects who were not going to participate in the fMRI study. These participants were asked to press a button at the instant they "felt" that the magic effect has happened; b) later, those times were averaged across subjects and the resultant time was used (as stimulus onset) to lock the brain responses of a second group of participants who took part in the fMRI study. Although this could be an option for fMRI studies, in the case of EEG technique – which is time sensitive (i.e. it has high time resolution) – there needed to be more precision in defining the moment of the stimulus onset. Most of the ERPs are elicited hundreds of milliseconds before or after the presentation of the target event. For this reason, it was decided that the neural responses should be related to the first instant in which subjects receive retinal information about the outcome of the trick, that is, the first frame at which the magician started to tilt back the cup, in order to show if the ball was inside it or not; regard the following Figure 2:

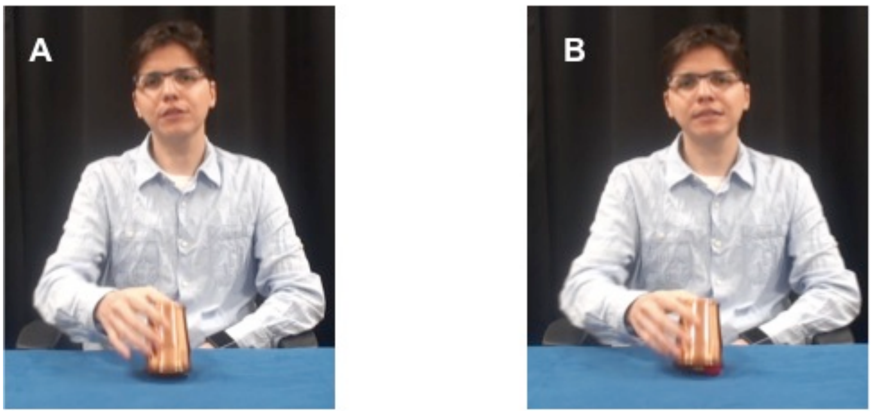

Figure 2. Frame of the stimulus. Frame at which the cup started to tilt back, by the magician, showing its content. This frame was considered the stimulus onset to which all the neural responses were related. (A) An example of a stimulus onset in which the cup was empty. (B) An example of a stimulus onset in which the ball appears under the cup.

The content of the cup was totally exposed for approximately 1 second before carrying on with the next trial. During this period, although the video was running, there wasn't any movement performed by the magician. This was made with the intention that subjects looked at the content of the cup (stimulus) for one second in order to avoid artefacts, such as eye movements, blinks et cetera. Although this instruction was carefully given and taught to the participants, due to the large number of trials, and the long duration of the total session, it was very difficult to completely avoid these kinds of artefacts, and they were present in some trials affecting the neural responses. After visual inspection, these trials were detected and not included in further analysis.

1.4 Video Player

All videos filmed were presented (with no sound) to subjects on a CTR monitor with a screen resolution of 1024 x 768 pixels and refresh rate of 100Hz. The viewing distance for subjects was set to approximately 55cm. In order to control the presentation of the videos to the subjects, MATLAB was used (Simulink & Natick, 1993) and Psychophysics Toolbox (Brainard, 1997). In general terms, this toolbox allows not only for perfect control of all the experimental variables, such as the starting and ending times of each event, et cetera, but also, and most importantly the synchronization of the EEG recording system with the video presentation. Although Psychotoolbox has proven to be a robust choice to implement classical psychophysics studies in which static images were flashed on the screen, the current versions of this program do not seem to be totally prepared to deal with long-duration videos that need to be paused and restarted every few seconds. In both of the experiments presented in Chapter 2, for each trial subjects were asked to guess the outcome of the trick—that is, whether they think the red ball was going to appear under the cup or not. Thus, before revealing the content of the cup, the video was paused, and the current frame remained visually frozen until the participant entered his/her response, in which moment the video began to play again; this will be explained in detail later in ''Back to play-effect': Effects of resuming the video after the pause'. At the beginning, this design did work properly, but as soon as the number of subjects started to increase, Psychtoolbox started to operate unstably, pausing the video at random times and, in the worst cases, closing unexpectedly in the middle of a session. After thoroughly checking that the problem was not in the code executing the program, researchers considered the fact that running the experiment from a laptop, as this was the case, was not the best option due to its limited memory power and its low processing speed. Thus, it was decided to try with a more powerful computer. Once this computer was all set, a new session was run with another participant, yet once again, halfway through the session the video suddenly stopped and the program shut down. More tests were done with this computer, but with no success. At this point the only other option was to consider whether or not Psychtoolbox was the best choice to run an experiment based on the presentation of long duration videos while recording EEG. After searching and considering the use of other versions of this toolbox, it was discovered that in order to play videos, Psychtoolbox uses QuickTime Player by default. The communication between these two programs works well when it comes to playing either short-duration videos or long, that need not be continuously paused; in any other situations, however, the functions that use Psychtoolbox to 'talk to' QuickTime Player operate unstably. This issue was ultimately resolved by using 'G-Streamer', another video player which, after testing it several times, proved to work properly and could support being stopped by Psychtoolbox every few seconds, as was necessary in order to collect data from subjects while keeping the computer synchronized with the EEG recordings. This was the program that was finally used for both experiments (Experiment 1 and Experiment 2, see Chapter 2). Finally, it is important to take into account that 'G-Streamer' can only play videos in 'mp4' format.

1.5 Synchronization

The synchronization between MATLAB and the EEG was done by sending—at each trial—electrical pulses from the computer that runs the code to the EEG recordings' system, in order to mark the times at which each of the events were presented to the subjects. More specifically, two pulses were sent per trial, one to label the number of the current trial, and the other to mark in the EEG recordings the exact instant at which the video resumed play after the pause. With the latter, it was possible to know the time at which the stimulus was presented to the participants (i.e. the first frame at which the cup was tilt back, as explained earlier).

Although this method of synchronization is classic (and has been proven to work perfectly in most of the psychophysics experiments that required EEG recordings), independently of the number of trials presented, in this particular experiment things were, once again, more complicated than normal. At each pause, Psychtoolbox not only needed to run the specific functions in order to pause the video, freeze the image, keep track of the current frame, and get the position of the next frame to print on the screen after the pause, but also had to check, get, and save the behavioural response introduced by the subjects. While all of this was being controlled, Psychtoolbox moreover had to send the mentioned two pulses to the EEG. Probably due to the number of tasks this toolbox had to perform in parallel, some of the pulses were not sent, or if they were sent they were spurious. In order to fix this problem, MATLAB was used to save, in an array, all the exact times at which Psychtoolbox sent pulses to the EEG. Thus, it was possible to have records of all the exact instants at which subjects perceived the stimulus. Then, another function was created in MATLAB that, by using this array of times, could identify and fix the missing marks/pulses of the EEG recordings (for each session).

1.6 'Back to play-effect': Effects of resuming the video after the pause.

In each of the presented trials, subjects were asked to guess the outcome of the trick performed by the magician, that is, whether they thought the ball was going to appear under the cup or not. For that, the video was paused some milliseconds before the content of the cup was revealed (stimulus onset), and this same frame was shown frozen, on the screen, until subjects entered their response, by pressing the corresponding button. However, due to the fact that the motor action required to press the button could add some undesired artefacts to the EEG recordings, once the participants manually entered their guess, the video was kept paused for 500 milliseconds, in order to separate the motor action from the stimulus onset. See Figure below:

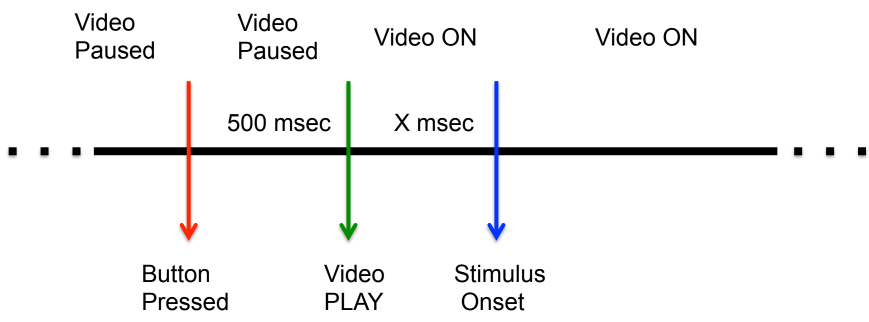

Figure 3. Scheme of the times at which the video was paused and resumed after subject's response, for Experiments 1 and 2. After subjects entered the response (by pressing the button), a delay of 500 ms was added before the video resumed play (time between red and green lines). This was done in order to separate subject's motor action, required to press the button, from the stimulus onset. Once the video was back to play, and after few frames (time between green and blue lines), the outcome of the trick was revealed (stimulus). In the figure, this time is indicated with an 'X', since it was different for Experiments 1 and 2.

After the delay of 500 ms (green arrow in Figure 3) the video restarted to play and continues ON until the next trial. The 'X' in the Figure indicates the time that precedes the stimulus onset and at which point the video was paused. Explained below, this time was different for Experiments 1 and 2.

