Methodology

As an inclusion criterion, the selection of scientific papers was based on references available, according to the keywords related to attention mechanisms correlated with practical applications not only on magic tricks studies, but also with other types of studies, namely in disease.

The most frequent terms used for searching were:

history of attention,

what is attention,

attention selection,

visual attention,

visual perception,

scene perception,

cognitive electrophysiology of attention,

gaze cueing,

joint attention,

social cues,

inattentional blindness,

change blindness,

attentional misdirection,

eye movements,

receptive field,

science of magic,

autism.

The database used was PubMed, without any temporal restriction, mainly because the historical context is essential to the purpose of the present paper.

TABLE OF CONTENTS

Resumo

A atenção é uma função cognitiva major que ainda não é totalmente compreendida. Como pode ser definida e como pode influenciar a nossa vida diária? Os mecanismos neuroquímicos e as teorias nas quais se baseia este conceito de atenção estão ainda em discussão.

Começando pelo mundo exterior, as informações competem para serem captadas pelo olho, chegando ao córtex. A compreensão total dos eventos externos é devida ao processamento da informação através da atenção. A direção do olhar, dando pistas, assim como a atenção conjunta, usam a consciência para promover as interações sociais.

A atenção tem falhas que podem ser exploradas, como a cegueira por desatenção. Existem profissionais do engano que conseguem fazer com que uma audiência não esteja consciente do que a rodeia, e ficar completamente maravilhada devido a esse facto: os mágicos. Pelo estudo das técnicas usadas por estes, será possível alterar a direção da atenção das pessoas e analisar esses resultados em estudos controlados. Através de uma abordagem diferente, podem ser alcançadas novas perspetivas acerca de doenças onde a atenção está comprometida, como por exemplo as que estão incluídas no espetro do Autismo.

Insights on attentional processing

- Magic as a new method of research -

Diana Gonçalves[1], Manuela Grazina[1,2*]

[1]*Faculty of Medicine, University of Coimbra, Portugal;*

[2]*CNC-Center for Neuroscience and Cell Biology – Laboratory of Biochemical Genetics, University of Coimbra, Portugal.*

*Corresponding author:

Professor Manuela Grazina, PhD., Faculty of Medicine, University of Coimbra, Pólo III – Subunit I, Azinhaga de Sta. Comba Celas, 3000-354 Coimbra, Portugal. Tel: +351 239 480040; Fax: +351 239 480048; Email: mmgrazina@gmail.com, mgrazina@ci.uc.pt.

Abstract

Attention is a major cognitive function that is not yet fully understood. How it can be defined and how it influences our daily life? The neurochemical mechanisms and cognitive theories behind the concept of attention are still on discussion.

Starting on the outside world, information competes to be captured by the eye and reaching the cortex. The full understanding of external events is due to information processing through attention. Both gaze cueing and joint attention use awareness to promote social interactions.

Attention has flaws that can be explored, such as inattentional blindness. There are professional misleaders that can make an audience not to be aware of surroundings, and be amazed by that: magicians. By studying magical techniques it can be possible to misdirect people's attention and analyze it on controlled trials. Through a different approach new valuable insights can be achieved concerning diseases where attention is compromised, such as Autism Spectrum Disorder.

Keywords: attention, top down/bottom up factors, vision, gaze, joint attention, change blindness, autism, magic.

List of abbreviations

ASD- Autism Spectrum Disorder.

EEG- Electroencephalography.

PET - Positron emission tomography.

FMRI- Functional magnetic resonance.

ERPs - Event related potentials.

LGN- Lateral geniculate nucleus.

RGCs - Retinal ganglion cells.

DAN - Dorsal attention network.

VAN - Ventral attention network.

STS - Superior temporal sulcus.

MT - Middle temporal.

APA - American Psychiatric Association.

TD - Typically developing individuals.

QI - Intelligence quotient.

Introduction

The brain is an amazing and complex structure. Many studies have been made in order to understand its function. Trying to discover and identify the neuronal pathways involved on several neuronal pathologies is a huge challenge; therefore, associated to methodologies already existent, it is always possibly to find other ways to study and evaluate these complex communication networks.

This review explores, from a different perspective, an important cognitive function which is attention. The general concept is known by most of people but it is not fully understood. What is attention? How it has been studied through history, and how has its concept evolved? Relations between the brain and the outside world must be considered, not forgetting the crucial role played by the eye, as a window to the external world.

Can attention be seen from a different point of view? Perhaps it is time to look back in order to innovate. Over the centuries until nowadays, the art of tricking human brain, playing with the audience's attention, is practiced and improved by illusionists, causing the spectator a sensation of wonder in view of these abilities. It seems like they defy the laws of physics and logic leaving the audience completely shuffled. The truth is that it is not possible to unravel magic tricks made just in front of our eyes, despite the fact that we can apparently see them clearly. In order to solve this mysterious fact, possible explanations need to be searched inside the brain, where all input information is processed and analyzed.

This ability to manipulate people's attention, perception and public's choice can be studied on controlled trials as a tool to better comprehend the physiological mechanisms which modulate these nervous functions and how they are compromised on several pathologies. A limited number of studies have been undertaken to correlate the manipulation of attention by magicians on a selected disease, but one in particular that has focused on the Autism Spectrum Disorder (ASD), deserves to be stressed out.

After all, making science is not too far from creating magic. Or, saying it in another way, magic needs neuroscience to happen.

Attention – History and Evolution

a) How we define attention?

The word itself has its roots on latin: attenti, from attentus, the past participle of attendere, meaning “to heed.” Despite the origin of the word in Roman times, only few references to any scientific evidences about the human capacity of attention exist until Descartes, in 1649. He linked pineal body movements acting on animal spirit to attention.

Every day, many inputs of the outside world reach the human brain: sounds, smells, tactile sensations and visual data, which need to be selected and filtered. The full understanding of environmental and even internal events is due to information processing through selective attention. Across history many have researched on this field and introduced theories and concepts that helped to better comprehend the concept of attention in the modern era.