At first for Experiment 1, the pauses, were set at 480 milliseconds before the presentation of the stimulus in all the trials. So, in this case, the motor response was separated from the stimulus onset by 980 milliseconds (500 ms + 480 ms).
After analysing and averaging the neural responses of the first few subjects, an unexpected 'artefact' reaching its maximum (positive potential of about 3 μV) at around 100 milliseconds before the stimulus onset (shown in Figure 8, Chapter 2). This artefact appeared to be consistent in all of the single subjects' averages as well as in the grand average. This new issue was more difficult to sort it out. Many different points were considered as potential causes. First of all, all the codes used to analyse the data and calculate the averages were carefully checked. Since no inconsistencies were found in the code, the possibility was considered that such an artefact could be related to the subject's motor activity of entering the response. However as was explained above, this action preceded the pick amplitude of this 'spurious potential' by 800 milliseconds. Anyway, all the single trials recordings were again visually inspected, one by one, in order to identify any missed artefact

around the latency of interest. Again, no abnormalities were found at a single trial level. The next step was to consider whether this artefact was not such, but rather a neural response elicited by subjects' anticipation of the impending outcome of the magic trick. In order to rule this possibility out, the literature about ERPs elicited by pre-stimulus anticipation was revised. It was found that none of the classic ERPs of this family, such as CNV (Contingent Negative Variation), RP (Readiness Potential), SPN (Stimulus-Preceding Negativity) (Böcker, Baas, Kenemans, & Verbaten, 2001; Luck, 2014) had a positive polarity, (as can be deduced from some of these ERPs' names). Although, in the case of Experiment 1, the stimulus used was unusual (magic trick), it was very unlikely that the expectancy of its outcome elicited a "Stimulus-Preceding Positivity" potential. More subjects were run in order to test whether this 'artefact' continued appearing in the averages. Surprisingly, that was exactly what happened. The 'non-causal potential' was present in all of the neural responses recorded.

Another possibility to contemplate was whether this 'artefact' was actually a neural response elicited by subjects' perception of the image's state change, from frozen to movement, when resuming the video after the pause. Such an assumption made sense since the pick amplitude of the artefact was the same for all trials, conditions and subjects, and it seemed to be locked to the instant at which the video was back to play, which was 480 milliseconds before the stimulus onset. As was demonstrated with Experiment 2, this was exactly the cause of the 'spurious potential'. However, due to the fact that this potential didn't at all affect the neural responses elicited by the magic stimulus, the data collected in Experiment 1 was considered for further analysis, and its noteworthy results were included in the article published in (Caffaratti et al., 2016), as well as in the second chapter of this thesis (see Chapter 2).

As will be explained in Chapter 2, for Experiment 2 the times at which the video was paused were randomized between 280 and 680 milliseconds before the stimulus onset. In this way, if the spurious potential were actually locked to the moment at which the video resumed play, it would disappear when averaging the responses across the different conditions and subjects. That was exactly what happened, as it can be observed in Figure 9.A in Chapter 2.

It is important to remark, once again, that all of the problems and issues commented on in this chapter were mostly due to the novelty of the experimental design. None of the ERPs studies found in the literature have used videos as stimuli. In this case, it was necessary to sort out not only the expected technical challenges, such as the filming process, synchronizing the video presentation with the EEG recordings, but also those that were unexpected, which delayed the whole process of acquiring useful data. In this sense, the published article '*Where is the ball? behavioral and neural responses elicited by a magic trick*', which is discussed in detail in the following chapter, represents a novel work for the Cognitive Neuroscience field not only because it is the first EEG recordings ever performed with magic, but also because it sets the basis of how to use more ecological stimulus in the ERP research in general.

Chapter 2. Behavioural and neural responses elicited by a magic illusion.

'The eyes are faster than the hands, the brain is even faster than the eyes. That's why you [magicians] have to attack the brain. Magic is then, ***surprise****, before everything* ***surprise****.'*

David Bamberg (aka Fu Manchu)

2.1 Introduction to Chapter 2

It is well known in the field of magic that each illusion 'plays', in one way or another, with spectators' expectations. These expectations could either be built up by the magician, during the performance, or pre-exist due to the spectator's established prior beliefs (e.g. basic physical principles, et cetera). The magician changes or breaks the spectator's predictions or inferences about immediate reality, in order to produce a perceptual illusion that generates feelings of surprise and mystery (or impossibility) in the spectator's mind (Ascanio & Etcheverry, 2005). Although there are many subtleties to be considered (the details of which are out of the scope of this work), one would not be mistaken in stating that, generally, a magic illusion is a surprising effect produced by a twist in spectators' expectations and anticipations. Thus, since this ancient art was born, magicians have deeply studied how to play with these elements in order to manipulate people's perceptions. As was mentioned in the 'General Introduction' of this thesis, all of this knowledge, (only completely revealed to, and understood by, expert magicians), is a powerful tool and source of information that could be used by scientists not only interested in the study of perception, but also of other cognitive processes.

For many years, cognitive psychologists and neuroscientists have given attention to the study of 'Expectancy' (James, 2013). The psychologist Daniel Ellis Berlyne, who has written extensively about surprise and curiosity, defined expectations as '*mental representation of a stimulus or event that is aroused by some cue or set of cues that has regularly preceded that stimulus or event in the past. Alternatively, an expectation might be aroused by an inferential process that predicts the occurrence of a stimulus or event.'* (Berlyne, 1960). At the same time, expectancy can be defined in terms of the probability distribution of possible observations, with the occurrence of the less probable observation being the generator of surprise (Barto, Mirolli, & Baldassarre, 2013).

Recently, neuroscientists have been using different techniques (fMRI, MEG, iEEG, ERPs) to unveil the neural correlates of surprise and uncertainty, as a means to understand how these processes influence perceptions. In past decades, a great number of studies described different ERPs components that appeared to correlate with different behavioural states (Luck & Kappenman, 2011; Luck, 2014). Among this research, it is remarkable how large an amount of work focused on the study of one particular component, elicited by high-level processes related to uncertainty, such as surprise and expectancy.

In 1965, Sutton et al. published a groundbreaking article in which they presented an ERP component that was elicited under certain experimental contexts involving an unexpected task-relevant stimulus (Sutton's study utilised audible tones and flashes) (Sutton, Braren, Zubin, & John, 1965a). Sutton et al. called this new component P300 and, although its functional role is still not fully understood, it has shed light on the understanding of different high-level processes, such as attention, working memory, perception et cetera (Polich, 2007b).

It is important, before continuing with this introduction, to describe very briefly what the EEG and ERPs techniques are before revising some of the classical experimental manipulations that have been found to elicit this famous component (P300)—the reason for a big bulk of studies published in peer-reviewed journals since its discovery.

2.2 Electroencephalography (EEG) and Event-related potentials (ERPs)

It was Hans Berger who in 1929 observed, for the first time, electrical activity of the human brain, by placing an electrode on the scalp (Tudor, Tudor, & Tudor, 2005). This electrical activity is known as an Electroencephalogram (EEG). Since its discovery, this electrophysiological recording technique has become an important tool, not only in research of the brain, but also for clinical applications and diagnosis. EEG has three main advantages that makes this technique unique and still-relevant tool to be used in cognitive neuroscience research: i) it is non-invasive, since the brain activity is recorded from electrodes that are placed on the scalp, ii) it is relatively low cost, iii) and does not require a subject's overt response.

In order to record EEG activity, the electrodes are placed on the scalp with a distribution that is regulated by the 10/20 System (see Figure 4 below), which was developed in the 1950s by the International Federation of Clinical Neurophysiology (Jasper, 1958). Named '10/20' because electrodes are placed at 10% and 20% points along lines of latitude and longitude. The activity recorded by each of the active electrodes is classically referenced to a pair of linked electrodes that could be placed on each of the earlobes or on each of the mastoids bones.
However, due to the fact that the activity recorded represents the activity of different groups or assemblies of neurons activated at the same time, it is difficult to determine which are the neural-sources of specific cognitive processes (Luck & Kappenman, 2011; Luck, 2014) which means that EEG has a low spatial resolution.

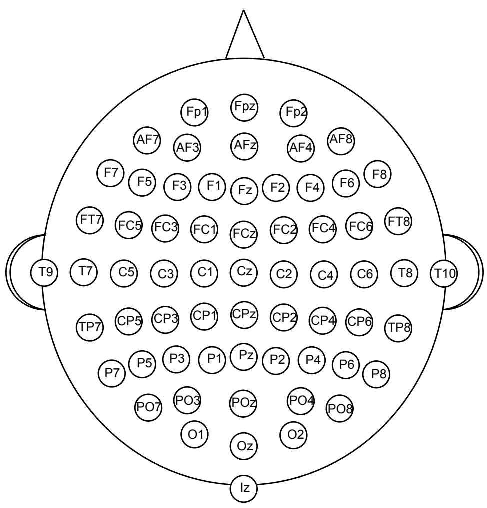

Figure 4. Electrodes' distribution according to the 10/20 system, (Jasper, 1958).

Thus, different analysis techniques have allowed researchers to 'extract' from the EEG recordings the neural responses elicited by sensory events presented to subjects in organized sequences, depending on the paradigm. Classically, the presentation of a several number of trials with the same stimulus allows to average the individual EEG recordings, in order to cancel the noise, and thus to get the neural (activity) response that is normally locked to the onset of the stimulus. These responses are known as event-related potentials (ERPs).

This technique has long served researchers in studying neural responses elicited by specific sensory events. One of the main advantages of ERPs is its temporal resolution allowing the study of the dynamics of different cognitive processes related to presented events (Quiroga, 2006).

An ERP is classically described by its polarity, if it is a positive or negative wave, and by its latency, (i.e. the time at which the potential reaches its peak amplitude). Thus, the combination of these two factors (polarity and latency) allows us to label the different ERPs components that exist. For example, N100 means that it is a negative (polarity) component that is elicited 100 ms (latency) after the stimulus onset, whereas P200 refers to a positive potential that appears 200 ms after the evoking event. However, depending the paradigm, and so the presented stimulus, the latency of the different components could vary. For this reason, another naming convention is to label the ERP using its polarity (i.e. P or N), and instead of its latency, to use the sequence in which the peak occurs after the stimulus presentation. Ergo, considering the two components mentioned above, they could also be named as N1, P2 respectively.

Finally, there is a third possibility in which the different ERPs could be classified in two different groups: exogenous and endogenous (Donchin, Ritter, & McCallum, 1978). On the one hand, exogenous components are those that are elicited by the physical features of the presented stimulus, like its colour, shape, and size. On the other hand, endogenous potentials are evoked by the information processing of the external stimulus (that could be absent).

In the past few decades, neuroscience has developed different paradigms which, depending on its characteristics, can elicit a particular ERP. Although, as previously mentioned, this technique has a poor spatial resolution, depending which component is elicited and the changes in the morphology (amplitude and latency) produced by the evoking stimulus, it is possible to theorize about the distribution of brain mechanisms that underlie the cognitive processes involved in the execution of the task.

2.3 P300 & Oddball Paradigms

P300 is a late, positive deflection that is elicited around 300 ms after the stimulus presentation, hence the name P300. This large component can reach amplitudes above 10uV and – as Ritter and Vaughan first shown – it has a parieto-central scalp distribution, although its amplitude can vary across the scalp, being smaller in the frontal areas and becoming larger in the parietal locations (Ritter & Vaughan, 1969).

Sutton's original experiment consisted of a presentation, with different levels of probability, lights (flashes), and sounds (clicks), which served as a feedback of the subject's previous guess about the stimulus modality. Although P300 was elicited by both visual and auditory events, the component presented larger amplitude when the eliciting stimulus was unexpected. In this context, Sutton et al. proposed that P300 is an 'endogenous' component, meaning that it is not related to the physical characteristics of the stimulus (visual or auditory modality), but rather to the subject's cognitive processing of the stimulus information. In this way, it can be affirmed that P300 is sensitive to the experimental context in which the stimulus is embedded. In the following years after Sutton's publication, several studies have manipulated different experimental variables in order to describe morphological changes in P300 that allowed researchers to know more about this late potential waveform. One of these variables, already suggested by Sutton in his 1965 study, was the 'stimulus probability', defined as the prior probability of the stimulus occurrence, which is determined by the experimenter (Sutton et al., 1965a).

In 1969, Ritter and Vaughan presented results from an experiment in which subjects were asked to detect infrequent target stimulus embedded in a series of more frequent—or standard—non-targets (Ritter & Vaughan, 1969). This particular arrangement of events received the name of 'oddball paradigm'. In this study, the researchers could replicate Sutton's results, finding an inverse relation between P300 amplitude and the stimulus prior probability. The less probable, less expected, and rarer the stimulus, the larger the amplitude of the elicited P300.

Although oddball paradigms became a classical study in the P300 research, and provided a significant amount of detail about this endogenous component, soon it was found that only manipulating the stimulus' prior probability was not enough, or sufficient for its elicitation (Pritchard, 1981). Instead, the eliciting stimulus has to be attended (or signal) and, more importantly, has to be task-relevant or informative in order to elicit a P300 (Duncan-Johnson & Donchin, 1977). It is important to note, as Sutton et al. pointed out, that even if the stimulus is omitted, from the oddball sequence, it could produce a P300 but only if the omission is informative (Sutton, Tueting, Zubin, & John, 1967). On the contrary, if the infrequent target is task-irrelevant or is ignored by the subject, the mentioned component would not be elicited.

It is important to stress the fact that what makes a particular stimulus signal task-relevant or irrelevant, is the experimental context and the instructions given to the subjects, (i.e. the discrimination task that subjects have to preform) rather than the actual physical characteristics of the stimulus (Pritchard, 1981).

To date, several studies have been carried out using different versions of the oddball paradigms, consisting in different combinations of signal task-relevant/irrelevant stimulus that allowed psychophysiologists and neuroscientists to know more about this endogenous component; for a review see (Polich, 2007b).

Although there is controversy about some aspects of P300, (perhaps the major one being related to the functional role of the process manifested by P300; (Donchin, 1981)), there is a general agreement that this component is strongly related to subjects' expectations and feelings of surprise (Donchin, 1981; Duncan-Johnson & Donchin, 1977). As Tueting et al. have found, P300 amplitude is directly proportional to the 'surprise value' of a stimulus, the more surprising the event, the larger the P300 amplitude (Tueting, Sutton, & Zubin, 1970).

At first, expectancy was understood to be a function of the prior probability of the target in an oddball paradigm. Thus, the surprising effect was produced by a low-probable task-relevant stimulus that violates a subject's expectations. However in 1976, Kenneth C. Squires et al. gave a more precise definition of expectancy, proposing a model in which expectancy was determined by three factors: a) the memory of event frequency within the prior stimulus sequence; b) the structure of the sequence immediately preceding stimuli; and c) the prior probability of stimulus occurrence, which is determined by the experimenter (Squires, Wickens, Squires, & Donchin, 1976). As Squires et al. showed, these three factors interact in a linear additive way to produce changes in the P300 amplitude (Squires et al., 1976). With this in mind, they proposed that the P300 amplitude is not influenced by the prior probability but rather by the subject's *perception* of this relative probability of events, that is, the 'subjective probability' which is a function of the short-term structure of the stimulus sequence plus the short-term stimulus probability (Pritchard, 1981; Squires et al., 1976). As an example, a subject's 'subjective probability' would make them expect that after a few repeated non-target stimulus would come the target one, although the prior probability remains constant and so, the probability of the outcome of each trial is pre-defined.

Above, it has been enumerated some of the most important variables and experimental manipulations that affect P300 amplitude. However, there is, as well, a considerable amount of research focused on the study of another important aspect of this endogenous component: its latency. As mentioned at the beginning of this review, P300 reaches its peak amplitude at about 300 milliseconds after the stimulus onset (P300 latency could vary between 250 ms and 700 ms see (Polich, 2007b)). Although, once again, there are different perspectives about the meaning of P300 latency, most researchers concur that it is *proportional to stimulus evaluation* (Coles, Smid, Scheffers, & Otten, 1995; Courchesne, Hillyard, & Courchesne, 1977; Donchin et al., 1978; Kutas, McCarthy, & Donchin, 1977). This means that P300 latency is proportional to the time that it takes for subjects to identify and discriminate, or categorize, the present stimulus as the important and improbable one. This category of stimulus would elicit a large P300, as was described above. In summary, the more time it takes for subjects to categorise the target stimulus, the later the P300 would reach its maximum.

In the early 1970s there was the question of whether P300 latency was related with reaction time or not (RT), since both seem to be the 'end' of the information process initiated by a stimulus (Ritter, Simson, & Vaughan, 1972). However, a few years later Kutas et al. found that when they asked subjects to respond as quickly as possible after target detection, RT appeared much earlier than P300 latency, meaning that subjects responded before they finished evaluating the stimulus (indeed subjects made many mistakes in the discrimination task). But, when subjects were asked to respond without making mistakes, RT and P300 were actually positively correlated, although RT appeared later than P300 latency (Kutas et al., 1977). Other researchers have replicated the same results adding evidence that P300 latency is independent of response selection and execution time, both of which are considered post-categorization processes, (Adam & Collins, 1978; Kutas et al., 1977; Magliero, Bashore, Coles, & Donchin, 1984; McCarthy & Donchin, 1981). More clear proof of this, is the 'passive oddball paradigm', with which P300 is elicited by the attended stimulus, without the need of a subject's open response (Ford, Roth, & Kopell, 1976; Polich, 1986; Pritchard, 1981; Roth, 1973). As will be explained later, one of the hypothesis about the functional role of P300 proposes that this component is in fact related to limited-capacity processes, but of *perceptual resources* only, not involving response selection processes (Posner, Klein, Summers, & Buggie, 1973).
The same as happens with the amplitude, P300 latency has been found to vary across the scalp, being earlier at frontal locations and longer at the centro-parietal areas (Polich, 2007b).

The hypothesis of stimulus evaluation has brought some misunderstanding about which is the process that underlies P300. The fact that a surprising event (understood as a twist in expectations) elicits a P300 does not mean that P300 is manifested by surprise (Donchin, 1981). What it means is that subjects had to categorize the event as surprising before it invoked the process that underlies the

P300. In other words, the stimulus evaluation process has to be completed before it invokes the one that manifests P300.

Most of the research that has been done about P300 has shown, with great amount of detail, which are the variables and experimental manipulations that produce changes in P300 amplitude and latency. It is important to notice, however, that all these results showed the conditions that invoke the process that underlies P300, but, in any case reveal which is the process and—more importantly—which is its functional role, (i.e. its consequences).

The sizable amount of data related to the antecedents' processes of P300 and the uncertainty about its functional role have made the formulation of a complete *theory* of this component difficult (Pritchard, 1981). The only thing known for sure is that, as Donching has suggested, all the antecedent processes coincide – in that '*at some point'* they all need the '*services performed by P300*' (Donchin, 1981).
Some first attempts to explain the functional role of P300 were reported in the research of Thatcher et al. presented in 1977, in which they found that P300 amplitude was modulated by match/mismatch processes (Thatcher, 1977). When subjects found that the physical attributes of two consecutively presented stimuli matched, they elicited a P300 of greater amplitude than when these two stimuli did not match. These results led Thatcher et al. to conclude that the P300 process is related to the comparison process between the sensory entering data, and an internal neural representation. However, as Sutton et al. mentioned, in 1965, P300 is an 'endogenous' component that does not appear to be related to the physical characteristics of the stimulus (visual or auditory modality), but rather to the subject's cognitive processing of the stimulus information (Sutton, Braren, Zubin, & John, 1965b) and so can be elicited in the absence of a stimulus.

In 1981, Donchin et al. proposed what is considered one of the most accepted hypothesis of the functional role of P300. Their theory is known as the *context–updating theory*, and it also relates P300 with a match/mismatch process between the stimulus sensory data and a more cognitive neuronal model instead of a physical one (Donchin, 1981). Thus, this neuronal model would be related, not with physical attributes of a previous stimulus, but rather a subject's expectancy about future events. If expectancies are fulfilled, depending on whether or not it is a signal task-relevant stimulus, it will elicit a P300 with smaller amplitude than if the same stimulus does not follow a subject's (subjective) expectations. Donchin's hypothesis is in line with the findings that P300 could be elicited in the absence of the stimulus, as was explained above.