The idea of apperception (Leibnitz, 1765; Wolff, 1734) explain the process that admits perceptions into consciousness. Important discovers to the Phenomenology and Early Psychological studies argued that the mind does a series of mental adjustments (mental activities), “unconscious inferences”, to construct a coherent picture of its experiences. Spatial position, often used as a criterion to individualize objects, is an interpretation of our sensations, and not their immediate result (Helmholtz, 1860). The idea of covert attention, independent of eye movements, dates back to Helmholtz experiments. He has also introduced concepts of early neuroanatomy and neurophysiology, demonstrating that the rate of nerve conduction was not infinitely fast, but so relatively slow as only 100m/s; consequently every mental task required a period of time for its processing (Helmholtz, 1866).

On "The Principles of Psychology" William James (1980) characterized different models of attention in terms of "active" and "passive". The first refer to goal driven attention controlled on a "top-down" manner, and the second is defined as a stimulus driven attention, controlled on a "bottom-up" way. If one is looking for a particular type of shampoo on a shelf at the supermarket, and that shampoo is known to have a green bottle, then is more likely to be selected by attention and recognized: this situation fits on goal driven attention because it is controlled by the observer's deliberate objectives. If it is stimulus driven, attention is controlled by a salient feature that is not necessarily important for the observer's perceptual goals: on a similar example, if on the shelf there are mostly yellow bottles of shampoo, a green one on the middle will pop out and direct attention of the observer automatically. For James, attention was a high-level mental operation: "Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought".

Morray (1959) conducted experiments about the Cocktail party effect, the ability to understand something in a room full of people speaking, if attention was focused on one speaker at a time. According to his achievements, information from an irrelevant source may be recalled under some conditions, depending on its intrinsic value to the subject.

The first models of attention and information processing were improved by Broadbent (1958) that summarized previous knowledge and investigations undertaken by Cherry (1953) and Poulton (1953). According to Broadbent, humans can be viewed as systems with a limited capacity of information processing (Figure 1). He suggested a model that can be compared to a filter: it incorporated a short term store acting to extend the stimulus duration, so that the same stimulus could be divided into several channels and then the selective filter select among channels. The limited capacity stage of perception (P-system) is preceded by parallel analysis of simple stimulus features and that access to the P-system is controlled by the selective filter.