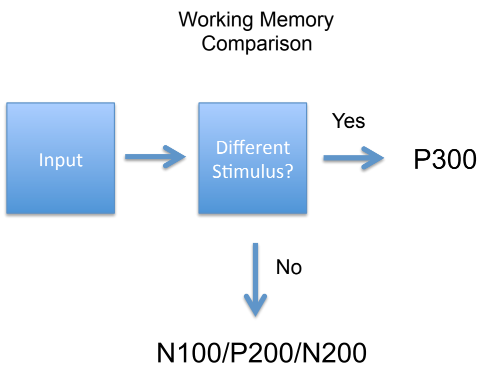

Figure 5. Context-updating theory model of Donchin et al. (Donchin, 1981). It consists of a comparison system that involves working memory among other processes, in order to find matches between the input's sensory data and a mental representation of the previous stimulus. If the present event is equal to a previous one, only exogenous components will be elicited whereas if the input data does not match previous events, it will elicit a P300, whose amplitude will be related to the surprising factor of the stimulus, and its latency will be proportional to its categorization time. *This figure has been adapted from Polich's review (Polich, 2007b).

2.4 Experiments

After revising some of the most important aspects of P300, it can be observed that this 'cognitive component' – which has been largely demonstrated to be a marker of high-level processes, such as expectancies and surprise – can be of great help to study how perception is affected when the expectancies and inferences made of a particular stimulus are 'magically' (and surprisingly) broken. In this context, a novel oddball paradigm was designed. This paradigm consisted of a sequence of non-edited videos of a magic trick that were shown to subjects while recording EEG. One of the key aspects of the design was choosing a magic trick that could be repeated several times to the same subjects without them realizing the secret. After some research in magic literature, it was decided to use an adaptation of a classic trick named 'Chop Cup' (Mark Wilson & Earl Nelson, 1979) in which a ball taken from a cup, 'magically' reappears inside it. Such an experimental setting allowed researchers to characterise brain responses elicited in a much more natural condition (i.e. freely gazing at a video presentation) compared to the paradigms classically used to study ERPs, which normally consisted of a series of images flashed, while subjects keep their fixation at the centre of the screen.

In the first experiment carried (Experiment 1), subjects were asked to watch two different blocks of videos with sequential trials, in which the magic trick was performed under the subjects' view ('Direct Load' condition, see Paradigm section, and Figure 6.A). In the first block, the probability of the ball appearing in the cup was 50%, and in the second block it was 30%. As described with classical oddball paradigms (see P300 section) with the sequence, it was expected that, in Block 2, the strength of the P3-like response should be modulated by the probability of appearance of the infrequent stimulus (ball in the cup). However in Block 1, the aim of using 50/50 probability was to test if, besides the equal probability, the appearance of the ball inside the cup would still elicit a P3 due to the unexpected nature of this 'magical' effect.

In Experiment 2, a control condition, ('Indirect Load' condition, see Paradigm, and Figure 6.B), was introduced, consisting of manipulating the cup and ball under the table, out of the subjects' view. It is important to note that, in this case, the eventual appearance of the ball in the cup (or not) cannot be considered an 'impossible' event due to a magic trick. In this second experiment, the probability of the ball appearing in the cup, was the same (30%) for both conditions (i.e. 'Direct Load' and 'Indirect Load'). The rationale for this was to test the hypothesis that the same stimulus (ball in the cup) may trigger different brain responses when appearing as a result of a magic effect (Direct Load) or no magic effect (Indirect Load). As will be discussed (see 'Discussion' section), altogether it was found, on the one hand, that the video presentations of the magic trick elicited strong ERPs, similar to the ones described in classic oddball paradigms. On the other hand, oddball subjects' neural responses, as well as the behavioural ones, were modulated both by the prior probability of the task-relevant stimuli, and by the performance of the magic trick.

2.4.1 Subjects

Thirty-five subjects participated in this study (mean age 25 years old; range 19-40; 24 females; 26 right handed). None of them had a history of neurological disorders or vision problems. Ten of the 35 subjects participated in Experiment 1 and 25 in Experiment 2. Data from 5 subjects were not considered for analysis due to the high amount of artefacts found in the EEG recordings.

2.4.2 Paradigm

As explained in the Methods chapter (See Chapter 1 'Methods'), different series of 50 consecutive trials were filmed in separate videos in which an adaptation of the classic 'Chop-Cup' magic trick was shown. In Experiment 1, the movement performed by the magician on each trial was as follows (see Figure 6. A): 1) the ball was inserted inside the cup, 2) the cup was turned upside down, and its mouth was covered by the other hand of the magician, in a movement that pretended to catch the ball in its way down, (for the gravity effect), in order to remove it from the cup, 3) then the hand closed in a fist, while moving away from the cup. The cup was maintained upside down in the air for few seconds and it was slightly tapped on one side, as a subtle way to show its emptiness. This handling made that the reappearance of the ball under the cup, was more surprising or 'magical' (this technique is called 'Psychological Misdirection' in the magic theory, and it is the main secret behind this prestige, which made possible to properly manipulate subject's expectations (Kuhn et al., 2014)), 4) immediately after the cup was lowered and deposited on the table. At this point the video was automatically paused, (the current frame was visually frozen), and the participants were asked to press the left arrow on a keyboard if they thought the ball was going to appear under the cup, or the right arrow if they thought the ball was actually removed by the magician. The sequence of movements described above, was called 'Direct Load'.

Experiment 1 consisted of two consecutive 'Direct Load' blocks, each block made up of 5 sub-blocks of 50 trials each (i.e. 250 trials per block). The difference between these two blocks was the probability with which the ball appeared 'magically' under the cup. In this regard, in Block 1 this probability was 50%, whereas in Block 2 it was 30%. Between the presentations of the two blocks there was a break of 5-10 minutes. Subjects took 90 minutes approximately to perform Experiment 1.

Regarding Experiment 2, 8 separated sub-blocks of 50 trials each were filmed (i.e. 400 trials in total) in which the global probability of the ball appearing under the cup was 30%. In this case, however, half of the trials shown (200 trials) consisted in the 'Direct Load' condition, explained above, whereas for the other half of trials, a different movement was performed. As is shown in Figure 6.B, after introducing the ball inside the cup, the magician manipulated its content under the table, before bringing it back to rest upside-down on top of the table. This sequence of movements was called 'Indirect Load'. As is easy to deduce, the appearance of the ball under the cup, after manipulating its content out of the subjects view (i.e. under the table), cannot be considered a magic effect.

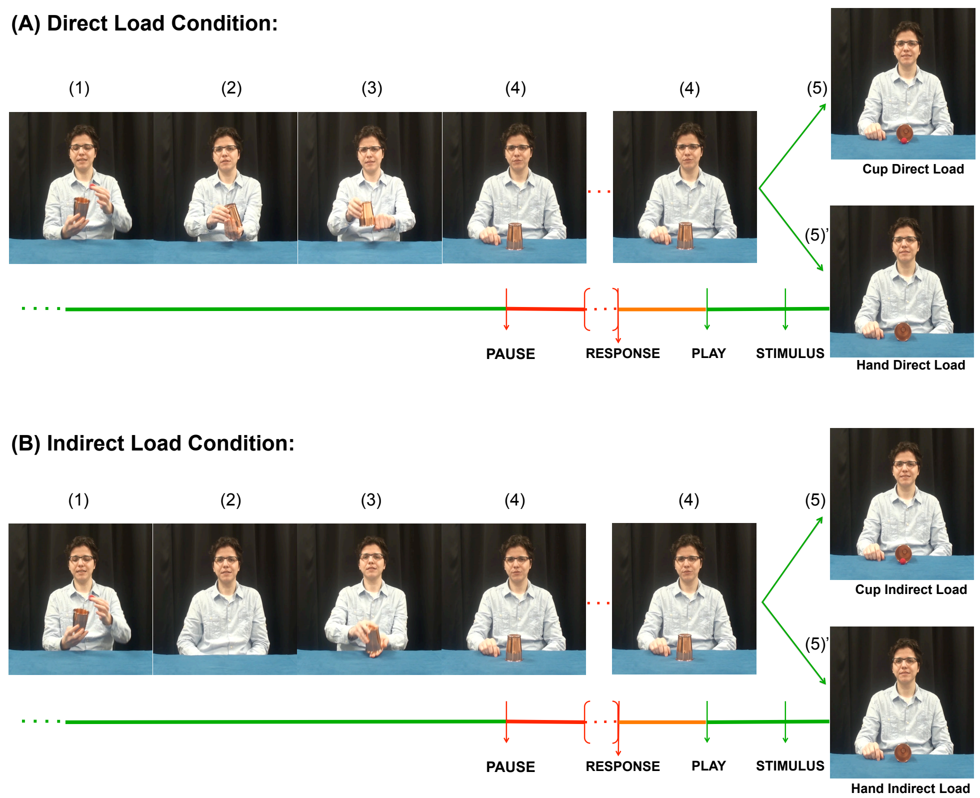

Figure 6. Sequence of movements of 'Direct' and 'Indirect' load. (A) Sequence of movements corresponding to the 'Direct Load' condition. The ball was introduced inside the cup (1). The cup was turned upside-down while the magician pretended to remove the ball (2). The magician maintains the cup upside-down in the air, in a subtle way to show its 'emptiness' (3). The cup is placed on the table, the video is paused, and remained like this until subjects responded whether they think the ball was going to appear under the cup or not (4). The orange line indicates the delay that there was between the response and the restart of the video. Immediately after the video was back to play, the magician showed the content of the cup (5 and 5'). Then the magician took the ball, introducing it in the cup again, in order to start a new trial. (B) Sequence of movements corresponding to the 'Indirect Load' condition. In this case, after the ball was introduced in the cup, the magician manipulated its content under the table (2-3), removing (or not) the ball from inside the cup. Trials corresponding to both of the conditions, ('Direct Load' and 'Indirect Load'), were interleaved in Experiment 2 (Caffaratti et al., 2016).

In total there were 4 conditions, depending on the movement performed, ('Direct Load' or 'Indirect Load') and the outcome of the movement, ('ball in the cup' or 'ball in the magicians hand'):

Cup_Direct-Load: 'Direct Load' movement is performed.

- Outcome: The ball 'magically' appears under the cup. This is the only condition that is considered a 'magic effect'.

Hand_Direct-Load: 'Direct Load' movement is performed.

- Outcome: The ball is actually removed by the magician's hand, and so the cup is shown empty.

Cup_Indirect-Load: 'Indirect Load' movement is performed**.**

- Outcome: The ball is shown under the cup.

Hand_Indirect-Load: 'Indirect Load' movement is performed.

- Outcome: The ball is kept under the table, and so, the cup is shown empty.

In Experiment 2, these conditions were randomly interleaved and presented with equal probability. For both 'Direct Load' and 'Indirect Load', the probability of the ball appearing under the cup was 30%.
Participants took 70 minutes approximately to complete Experiment 2.

2.4.3 EEG Recordings

Neural responses were recorded through 64 scalp electrodes mounted in an elastic cap, according to the standard of 10/20 system, using a Biosemi Active-Two System with sampling frequency of 256Hz and data acquisition bandpass filter between 0.001-100Hz in order to avoid aliasing. As a reference it was used a linked bilateral mastoids, keeping electrode impedances below 5KΩ. Epochs had a time window of 2000 ms. in total, 1000 ms. before and 1000 ms. after stimulus onset, and were extracted from the EEG data for each of the electrodes. Subsequently each of the epochs was de-trended and baseline corrected. Trials with artefacts, such as eye-blinks/eye movements, among others, were removed by visual inspection of the electrooculogram (EOG) channels. As is classically done in studies of P3, only the results of the midline electrodes Fz, Cz, Pz and Oz, are reported.

2.4.4 Data Analysis

The post-stimulus late positive potential, P3, elicited under different conditions, was analysed. For each subject and condition, the averages of the evoked potentials were denoised as done in previous works (Ahmadi & Quian Quiroga, 2013; Quian Quiroga, 2000). The wavelet transform of the signal was performed, and the wavelets coefficients that were correlated with the evoked potentials were selected. Finally, using the inverse wavelet transform the signal was reconstructed using the selected coefficients only. It is important to mention that for each subject the set of wavelet coefficients chosen to perform the donoising was the same for all the conditions. Then, the P3 peak amplitude and latency were detected, in the denoised signals, as the maximum peak in the post-stimulus time window [250-750 ms.]. The test used to perform the statistical comparisons, among conditions, was the non-parametric SignTest, with a Bonferroni correction for multiple comparisons.

2.4.5 Results

2.4.5-1 Behaviour

As was mentioned, on each trial, subjects were asked to guess whether the ball was going to appear under the cup or not (i.e. removed by the magician's hand), pressing the respective button. In this way, it was possible to study—if in general—how the magic trick ('Cup_Direct-Load') biased the subject's decision about the content of the cup at the end of the trial. The behavioural results for the Experiment 1 are shown in the left side of the Figure 7 (Figure 7.A), in which the average percentage across subjects of the 'cup-responses' is plotted, (for each block). As can be observed, subjects could track the specific proportions of the occurrence of the magic trick for each of the blocks (50% in Block 1 and 30% in Block 2). As is reflected by the difference in the averages of the cup-responses entered, although this difference was not significant (p = .17; Sign test).

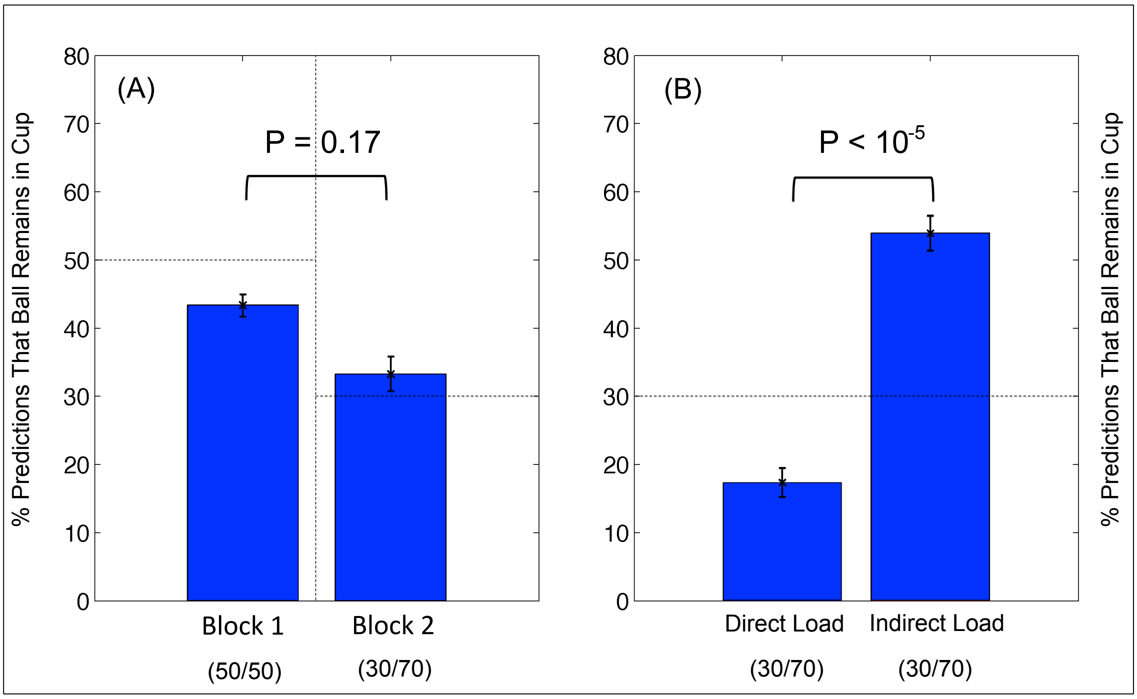

Figure 7. Behavioural responses in Experiment 1 & 2. Percentage average across subjects of the ball appeared under the cup, for Experiment 1 (A) and for Experiment 2 (B). (A) The proportion of cup-responses entered by subjects was not significantly different between Block 1 and Block 2. (B) The percentage of cup-responses was significantly different between the 'Direct Load' (movement performed on top of the table) and 'Indirect Load' condition (cup manipulated under the table) (Caffaratti et al., 2016).

However, it is also interesting to note that the proportion of 'cup-responses' in Block 1 (42.8%) is significantly smaller than the percentage of 'Cup-Direct-Load' trials (50%; p < .05; Sign-test), indicating that subjects' responses might have been influenced by the fact that once the ball had been visually removed from the cup, it is very unexpected or unlikely that the ball will reappear under the cup. With respect to Block 2, of Experiment 1, the proportion of ‘cup-responses’ entered, 31.9%, was larger, although not significantly different, than ‘Cup-Direct-Load’ trials presented in this block (30%; $p = .58$; Sign test). The fact that this time, subjects expected more times the ball to appear under the cup after observing the magic trick, could be due to the fact that participants were adapting their response pattern from the higher proportion of ‘Cup_Direct-Load’ trials presented in Block 1.

On the other side of Figure 7 (Figure 7.B), we see the behavioural responses entered in Experiment 2. Same as in Experiment 1, these are the averages across subjects of the ‘cup-responses’ entered for the conditions Cup_Direct-Load and Cup_Indirect-Load, respectively. As can be noticed in the figure, there is a significantly large difference between the percentages of ‘cup-responses’ entered by subjects for each of the mentioned conditions, although the probability of the ball appearing under the cup—in both of them—was the same, 30% ($p < 10^{-5}$; Sign test). Once again, as in Experiment 1, when subjects observed the ‘Direct Load’ movement performed, they were less inclined to expect the ball to appear under the cup, as reflected in the left hand bar of Figure 7.B, which shows that the percentage of ‘cup-responses’ entered, in this case, was significantly lower than the proportion with which the ball did actually appeared under the cup, ‘Cup_Direct-Load’ (30%; $p < .001$; Sign test). On the other hand, for ‘Indirect Load’ condition, in which the cup was manipulated under the table, subjects were equally likely to guess that the ball was going to appear underneath the cup or in the magician's hand. The bar on the right of Figure 7.B reflects this fact, as the percentage of ‘cup-responses’ entered, for ‘Indirect Load’ was not significantly different than 50% (SignTest), though it was significantly larger than 30% ($p < 10^{-7}$; Sign test).

Overall, the behavioural responses reflect that subjects could track the differences in the probabilities of the ball appearing under the cup. However, the magic trick had influenced subject’s responses, as they were less likely to expect the ball to appear under the cup when the ‘Direct Load’ movement was performed. On the other hand, when the cup was manipulated under the table, as done in the ‘Indirect

Load' condition, participants were equally likely to respond either way – though the percentage of 'Cup_Indirect-Load' trials was 30%, the same as the statistics of 'Cup_Direct-Load'. This difference found in the 'cup-responses' between these two conditions demonstrates that subjects could not track the percentage of trials in each of the them and, thus, compensated downwards for the 'Direct Load' case and upwards for the 'Indirect Load' condition, as shown in Figure 7.B.

2.4.5-2 Neural Responses for Experiment 1

The grand average of the neural responses recorded while subjects performed the task in Experiment 1 are shown in Figure 8. As can be observed in this figure, preceding the stimulus onset there is a slow negative shift, more pronounced in central-parietal electrodes. This is the well-studied potential, known as the Cognitive Negative Variation (CNV) which was the first ERP ever described, and it is classically elicited by the expectations produced by the outcome of the stimulus, in the particular case of the experiments described here (whether the ball was going to appear under the cup or not) (W. G. Walter, Cooper, Aldridge, McCallum, & Winter, 1964). Since no difference was found in the morphology of the CNV among the different conditions, no further analyses were performed.

Also, in all the conditions, and 200 ms previous the stimulus onset, there was a positive deflection, which was related to resuming the video after the pause. As can be seen in Figure 9.A, this deflection disappeared since, in this case, the times at which the video was restarted were randomized.