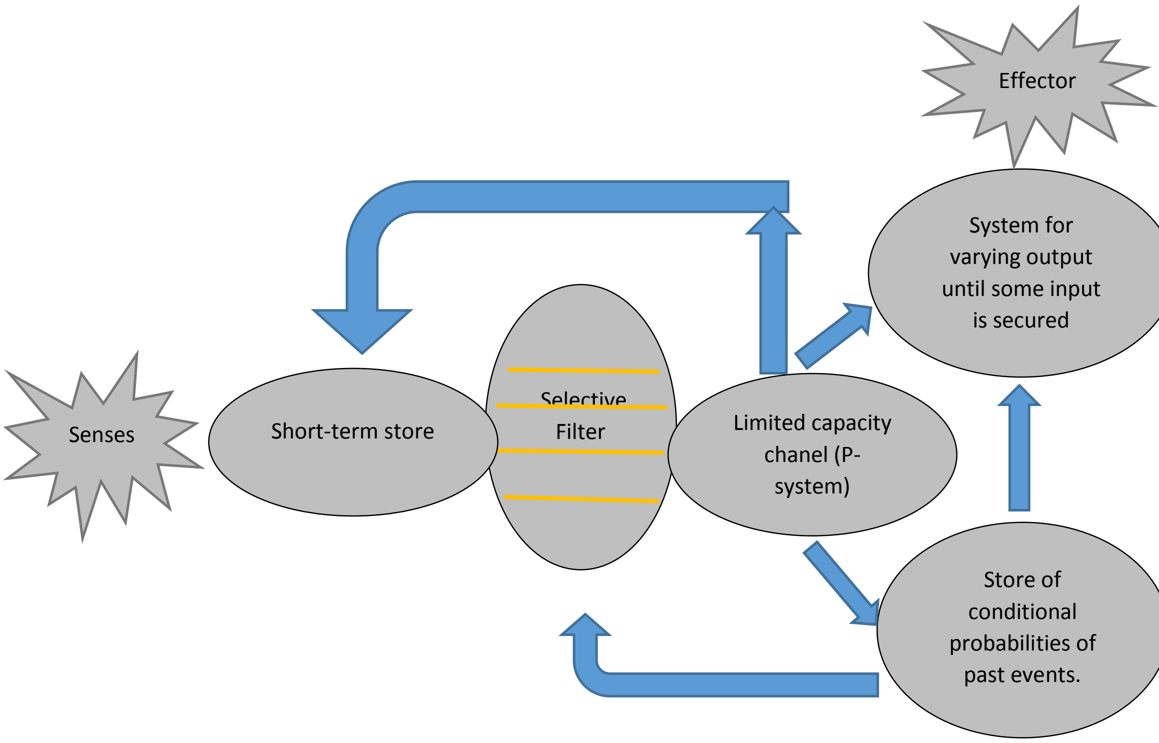

Figure 1 – Broadbent model

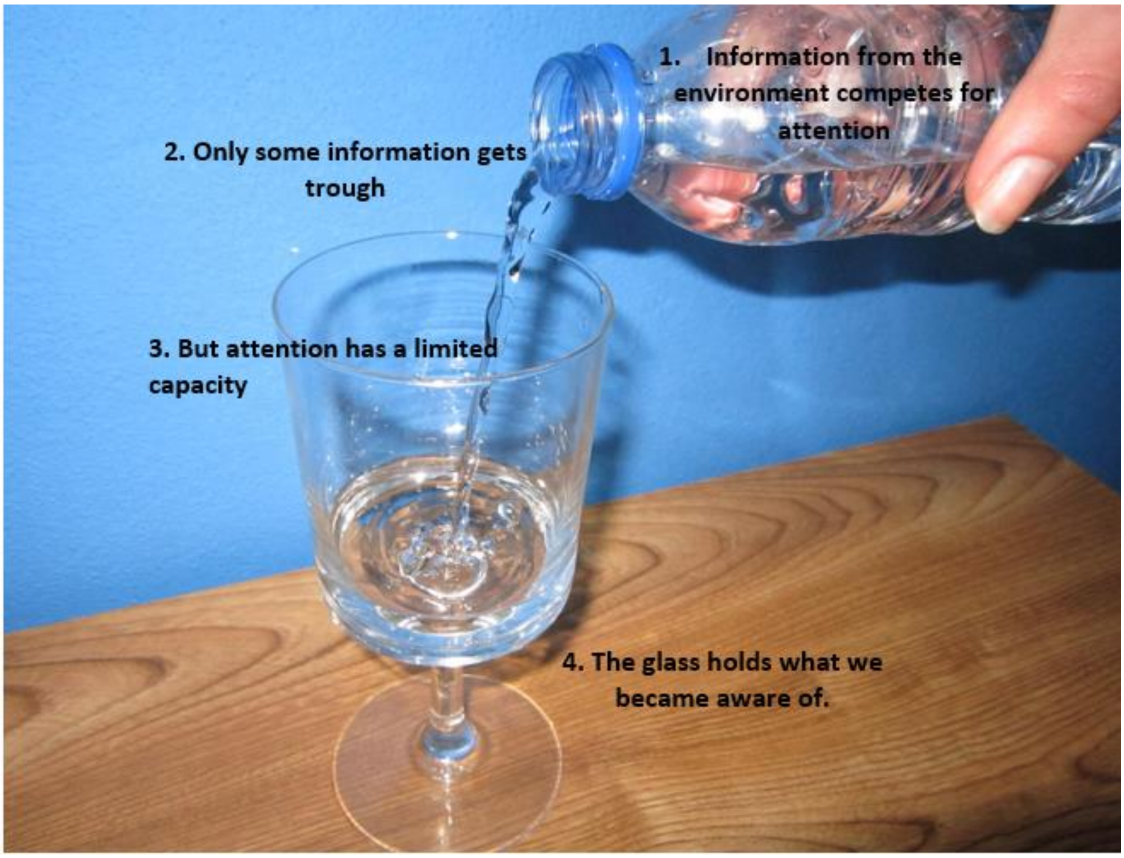

Figure 2 – Simplified model - Bottleneck

Short-term and long-term memory systems (store of conditional probabilities of past events) were postulated and integrated into the information processing system.

On a simplified version (Figure 2), representing attention and its limited capacity, not letting all information get through, functioning as a filter or bottleneck.

The model developed by Broadbent was recognized as the prototype of the early selection model of attention. After his research, models for representing late selection of attention have emerged: most of them proposing that all information is completely processed and recognized before it receives the attention of a limited capacity processor. Relevance of stimulus defines what is attended to and recognition can occur in parallel. Treisman (1964) suggested a hybrid view between the two models for early and late selection of attention. The debate between the early *vs*. late selection was indeed strong and prolonged in time, with many experiences and data supporting either of them, trying to unravel if focused selective attention could alter early sensory processing.

Vision has a major function for object recognition. In many cases, experimental evidences suggested that the visual system can recognize an object by selecting a relevant part of the visual image (like the clusters of features constituting an object located in a region of space) and operating only on that cluster, then selecting another part of image and so forth (Yamtis, 1998).

Many studies have demonstrated that different features of a stimulus, such as its color and shape, may be coded by different neurons, and these neurons may be located in very different areas of the visual cortex. The binding mechanism between different features is still on discussion, being the issue introduced by the *Feature Integration Theory* postulated by Treisman & Gelade (1980). These authors strained to explain how we can perceive or became aware of a unitary object. They introduced the concept of focal attention as necessary to relate separated features to each other: the features were all connected to a master map of locations whereupon spotlight of attention would move. This spotlight would be drawn automatically if an item contains a unique feature, and so the item is seen. Otherwise, the spotlight must travel form item to item in order to integrate all clusters of features. The attentional spotlight is an often described metaphor of attention in the literature. Its structure usually implies the existence of one beam only (La berge, 1997). The metaphor can include some other properties, such like working as a zoom-lens: the attentional beam is strongest at the center and decreases in strength with distance from the center (Eriksen et al., 1985). Beyond focal attention, top-down processing was reported as the second mechanism of the *Feature Integration Theory*. This theory influenced the definition of an attention's type named "selective integration" the ability to bind selected parts or properties into more complex structures (Rensik, 2007).

Other important related cognitive concepts were defined over time, such as orienting and detecting. The first is defined as the direction in which attention is pointed, allowing to select a position in space. The second is considered as the subject's capacity to be aware or conscious of the stimulus. Through orienting, a target could undergo a more accurate processing allowing items to be reported more rapidly and at a lower threshold. If cued to its location, observers can detect a target more quickly (Posner, 1980).

More recent definitions have been used to explain selective attention: increasing the perceptual ability to focus on task-relevant information while ignoring potential distractions. It discriminates relevant stimuli (targets) form irrelevant stimuli (distractors) that compete for a person's attention (Moran, 1996; Moran, 2004). Another model stated that attention is an emergent property of many neural mechanisms working to resolve competition for visual processing and control of behavior (Desimone et al., 1995).

Although many researchers have tried to define this concept, many questions still remain. Is attention focused on one location at a given moment and shifted sequentially – serial model - Treisman and Gelade (1980) - or divided into multiple foci simultaneously working in parallel for processing (Desimone et al., 1995; Matsushima et al., 2014; Eimer et al., 2014). The literature suggests that more studies must be addressed for clarification of this issue.

In the following sections, the mechanisms underlying attention are examined in detail, as well as the clinical impact of this knowledge.

b) Neurophysiology

Innumerous theories were postulated through many decades aiming to discover the attentional mechanisms and many of them were supported by new discoveries on neurophysiology, starting with the invention of human electroencephalography (EEG) testing. The EEG is generally defined as a sum of many different sources of electrical activity within the brain (Berger, 1929).

Three types of neurophysiological methodologies have been employed over time: i) direct electrical recordings of individual neurons in monkeys; b) indirect electrical recordings of a large group of neurons in humans (EEG); 3) noninvasive measures of cerebral flow in humans - Positron emission tomography (PET) and more recently fMRI - functional magnetic resonance imaging (Luck, 1998).

Usually it is not possible to insert electrodes in human brain; therefore, the alternative technique is to do it indirectly, using the EEG.

The Electrophysiology studies on attention were mostly initiated by ERPs (event related potentials) that could translate the brain's response to individual sensory, cognitive, or motor events, measured through the EEG. The ERPs can be used as a continuous measure of the processing between a stimulus and a response, providing information about the time course and neuroanatomical substrates of cognitive processing. The first records were performed on cats, raising the hypothesis that attention plays an important role by influencing early neuronal sensory processes. The auditory responses to clicks were larger in amplitude in cat's cochlear nucleus when the animal was passively listening than when it was distracted and paying attention to the mice (Péon, 1956).

The first recording from electrodes on the scalp of healthy humans convincingly demonstrated that, for the first time, selective attention could modulate sensory processing (Hillyard et al., 1973).

The study of neurophysiology of attention through electric and image records, allied with all the cognitive theories formerly postulated, would probably lead the scientific community to a new era. Improving the knowledge about these neuronal pathways could bring new insights to modern science in order to finally define what attention really is, how it really functions and how it can be compromised, namely in disease.

Visual processing of an image

Objects' images pop out of the everyday life surroundings and must be somehow understood to elaborate an answer that may have several forms. In the visual field approximately 30 or more visual areas compete for processing (Desimone et al., 1989; Felleman et al., 1991). These areas are responsible for different aspects of visual perception, including depth perception, motion, discrimination, spatial frequency analysis, color processing, and face recognition (Luck, 1998).

a) Retina to cortex

The retina transmits visual signals from a neural population of 10^8 photoreceptors into the lateral geniculate nucleus (LGN) via 10^6 optic nerve fibers of the retinal ganglion cells (RGCs) (Choi et al., 2013).

Visual information enters the nervous system at the retina, travels to the LGN of the thalamus, reaching the cerebral cortex at the back of the head in an area named V1 (also known as "striate cortex" because of a prominent striation that defines this area). From V1, information divides itself traveling forward into the many specialized visual areas that are located in posterior half of the brain (called extra striate visual areas). As the information travels forward from the striate cortex into extra striate cortex, the features coded by single neurons change, from simple bars and edges to more complex attributes of object identity (Luck, 1998).

b) Forward system

There were described two different pathways whereby visual information travels rapidly forward in the brain: One system projects from the occipital lobe and is centered on the dorsal posterior parietal and frontal cortex, being involved in the cognitive selection of sensory information and responses. The second system, which is largely lateralized to the right hemisphere and is centered on the temporal-parietal and ventral frontal cortex, is recruited during the detection of behaviorally relevant sensory events, particularly when they are salient and unattended (Shulman et al., 2002). The first one is also called the dorsal attention network – DAN - and the second, the ventral attention network –VAN (Vickers, 2012).

Top down and bottom-up control

The concepts of top-down and bottom up control were previously mentioned and already defined by William James (1890) and many research studies were performed since then, attempting to redefine and better explain how they work, what they can influence and how they are influenced.

Top down control can be translated as the flow of information from 'higher' to 'lower' centers, conveying knowledge derived from previous experience rather than sensory stimulation. As examples of top-down factors, knowledge, expectations and current goals can be pointed. Bottom up control includes the information processing that proceeds in a single direction from sensory input, through perceptual analysis, towards motor output, without involving feedback information flowing backwards from 'higher' centres to 'lower' centres. Other factors beyond those two affect attention, such as novelty and unexpectedness, reflecting an interaction between cognitive and sensory influences (Shulman et al., 2002).

Receptive field

A simple description presents a neuron's receptive field as the area of space to which the neuron is sensitive and where the presence of an appropriate stimulus will modify the neuron's activity.

The first researcher to observe how retinal ganglion cells of mammals (like the cat) are influenced by small spots of light was Stephen Kuffler (1950). According to his studies, the resting discharges of a cell were intensified or diminished by the light in a small and more or less circular region of the retina, being this small region the cell's receptive field. In each succeeding layer of the retina, the receptive fields become more complex, and when they reach the visual cortex its complexity is even higher **(**Hubel**,** 1963). An individual neuron in the initial cortical visual area V1 will respond only to stimuli presented on a very restricted area, but an individual neuron in the final area of the visual cortex will respond to stimuli presented almost anywhere within the central region of visual space (Luck, 1998).

The competition between visual processing of diferent inputs can be modulated by attention. The information available about any given object will decline as more and more objects are added to the receptive fields (Desimone et al., 1995).

Visual Search and Spatial cueing

Multiple objects compete for attention. When observing an object, relevant information must be selected and distractors (that are not relevant to the task goals) must be ignored (Eimer, 2014).

The processing of attended and ignored stimuli can be compared through visual search. Similarly to searching a friend in a crowd, this ability can be tested by presenting to subjects arrays containing multiple stimulus elements, and they must indicate if the target item is or is not present within the array. The amount of time needed to detect the target increases as the number of elements in the arrays also increases. This fact could explain visual search as a serial mechanism with moving shifts of attention from item to item. However, under certain conditions, subjects can detect the target rapidly, no matter how many distractors exist on the display – this detection is made independently and in parallel (Luck, 1998) which has been supported by ERP studies of multiple object tracking (Drew et al., 2008; Drew et al., 2009).

Informative visual cues can drive attention voluntarily to spatial locations (Posner et al., 1980). The cue indicates a likely location for the target to appear, and usually comes in first place. It allows subjects to focus attention on this location before the onset of the target (Luck, 1998). On valid trials, the target appears at the location indicated by the cue, on invalid trials, the target appears at an uncued location: for example, on an array of eight letters containing either a "L" or a "R", subjects were induced to determine which of these targets was present by pressing correspondently a left or right button. Before the letter appeared, an arrowhead cue appeared indicating one of the display locations. Some trials were executed using a valid cue and others an invalid cue (Jonides, 1981).