At around 500 ms after the stimulus onset, one can observe a large positive component that resembles the P3 evoked potential, classically elicited by task-relevant signal in oddball paradigms (Picton, 1992; Polich, 2007b; Sutton et al., 1965a). As shown in Figure 8, for Block 2, the P3 elicited by the less frequent condition 'Cup_Direct-Load' (30%) was larger than the one triggered by the more frequent trials 'Hand_Direct-Load' (70%), a fact that coincides with previous evidences of P3, as was explained in the background introduction of this chapter.

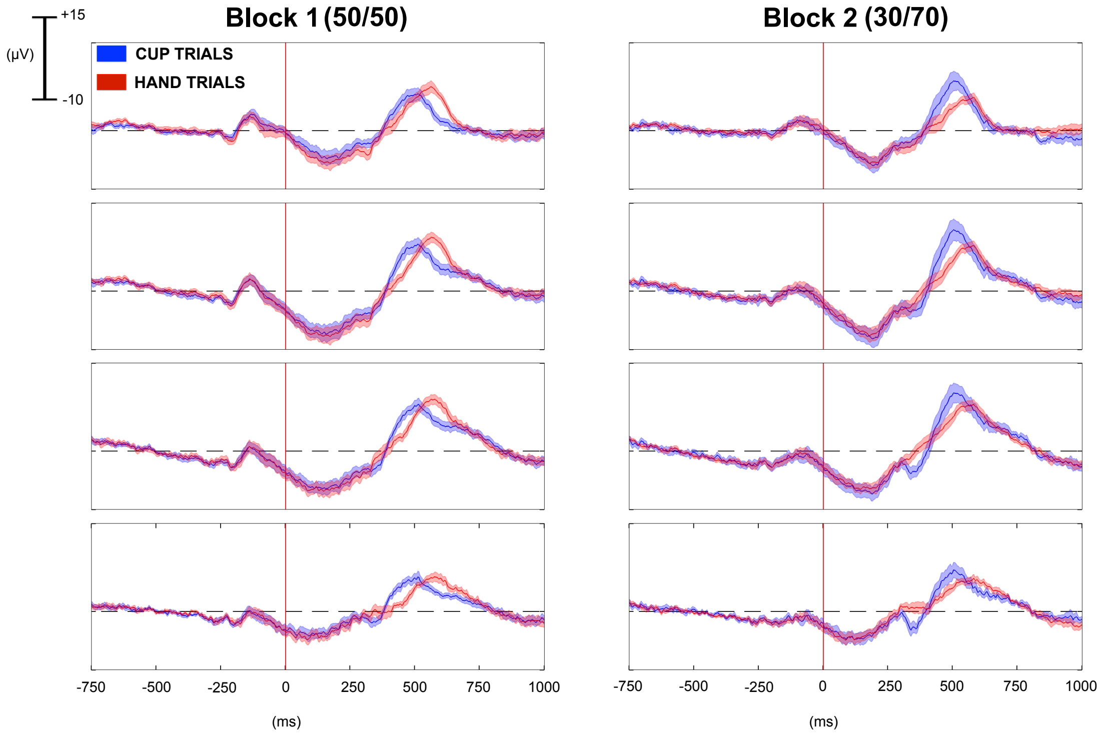

Figure 8. Neural responses in Experiment 1. Grand averages across subjects of the neural responses in Experiment 1. Time 0 marks the stimulus onset. Shaded areas overlapping mean values indicate SEM. In Block 1 the percentage of 'Cup_Direct-Load' trial was the same as the 'Hand-Direct-Load' (50% for both conditions). However for Block 2 the magic trick was performed 30% of the times, whereas the cup was shown empty the remaining 70% of the trials. In both blocks, for all conditions, and preceding the stimulus onset, there is a negative ERP elicited by expectations, which is known as Contingent Negative Variation (CNV). In Block 2, the P3 elicited by the less probable condition ('Cup_Direct-Load'; 30%) is larger than the more probable one ('Hand_Direct-Load'; 70%) (Caffaratti et al., 2016).

The difference between the 'cup' and 'hand' neural responses was also measured; it was found to be larger for Block 2 than for Block 1, where the percentage of 'Cup_Direct-Load' and 'Hand_Direct-Load' was the same – 50% (for all electrodes $p < .05$, except Oz with $p = .08$; Sign Test).

It can also be observed, that preceding the P3 elicited by 'cup trials', there is a negative potential described in the ERP literature as N2, which is normally triggered by the less probable event, as is the case here.

Last, although it was further analysed with more subjects in Experiment 2, it is important to notice that for all conditions, 'Cup_Direct-Load' trials elicited earlier neural responses than the 'Hand_Direct-Load' ones.

2.4.5-3 Neural Responses for Experiment 2

This second experiment was designed with the aim to compare behavioural and neural responses elicited by the same physical stimulus (red ball) used before, but under two different conditions. The first condition was the same as the one used in the previous experiment ('Direct Load'), in which the cup was visually manipulated on top of the table, however, in the second one, named 'Indirect Load', the manoeuver of the cup was performed under the table (See Methods). In this way it was possible to study subjects' responses when observing the ball appearing in the cup 'magically' ('Direct Load') or 'not magically' ('Indirect Load'). In the following Figure 9.A, are the grand averages of the responses across subjects. As can be observed, once again the anticipation of the outcome of the stimulus elicited a slow negative ERP, known as CNV, for all subjects and conditions. It is also important to notice that the positive deflection observed prior to the stimulus onset in Experiment 1 is not present in the neural responses of Experiment 2. This is due to the fact that in this second experiment the times at which the video was restarted were randomized.

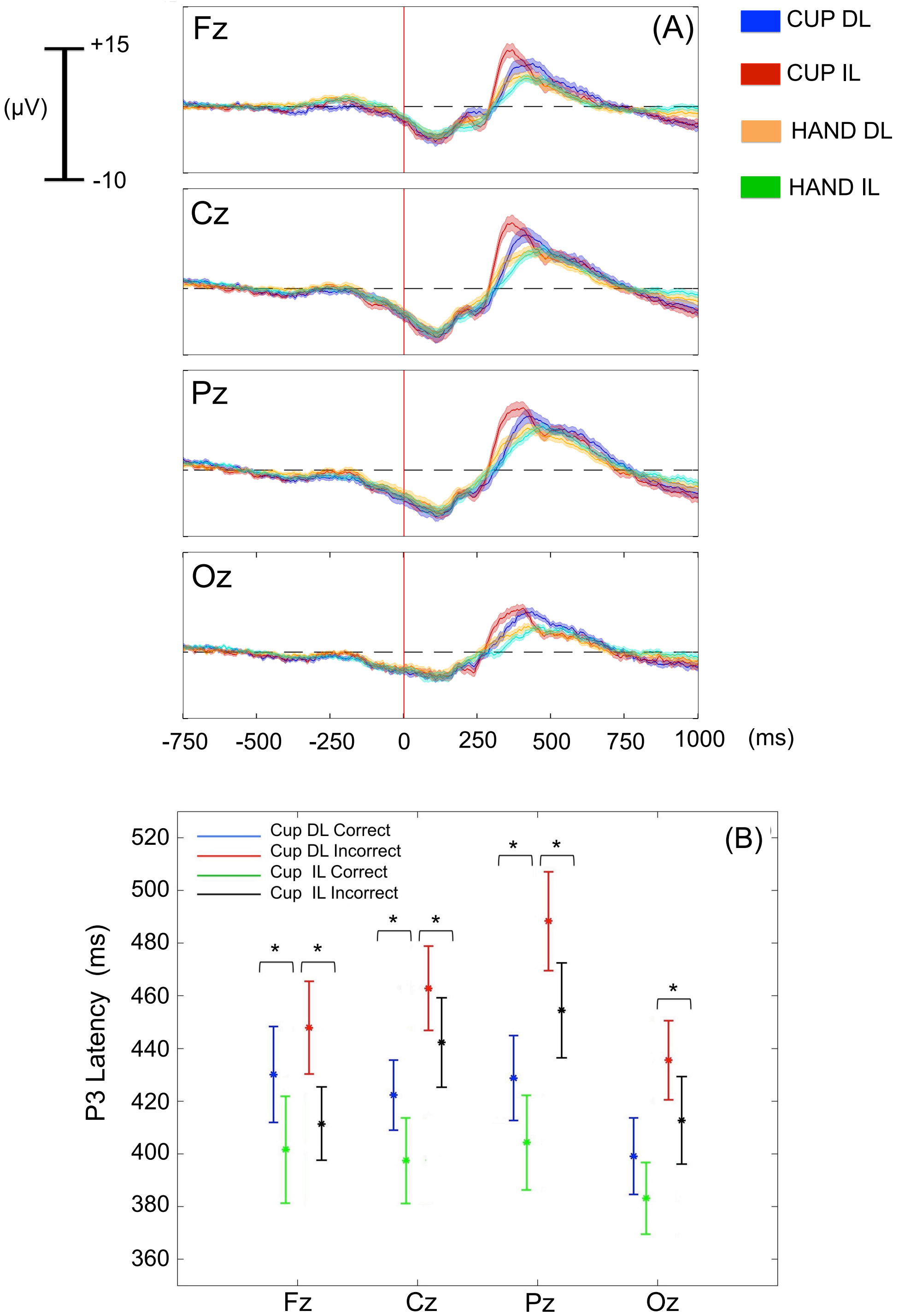

Figure 9. Neural responses in Experiment 2. (A). Grand Averages of the ERPs across subjects for Experiment 2. For each of the midline electrodes plotted there are four ERPs separated according to i) the type of trial, that is, if the ball appeared under the cup (Cup), or, on the contrary if the ball as retained in the magician's hand (Hand), and ii) the condition, Direct Load (DL) and Indirect Load (IL). For both conditions, DL and IL, 'cup trials' elicited a larger and earlier P3 than 'hand trials'. For the 'cup trials', the P3 was delayed under the 'Direct Load' condition compared to the 'Indirect Load' condition. (B) The notations in this figure are the same as in the previous one. Shown are the Grand averages of the P3 latencies for the cup response, only separated according to the type of trial, that is, 'correct' or 'incorrect' and to the condition, i.e. 'Direct Load' (DL) and 'Indirect Load' (IL). For both types of trials, 'correct' and 'incorrect' the cup responses were elicited later for 'Direct Load' condition. The significant differences were marked with asterisks (Caffaratti et al., 2016)..