Attention and eye movements

Where to look and how to direct the eyes through what is important in our surroundings, in order to achieve a rightful perception and processing of information, is indeed a huge study field that can be exploited through many different ways. The attentional system is highly correlated with this information processing and the eyes' movements act like a window, receiving various and innumerous inputs.

High quality visual information is acquired from a limited spatial region surrounding the center of gaze called the fovea. Visual quality decreases at a larger scale, on a continuously mode from the center of gaze into a low-resolution visual surround. Rapid eye movements (saccades) happens about three times each second, functioning to reorient the fovea through the scene. Standard information is acquired during periods of fixations (when gaze is relatively stabilized) due to saccade suppression. It can be said that vision is effectively suppressed during saccades (Volkman, 1986; Thiele, 2002). Direct fixation towards an object or scene region is needed to notice local visual details, to identify the object and posteriorly encode the captured and processed information into short and long term memory (Henderson 2003; 2008). Early studies about fixations demonstrated that they are not randomly placed in a scene, but that viewers tended to cluster fixations on informative regions. These studies have also estimated the mean fixation durations, saccade amplitude and their variability, concluding an important correlation between eye movements and visual attention (Buswel, 1935). It is crucial, not only to evaluate the object processing in scenes, but also the whole scene captured along with the object of interest. The object is not perceived as a single unit undervaluing its surroundings, all elements must be analyzed. Global coarse information about a scene (its category - the gist, and its spatial structure - the layout) is crucial in memory free models of scene perception (Rousselet et al., 2005). During a typical scene viewing, approximately 150 ms are needed to acquire sufficient information to understand the gist of a scene (Rayner et al., 2009), contradicting the

40-100 ms previously advocated (Biederman et al., 1982; Rousselet et al., 2005; Castelhano et al., 2008). The individual fixation duration is also influenced by factors like scene luminance (Loftus, 1985) and contrast (Loftus, 1992).

Studies evaluating eye parameters on scene perception, face perception and visual search revealed different conclusions that others made about the reading process, suggesting that each process must be studied separately (Rayner et al., 2007). Neural mechanisms underlying the oculomotor activity do not vary across tasks. The differences are in the cognitive processes associated, which manifest themselves in different ways, like the encoding of scenes properties that take longer than encoding words in reading (Rayner, 2009).

To understand the processes that determine where humans attend and look to in scenes, two mainly theoretical models of visual attention allocation have been presented, not functioning as unitary models, but as two halves, which complete each other, to reach the same purpose. The first theory, named "Saliency Model", advocated that bottom-up stimulus based information is generated from an image, directing the allocation of visual attention, and consequently placing the fixation in a scene (Itti and Koch, 2000; 2001). The salience model is computational and clusters the visual characteristics presented on an image, and specifically mark regions that differ from their surroundings based on properties as color, intensity, contrast, edge orientation, and other multiple spatial scales. It is based on the intuitive idea that regions, which are different from the surroundings, will probably be more informative that those that are homogeneous with the neighborhood. After the scene analysis, all the mapped regions are combined in a unique saliency map, producing a sequence of predictive fixations, scanning the scene in order of decreasing saliency. Other researchers propose that fixation placement in a scene viewing is not only affected by the saliency, but also influenced by cognitive factors like it is presented on the *Cognitive Relevance Theory* (Henderson et al., 2009). In this study, the authors stated that the scene image is needed to create a representation that will guide and direct the eyes, and that image will serve as basis for the input to activate important cognitive knowledge structures. Contradicting the saliency hypothesis, fixation locations are selected based on the needs of the cognitive system related to the current task and the actual scene understanding.

Trying to figure out all these interactions between lower and higher structures is still a challenge and great advances in technology have contributed to more accurate studies about eye movements, including the development of better eye trackers that allow the investigator to know where the subject of the experiment is looking to, and for how long (Henderson, 2003).

Gaze cueing

The face is an essential mean whereby communicative social signs can be transmitted. It gives information about other's identity, gender, emotional state, intentions and even personality traits (Zebrowitz et al., 2005; Leopold 2010). Most specifically within the face, the eyes act as a window to the brain, they are among the first and most frequently fixated regions (Yarbus, 1967), communicating complex mental states, such as emotions, beliefs and desires.

Gaze plays a central role on social interactions, giving invaluable information of others' intentional and emotional states, such as love or dominance and it can also be used to signal turns in a conversation (Kleinke, 1986; Frischen et al., 2007). In a similar way, animals use gaze as signals of threat, appeasement or affiliation – for example, if a predator or a potential mate approach, they will often be signaled by a sudden change in another's gaze, head orientation or body posture. It appears that monitoring other's attentional signals can be part of an adaptive advantage for animals (Langton et al., 1999).

Concerning Humans, there are evidences that gaze following is already present in the infancy in early ages, as young as 3 months old (Hood et al., 1998) and persist until adulthood, with adults reflexively directing their attention toward targets falling within another's gaze direction (Driver et al., 1999; Friesen et al., 1989; Langton et al., 1999).

A person's gaze direction primarily indicates her/his direction of attention and focus of interest in the surrounding space. There is a tendency to align our own attention to where someone else is directing their (Baron-Cohen, 1994; Langton, 1996). Objects previously cued by another agent's gaze direction are preferred to objects toward which no attention was manifested (Bayliss et al., 2006). In addition, there is a strong relationship between gaze and emotion – target objects formerly cued by the gaze of a happy face are preferred comparing with those cued by the gaze of a disgusting face (Bayliss, 2007). A central component of the neural system for social perception is the cortical region within and near the superior temporal sulcus (STS). The STS is responsive to movements of the hands and body, as well as the eyes and the mouth, and therefore it is supposed to code biological motion (Oram et al., 1994; Puce et al., 1998; Pelphrey et al., 2005).

The perception of a gaze directed to the surrounding environment, is known as averted perception. It induces an automatic shift of the observer's spatial attention in the seen gaze direction. This is now established as a fact, but it was previously postulated on the attention orienting paradigms (Posner et al., 1980), where gaze was used as a central attentional cue. Face stimuli, indicating direction by virtue of their head and eye position, can produce a reflexive orienting answer on behalf of the observer. However, it still remains to explain whether these effects are based on an orienting response to the head, the direction of gaze, or a combination of the two (Langton et al., 1999). On the same study, it was stated that pointing gestures also serve as an important cue to social attention direction.

Joint Attention

Humans have innumerous cognitive capacities, and beyond introspect and meditate upon their own experiences, they can also, on a natural way, try to capture other's state of mind. An important development on the infancy cognitive systems is the emerging awareness that others have minds with mental states that may differ from one's own (Charman et al., 2000.) Joint attention is one example of a shared experience between two minds (Baron-Cohen, 1995; Kleinke, 1986; Mundy et al., 2007). When subject X perceives the shift of attention of subject Y, the mind sharing state can be achieved. Subject X then orients his attention, by driving gaze to the same object. Now, both X and Y subjects are attending to the same object owing to Y's initial sign (Emery, 2000). This ability to follow joint attention signals has been shown to be a relevant matter in social development (Moore, 2008). The failure to properly engage in joint attention is associated with disease status, such as in autism. People with ASD miss out information generated and transmitted in these messages exchanges built by the mechanisms of joint attention, revealing social difficulties in their daily life (Dawson et al., 1998).

Change blindness

In many situations, observers fail to detect even substantial changes to the visual details of objects and scenes, a phenomenon named change blindness. In the early 90's it was already recognized the existence of a phenomenon that could made people not notice what is happening in their surrounding environment if they were emerged or absorbed in the inspection of something (Balint, 1907). This focus could be so intense that they could not perceive other objects placed in the peripheral parts of their visual field, despite the visual information emitted was arriving properly to the cerebral cortex (Husain et al., 1988).

In the attempt to prove the constant manifestation of this phenomenon on daily life, it is only necessary to try to remember, for example, the time when someone went to the cinema, entered a bus or a train searching for an open seat in the middle of the crowd. After looking for several minutes it is possible to spot a free space and sit. On the next day, after meeting several friends for some reason, they were really annoyed because they were waving to that person to seat next to them, and she/he was looking on their direction. How could it be missed?

This inability to notice change on a visual scene can occur across saccades, blinks, blank screens, movie cuts and other interruptions (Simons, 2000). Most explanations assume a failure to detect changes because the altered display masks or overwrites the initial display. For example, on the construction of a film scene, one inevitable consequence is the necessity to shoot scenes out of order, and often to shoot components of the same scene at different times. To accomplish a final sequential result, unintentionally, many details within the scene may change from one view to the next (Simons et al., 1997) – looking at a movie scene, we can see a men holding a red coat on his hands but on the immediate following shoot the coat is lying on the back of a chair. A reasonable thought is that the majority of the observers will notice the editing mistake, but the truth is that even for large changes like this one, they may be blind to it most of the time. The research on visual memory made by Simons et al. (1997) found that people are surprisingly unable to notice large changes to objects, photographs, and motion pictures from one instant to the following.

Studies about change blindness are an emerging field since the 20th century and so it is its relationship with visual short term memory. As an explanation to change blindness effects, certain limitations of the visual short term memory have been considered (Irwin, 1996; Irwin et al., 1998). The failure to notice change in change blindness experiments may not always be due to the limited capacity of visual short term memory, but rather a failure to engage it although attending to the object (Treich et al., 2003) which is consisting with previous studies, suggesting that humans seem to structure tasks so as to minimize short term memory requirements (Ballard et al., 1995; Hayhoe et al., 1998).

Another element that can be considered is gaze, more specifically the fixation position and saccade direction, and how it influences the inability to notice changes. A pioneer study about this matter found that disappearance of an object was easily noticed when it occurred during a saccade on the object's direction rather than away from it (Henderson et al., 1999). Change blindness for objects in natural scenes can also occur during fixation if the effects of a saccade are simulated by disrupting the retinal transient normally associated to a scene. For this disruption, many studies use blank screens introduced between the original and changed image (Blackmore et al., 1995; Rensink et al., 1997; Simons, 1996).

Five hypothetical "causes of change blindness" (Simons, 2000) were proposed. Simons' paper ensures an extensive review on the literature about the matter, finding evidence to support for each of them (Figure 3).