Once again, and after the stimulus onset, a large positive component appeared, for all conditions, that resembles a P3 waveform. However, as can be seen in Figure 9.A, 'cup trials' elicited a significantly earlier (for all electrodes $p < .05$, except Pz with $p = .17$; Sign test) and larger potential (for all electrodes $p < .005$; Sign test) than the P3 triggered by 'hand trials'. As was explained in the introduction of this chapter, the differences in the amplitude of P3 are due to the differences between the prior probabilities with which both trials ('cup' and 'hand') were presented. On the other hand, the fact that the appearance of the ball in the cup (cup trials), established a better-defined onset for target detection than 'hand trials' (in which the cup was shown empty), could potentially explain the differences found in the P3 latencies elicited by these two types of trials.

The conditions 'Direct Load' and 'Indirect Load' were also compared. First of all, there was not found to be any significant difference in the amplitude or latency of the P3 responses elicited by 'Hand trials' between the aforementioned conditions. Such a result is not so surprising since, on the one hand, the objective probabilities of occurrence of 'Hand trials' were the same for both cases, and on the other, no magic trick took place in this type of trial. Secondly, and same as before, for 'cup trials', no significant differences were found in the amplitudes of the late positive component elicited between 'Direct Load' and 'Indirect Load' (p = n.s. for all the electrodes; Sign test). However, in this case there was a significant difference in the latency of the 'cup responses', P3, between the two conditions, being the one triggered by the magic trick 50 ms delayed with regard to 'Indirect Load', (for all electrodes $p < 10^{-5}$; Sign test). This effect in the latency was further analysed. It could have been possible to attribute such a difference to some variations in the physical stimulus shown in the cup-trials between the two conditions ('Direct Load' and 'Indirect Load'), however, as was explained earlier, in both cases the visual stimulus was the same (i.e. the red ball appearing under the cup). The other possibility that was considered was that this difference in latency could have been attributed to the different number of correct responses entered in the 'Direct Load' and 'Indirect Load' conditions, since: a) correct P3 was elicited significantly earlier that incorrect P3 (for all electrodes $p < .05$; Sign test), and b) the number of correct responses for cup trials in 'Indirect Load' condition (59%) was larger than in

'Direct Load' one (17%) due to subjects' tendency to answer 'cup' more times in the 'Indirect Load' condition (See Figure 7.B). This confound was resolved by calculating a 2-way ANOVA of the P3 latency of the 'cup trials' with two factors: 'condition' (with two levels: 'Direct Load' and 'Indirect Load'); and 'response' (with two levels: 'correct' and 'incorrect'). It was found that the differences in the latency were significant for factor 'condition' ($p < .05$; in all electrodes except Oz) as well as for 'response' ($p < .05$; in all electrodes except Fz). These two effects appeared to be independent since no significant interactions were found between them in any of the electrodes. The next step, in order to ensure that the differences in the latency between 'Direct Load' and 'Indirect Load' were not due to the different number of correct trials, each of the latencies were analysed for each of the response types, separately (See Figure 9.B). It was found that the P3 elicited by 'cup trials' reached its peak significantly later in the 'Direct Load' condition than in the 'Indirect Load' condition, both when only the correct responses were considered (in all cases $p < .01$, except Oz with $p = .13$; Sign test), as well as when only the incorrect ones were considered (in all cases $p < .05$; Sign test). In summary, the neural responses obtained in Experiment 2 indicate that the perception of the magic trick delayed the neural response onset, independently of whether the trial was correctly or incorrectly guessed by subjects.

2.4.6 Discussion

Altogether, the experiments presented in this chapter, contribute to the growing number of works done in the field of *Neuromagic* (discussed in the 'Literature Review' of this thesis), exemplifying how magic tricks can be used to design novel neuroscience paradigms, with which to study perception, among other cognitive processes (Cui et al., 2011; Johansson et al., 2005; Kuhn & Land, 2006a; Kuhn et al., 2010; Macknik et al., 2008; Martinez-Conde & Macknik, 2008; Olson et al., 2012; Otero-Millan et al., 2011; Parris et al., 2009; Raz & Zigman, 2001; Rieiro et al., 2013; Shalom et al., 2013).

Due to its characteristics, the magic trick chosen, ('Chop Cup'), has successfully fulfil the conditions of a classic oddball paradigm, in which a task-relevant/irrelevant stimulus is repeated in a consecutive series of trials, without exposing the secret method. It was possible, therefore, to repeatedly present this magic effect in a series of non-edited videos. The use of a large number of trials meant that subjects could perform a meaningful estimation of the outcome's probability of the trick (i.e. the probability of the appearance of the ball inside the cup). As hypothesised, this novel paradigm allowed to the demonstration of three main points:

- The first, and perhaps one of the most important, due to a new experimental methodology, we demonstrated that it is possible to obtain electrophysiological responses of subjects under naturalistic conditions; i.e. when freely watching a series of trials embedded in continuous non-edited videos. As was stated in the introduction of this chapter, (see 'P300' section), most of the paradigms used to study ERP in general, and P3-like waves in particular, consisted of a series of static images flashed at the centre of the experimental screen, at which point subjects are asked to maintain fixation. In contrast to these classic paradigms we presented a continuous stimulus expanded along several seconds. Despite the time span of these stimuli we obtained a neurological event marker linked to a cognitive experience. This is a significant step towards the study of the underlying brain mechanisms in everyday behaviour.
- Second, it was possible to observe, in both experiments, that the physiological responses were significantly modulated by the prior probabilities of the outcomes of the trick, as previously reported with classic oddball paradigms. However, regarding the behavioural responses, the track of the prior probabilities of the outcome was only present in Experiment 1, whereas in Experiment 2 the decision of whether the ball was going to appear inside the cup or not, (for both conditions 'Direct' and 'Indirect' Load) was significantly biased by the performance of the magic trick. Therefore, in agreement with the literature, the amplitude of the measured neural event corresponded with the magnitude of the surprise.
- Finally, in Experiment 2, it was interesting to observe, that the neural

responses elicited by the presence of the red ball were different depending on whether the ball appeared as a result of a magic trick ('Direct Load'), or as a result of a non-visible movement performed under the table ('Indirect Load'). We see that differential neural responses were obtained, elicited by the same physical stimulus (the red ball). Therefore as described in the literature, the measured signal represents an internal cognitive state.

In the first experiment, the behavioural responses observed indicated that subjects could actually track the changes of the prior probabilities of the ball appearing in the cup, (i.e. 'cup trials') between the two presented blocks, (these probabilities being 50% for Block 1 and 30% for Block 2). As shown, in Block 1, the percentage of 'cup responses' entered by subjects was significantly lower than the 50% of times that the ball was actually shown inside the cup. This result could be attributed to the performance of the magic trick, by which the appearance of the ball was unexpected (see Cup_Direct Load). In Block 2, however, the percentage of 'cup responses' was visually higher – although not statistically different – than the presented rate (30%) of 'cup trials'. Although it would have been expected that the percentage of these 'cup responses' were biased by the magic performance (in the same way as in Block 1), it was considered that the effect found in Block 2 could have been due to an adaptation process from the higher proportion of 'cup trials' in the preceding block (Block 1).

In Experiment 2, the introduction of a new condition ('Indirect Load'), in which the Chop Cup was manipulated under the table and out of the subjects' view, allowed comparing behavioural responses elicited by a magic trick ('Cup_Direct Load') and non-magic trick ('Cup_Indirect Load'). For both of these conditions, the probability of the ball appearing inside the cup was the same (30%); however, it was interesting to notice that, in this case, subjects could not track this prior probability. In fact, the percentage of 'cup responses' was significantly different between these two conditions—a bias that was due, once again, to the performance of the magic trick ('Direct Load' condition). It can be concluded, therefore, that the perception of the magic trick produced a strong bias in subjects' behavioural responses.

The electrophysiological recordings also provided interesting results. First of all, in both experiments, one can observe a negative slow shift preceding the stimulus onset, that resembles the morphology of the first ERP ever described, known as 'Contingent Negative Variation' (CNV). As was largely documented, since first discovered (W. Walter et al., 1964), this negative wave is elicited by the expectations caused by an imminent stimulus; in the case of these experiments, the expectations caused by the outcome of the different conditions ('Direct Load', and 'Indirect Load'). In further agreement with the literature, after the stimulus onset, it was possible to observe large positive potentials that coincide in morphology with the well-known ERP P300. In fact, the amplitude of this wave was modulated by the number of presentations of the task-relevant stimulus (as reported), reaching higher potentials when this stimulus became more infrequent (as described in the review of this chapter, see 'P300 & Oddball paradigms').

The most interesting physiological results were the ones observed in Experiment 2. First, the P3-like waves, elicited in this experiment, did also vary depending on the percentage rate of stimulus presentation, as expected. However, in this case, the P3 responses elicited by 'Direct Load' trials were significantly delayed compared to the P3 elicited by 'Indirect Load' trials, although the physical characteristics of the visual stimulus that triggered both waves was exactly the same (i.e. the red ball). Different possibilities were considered in order to explain this effect: i) first, it was studied if the difference observed in the latencies of P3 were caused by the different number of correct responses entered by subjects, in each of the conditions, however the 'Results' section revealed that this was not the reason for the delays found.; ii) Second, it could have been attributed to the surprise effect provoked by the magic trick, but this was easily ruled out by the fact that the magic trick was repeated 60 times in each session; and iii) it was also considered that the effect in the latencies could have been due to differences in the prior probabilities of the stimulus that elicited these two P3 (i.e. that one stimulus was more infrequent than the other), however for this case the percentage rate of the ball in the cup for 'Direct Load' and 'Indirect Load' was the same (30%). Also, as has been reported in previous studies, the effect of prior probabilities of the stimulus is, normally, manifested in the amplitude of the P3 wave, and not in the latency, as was found in this case (Polich, 2007a). In fact, the latency of P3 has been largely proven to be proportional to the time needed to process and categorise (the meaning of) the task-relevant stimulus. In this context, it was concluded that the delay found in the P3-latency elicited by the magic trick could be attributed to the fact that subjects needed more time to process the outcome of seeing the ball appearing in the cup, under 'impossible' conditions (i.e. after observing that the magician removed the ball from inside the cup).