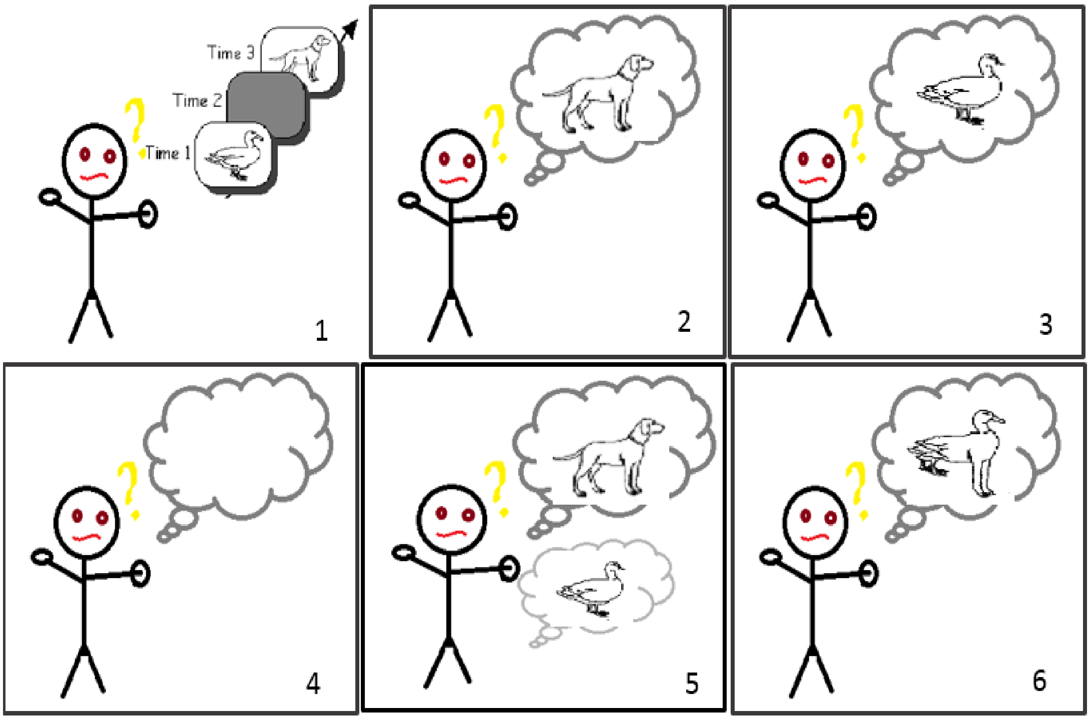

Figure 3 - Five hypothetical causes of change blindness- adapted from Simons, 2000. 1. Illustrates a potential sequence in which an observer views a duck followed by a dog. 2. Overwriting: new sensory information simply overwrites older information. 3. First Impression: the old representation persists, the new one is ignored. 4. Nothing is stored: no representation of the object is maintained at all. 5. Nothing is compared: representations of the object before and after the change co-exist without being compared. 6. Feature combination: the representation after the change has elements of the object's appearance before and after the change.

A closely related phenomenon to change blindness is inattentional blindness, defined as a failure to consciously notice an unpredictable stimulus when someone's attention is engaged on another task (Mack et al., 1998; Simons, 2000).

Inattentional Blindness can be considered as a variant of induced blindness (Beanland et al., 2011), along with attentional blink (Raymond et al., 1992). Despite the nonexistence of a formal explicative theory, it can be considered as a consequence of selective attention (Neisser, 1979), where observers experience inattentional blindness if their attention is simultaneously engaged by another primary task, preventing them to occasionally detect a clearly visible stimuli.

Correlating the incidence of inattentional blindness with performance on other tasks, several studies have strained to explain individual differences. Only working memory has revealed a substantial effect, with subjects who experience inattentional blindness showing less memory capacity (Hannon et al., 2010; Seegmiller et al., 2011).

Inattentional blindness has been studied in many naturalistic and laboratory experiments. On lab studies, people attend to one aspect of a complex event and fail to notice an unexpected event that happens precisely in front of their eyes, such as a gorilla or a woman carrying an umbrella (Simons et al., 1999). Studies on naturalistic settings, with more complex environments have been performed, studying inattentional blindness caused, for example, by cell phone conversations during driving and walking (Strayer et al., 2007; Hymanet al., 2010). In driving simulators, the cell phone use can lead to a diminished recognition of objects that individuals drove past, regardless of the high probability of drivers had looked to the objects (Strayer et al., 2003). Other people will fail to notice a fight when running and tracking another person (Chabris et al., 2011) or a unicycling clown when talking on a cell phone while walking (Hyman et al., 2010). A recent study shows how people can even miss money hanging on a tree directly in front of their faces, or a signboard while walking, using a phone (Hyman Jr. et al., 2014). They could avoid obstacles on their path, displaying them little awareness. They passed the signboard and fail to be aware of having done so within a few moments. Hyman Jr. et al. (2014) concluded that it seems people may be able to guide behavior without awareness. Inattentional blindness for objects someone avoids, can be a form of mindless wandering that allows people to walk and drive without awareness of avoided obstacles. On a complex environment, a division of attention is required, consequently decreasing people awareness of objects that aren't the focus of attention. These objects could indeed be interesting and surprising, but they didn't have a direct correlation with the person's primary task.

The neuroscience of magic

After all the revision made regarding the attentional processing, it is finally time to reach a core point of this article.

Magicians have learned how to deceive their audience's mind since early times in History, and tried to improve the methods used on magic tricks. The empirical knowledge which passed through generations amongst magicians was always evolving to achieve better results on the intended effect. They never stopped trying to upgrade the execution methods, much as filmmakers that experience many editing techniques until the one that will indeed communicate the adequate image to transmit effectively what they want. The ability to manipulate people's attention, to distort perception and influence choice without their awareness, is the main point of a magician's act. They leave the audience amazed but also confused about what just happened right in front of their eyes, making them believe that there is no logic explanation or trick behind the act, so that in the end, it is all about magic.

As such, the execution and the methods used by this misleading professionals are a valid and reproducible tool to study the behavioral and neural basis of consciousness under controlled conditions. Through eye trackers, questionnaires, brain imaging and other neural recording techniques it will be possible to achieve a better insight into human perception and cognition (Kuhn et al., 2008; Macknik et al., 2008).

This matter can be considered a not so much exploited field, with some research made but with just a few experiments undertaken, especially those including individuals with different characteristics such as the one carried out with people affected with ASD (Kuhn et al., 2010).

The devices used by magicians can include one or more of the following: visual illusions (after images), optical illusions (smoke and mirrors), cognitive illusions (inattentional blindness), special effects (explosions, fake gunshots), secret devices and mechanical artifacts (gimmicks) (Macknik et al., 2008).

Regarding visual and other sensory illusions, the stimulus perceived does not match the reality. Neural circuits in the brain normally amplify, suppress, converge and diverge visual information, leading to a final representation that is not the real one, but a subjective form carved by each one's perception. Lateral inhibitory circuits in the early visual system can enhance the contrast of edges and corners so that the final result is the apprehension that these visual features are more salient than what they really are (Troncoso et al., 2007; Macknik et al., 2004). An example of a visual illusion that contributes to a magic trick there is the famous trick of spoon bending: in this illusion, the magician bends a spoon, apparently only by using the power of his mind. He holds the spoon horizontally and moves it up and down showing that the neck of the spoon has apparently become flexible, with a rubber consistence (Lamont et al., 1999). The neural basis of this illusion probably lies on the fact that end-stopped neurons (i.e., neurons that respond both to motion and to the terminations of a stimulus' edges, such as corners or the end of lines) in the primary visual cortex (area V1) and the middle temporal visual area (area MT, also known as V5), respond differently from non-end-stopped neurons to oscillating stimuli. This differential response is the consequence of an apparent spatial mislocation between the end of a stimulus and its center, making a solid object look like it flexes in the middle (Pack et al., 2003; 2004; Tse et al., 2007).