Although the neural concomitants that manifest P3 remain unknown (Polich, 2007a), this 'cognitive component' has been largely considered as a neural signature of high-level processes involved in perception (Duncan-Johnson & Donchin, 1982; Kornmeier & Bach, 2006; Rutiku, Martin, Bachmann, & Aru, 2015; Verleger, Jaśkowski, & Wascher, 2005). With this in mind, it can be concluded that the violations of both inferences and causality, produced by the 'magical' appearance of the ball, (i.e. as a result of the magic trick), affected significantly the subject's perceptual experience. These results are in line with the two previous fMRI studies done in the field of *Neuromagic*, in which the video presentation of different magic tricks activated brain areas that are highly related to violations of causality, but not to surprise (Danek et al., 2015; Parris et al., 2009).

More generally, finding different brain responses elicited by the same retinal stimulus (red ball) is in line with other studies done with perceptual illusions, such as 'Monocular', 'Binocular' rivalry, and 'flash suppression' (Alais & Blake, 2005; Kornmeier & Bach, 2005; Kornmeier & Bach, 2006; Logothetis et al., 1996) which have largely helped to dissociate sensory processing from subjective representation. It is important to note, however, that the perceptual illusion produced by a magic trick is markedly different to the one generated by multi-stable figures. In this sense, as mentioned above, the effect in subjects' perception caused by magic, resides in violating inferences and expectations of natural causality, rather than in the observation of (unchanged) ambiguous figures, as is the case of perceptual rivalry.

To conclude, to our knowledge, we demonstrated for the first time that classical cognitive components of ERPs, as referred by the literature, can be elicited with continuous stimulus presented in videos (Freeman & Quian Quiroga, 2012; Luck & Kappenman, 2011). In this sense, the study presented in this chapter expands the results of more recent works, which have investigated evoked responses to freely gazed stimuli (Graupner, Velichkovsky, Pannasch, & Marx, 2007; Kamienkowski, Ison, Quian Quiroga, & Sigman, 2012; Kaunitz et al., 2014; Luo, Parra, & Sajda, 2009; Ossandon, Helo, Montefusco-Siegmund, & Maldonado, 2010). However, in most of these cases this complex stimulus consisted, again, of static images in which subjects had to freely gaze and look for a match with a previously presented target. Therefore our unique set up, together with the use of magic, opens the door to a new range of experiments to deepen our understanding of cognitive processes.

Altogether, the novel paradigm and methodology used in the present work pave the way for new studies focused on the research of visual responses and cognitive processes in more natural conditions, using magic illusions.

General Conclusions

There is no doubt that the first decade of research in the cognitive study of magic has proven to be both productive, and promising. A growing number of published articles has demonstrated that the art of magic constitutes, in fact, an useful tool of research with which to address the study of different cognitive processes. Indeed magic's unique ability to seamlessly manipulate subjects' experiences offer us the opportunity to both revisit already existing paradigms and create new ones. To date, this cognitive manipulation has been used to create a sense of wonder in the spectator's mind, however, as can be concluded from the Literature Review of this thesis, magic is helping neuroscientists, and psychologists, to further investigate different aspects of perception and cognition (Rensink & Kuhn, 2015a). The magic experience can be created by different techniques of the art of conjuring – such as Misdirection (technique that magicians use to deviate spectators' attention, Kuhn 2014) – that can be used to study processes of perception, visual attention, attention control, visual awareness, and of course the experience of wonder itself (that can be of great interest in the investigation of the neurobiology of some psychotic disorders, such as schizophrenia) (Kuhn et al., 2014; Kuhn & Land, 2006a; Kuhn et al., 2008; Kuhn & Rensink, 2016; Kuhn & Findlay, 2010; Kuhn & Martinez, 2012; Macknik et al., 2008a; Macknik et al., 2010a; Martinez-Conde & Macknik, 2008; Rensink & Kuhn, 2015a). However the magicians not only manipulate the spectators' attention, but also their expectations of the immediate reality. The magicians have learnt to exploit and manipulate space-time contingencies that are used to create expectations that are later violated. Doing so, allows the conjurer to create perceptual experiences that violate the basic laws of physics (e.g. flying objects, penetration of one object through another, transpositions et cetera). The important role that expectations and pre-experience knowledge play in the formation of perceptions has been widely investigated by psychologists and neuroscientists. To date, these phenomena have been mainly studied through different perceptual illusions, mostly based on ambiguous and monocular competing figures, leading to a better understanding of how high-level processes influence perception. These paradigms have demonstrated how one single (and unchanged) stimulus can produce different perceptions, depending on the viewer's previous knowledge based on past experiences (Alais & Blake, 2005; Kornmeier & Bach, 2005). However, there exists the concern that multi-stable figures are rarely found in nature, and so, can tell us very little about how visual system resolves ambiguity in more ecological environments (Alais & Blake, 2005; Gibson, 1966). In this sense, magic offers a more natural context in which visual perception and cognition can be studied. For example, Ekroll and colleagues have systematically investigated common magic tricks that rely on Gestalt grouping theories (e.g. amodal completion), which have uncovered new perceptual principles (i.e. amodal absence, amodal volume completion), (Ekroll, Sayim, & Wagemans, 2017). As mentioned, magic constitutes an innovative tool of research that neuroscientists can use to further study cognition and perception. Good proof of this is found in the two experiments presented in Chapter 2, which altogether constitute a novel paradigm, not only for the field of *Neuromagic* in particular, but for the neuroscientific research in general (Caffaratti et al., 2016). First of all, it demonstrates that it is possible to use ERPs to study vision using natural dynamic displays, in contrast with previous discreet presentations (most previous research has employed a series of images flashed at the centre of the experimental screen). This new approach helps to the extrapolations of ERP literature into everyday life, and opens the door to the design new experiments using natural dynamic. This is an important contribution in the field of neuroscience as it sets the basis for the design of newly evoked potential paradigms that seek to study brain responses in more natural conditions than those normally used. Secondly, it shows how useful the art of magic is in studying how expectations and natural inferences influence perceptions; an effect that was found in both behavioural and neural responses elicited by magic tricks. Also, using conjuring effects it was possible to observe different (perceptual) brain responses elicited by the same physical stimulus, something that has been largely studied with the phenomena of monocular and binocular rivalry (Alais & Blake, 2005; Blake & Logothetis, 2002; Kanwisher, 2001; Kornmeier & Bach, 2005; Kornmeier & Bach, 2006; Logothetis, 1998). Finally this thesis illustrates how it is possible to design magic tricks that can be used to tackle hypothesis-driven scientific questions to gain insight about perception and cognition.

Overall, this thesis constitutes a new building block for the field of cognitive neuroscience in general, and for the scientific study of magic in particular (i.e. *Neuromagic*). It also proves, once again, that a 'Science of Magic' – as coined by Gustav Kuhn (Kuhn et al., 2008) – is possible from both (complementary) perspectives: psychological and neuroscientific.
The intuitive knowledge that magicians have about human behaviour and cognition is an endless source of new and outstanding information that can be used to scientifically address unknown aspects of cognitive processes. It is important to remark, however, that the aims of this field are not restricted to the neurological explanations of how magic is perceived, or to point out the cognitive processes activated whilst observing magic. One of the main objectives of the neuroscience of magic is to open new doors to address the study of some anomalous experiences that would not be possible to address otherwise. This could help us to discover unknown aspects about the functioning of high-level processes such as attention, memory, decision-making, and reasoning, among others. Indeed, following this line of thought, it might be worth considering that the field so far named 'Neuroscience *of* Magic', may be better described as 'Neuroscience *with* Magic'.

It has also been proven (within the first decade of research in this field) that the contribution between magic and neuroscience is bidirectional (Macknik et al., 2010a)Many researchers in fact, when considering the results of some specific experiments, have given magicians particular advice on how to improve their performances (Macknik et al., 2010a; Rensink & Kuhn, 2015a; Wiseman & Nakano, 2016). That said, giving advice – as helpful as that could be for improving the art of magic – should be done carefully. An artistic and professional piece of magic is the product of years of both rehearsal alone, and performance in front of thousands of different people, and also involves techniques that have been proven to work successfully for centuries. A lack of magic theory knowledge by the researcher interested in this field, could lead to making wrong conclusions about the repercussion of some experimental results in the real world of the magic act. It is true that, there is a huge bulk of literature about magic theory, which can be referenced by scientists, and also that magicians and scientists are, every time more, collaborating and sharing knowledge (about human behaviour). However, magic is a performing art, and thus its mechanisms can only be well and completely understood if practised and performed.

A scientific study of the cognitive components of the magic experience has been proven to be possible and productive. However, as in any premature stages of the development of other fields, there still exists uncertainty about the best way to apply magic to investigate cognition; among other factors, magic is an old form of art that is performed under strict rules of secrecy. There exists a large number of very interesting experiments using different components of magic, however their results remained somewhat scattered, with little connection between them. Although this has proven to be a normal evolutionary process in many other fields—such as in the 'Science of Consciousness'—it is important to rapidly start constructing, with (accumulative) 'building blocks', the 'cathedral' that constitutes the 'Neuroscience *with* Magic'. Thus, who knows, perhaps illusionism's greatest trick of all will be to help us better know and understand the human brain.

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