Optical illusions are not a consequence of isolated brain mechanisms, they are based on light physical properties manipulation, such as reflection – using mirrors, and refraction (like the effect of a straw half submerse in a glass of water, that looks broken, due to the different refraction indices of air and water.)

Cognitive illusions are not like visual illusions, they do not have a sensory nature, involving higher level cognitive functions, such as attention and casual inference (Macknik et al., 2008). To explain cognitive illusions it is crucial to understand a huge magical concept called misdirection.

Misdirection

The magician needs to draw the spectator's attention far from the real "method" of execution, and through the effect he wants the audience to perceive. It is necessary to create areas of high interest that capture the spectator's attention, while the method is carried out in an area of low interest (Kuhn et al., 2008). Misdirection can be divided into "Overt", when the magician redirects the spectator's gaze away from the method, and "Covert", a more subtle way, where he draws the audience focus of attention away from the method, without redirecting the spectator's gaze – he can, for example, mislead the focus of suspicion of the spectator (Macknik et al., 2008; Kuhn et al., 2012). Other classifications were established (Ascanio et al., 2000), divided on three degrees: the first one would be when the magician is performing two simultaneous actions, the method behind the magic trick, and a distractor. The spectator cannot focus at two stimulus in a similar fashion, and generally is all it takes to disguise the method and made it go unnoticed. In the second degree, the two actions performed are not perceptually equivalent, the distractor is more attractive and of higher interest – a bigger move will cover a small move: like the sudden appearance of a flying dove. The third one relies on methods that draw spatial attention due to some kind of transient change in sound or movement. It should be noticed that the second degree can be correlated with bottom up processing modulated by attention: a large or fast-moving stimulus might decrease the perceived salience of a small or more slowly moving stimulus that is presented either simultaneously or subsequently. Novel stimuli are known to produce stronger neural responses in the inferotemporal cortex (area IT), the hippocampus, the prefrontal cortex and the lateral intraparietal area (Li et al., 1993; Desimone, 1996; Miller, 2000).

An important rule in magic states that the audience will look where the magician is looking, a fact already demonstrated on studies regarding eye gaze and joint attention, showing that someone's eye gaze leads to automatic shifts of visual attention to another individual (Emery, 2000; Langton et al., 2000; Frischen et al., 2007).

Covert misdirection can be related with inattentional blindness and change blindness. In change blindness, the observers fail to notice something that appears in the scene, but it was not present before a certain point in time. This change can be expected or unexpected, but a comparison between the pre-change and the post-change state is necessary (Macknik et al., 2008). It is also important the existence of a visual mask to disguise the transition in the scene, like saccades, blinks, blank screens, movie cuts and other interruptions (Simons, 2000). Although interruptions may be needed, observers can miss large gradual changes in the absence of interruptions. This fact is dramatically demonstrated in the "Changing cart Trick Video" by Richard Wiseman and colleagues, (available on Youtube.com), where the spectators fail to notice color changes that happen off camera (Macknik et al., 2008). In inattentional blindness, people fail to notice an unexpected fully visible event when their attention is engaged on a demanding distractor task (Mack et al., 1998; Simons et al., 1999). It has been discussed that the mechanism which prevents an audience from detecting the magician's method, the misdirection itself, is similar to inattentional blindness, although the difference between the two are under large scientific debate (Kuhn et al., 2012). A very interesting study correlated eye movements of the observers while watching a magic trick, being the first one that related the perception of magic with a physiological measurement (Kuhn et al., 2005) - Box 1. They tried to understand if the observers missed the trick because they were not looking at it at the right time, or because they did not attend to it, independently of the gaze position.

Box 1.

On their study, Kuhn et al. (2012) monitored eye movements by eye trackers, and the trick was performed "live" by the magician, in front of the participant. They selected by dotted circles the area of low and high interest. The magician begins by removing a cigarette from the packet and places it on the mouth but wrong way round. Then, he pretends to light the cigarette and the flame attracts attention. At this moment both the magician and spectator notice the mistake, which raise the interest on the cigarette. The magician turns the cigarette around, while keeping his gaze fixed on the cigarette and the hand manipulating it. During this maneuver, the hand holding the lighter is lowered and drop it on the magician's lap, which is a lower area of interest. After this moment, the magician snap his fingers and wave his hands revealing the lighter. At the same time, he make disappear the cigarette, dropping it also into the lap, by an action totally visible, from 15 cm above the table's top. Although it is a completely visible gesture, it is made in an area of low interest, because attention is now focused on the lighter, the high interest zone.

According to Kuhn and Tatler, there are three important main points on this experiment: the first is the element of surprise: the vanishing lighter, attracting the observers attention; second, the social cues, when the magician looks at the empty hand, that previously held the lighter and rotate his body in the same direction; and as a third point, the movement and sound he makes at the time he drops the lighter, snapping his fingers and waving.

Most participants did not notice the dropping cigarette but, when the trick was performed a second time, they always noticed it.

The results showed that the detection or not of the cigarette drop could not be explained at the retina's level. The magician mostly manipulates the spectator's attention, rather than their gaze, using similar principles to those that are used in inattentional blindness. To overcome misdirection, spectators must allocate their attention, rather than gaze, to the hidden event (the cigarette's drop).

Misdirection is just an example of a magical technique that can be rightfully studied to understand the neural correlations of the countless cognitive processes that make up our lives. Analyzing the various techniques used by this misleading professionals, using them in a controlled mode, monitoring the reactions of the participants with the many already existing imaging technology , is a different approach, but also a new one, that can bring unexpected and valuable outcomes.

Applying magic to patients with Autism Spectrum Disorder

The American Psychiatric Association (APA), and the DSM-5, actually define ASD as a single disorder, including disorders which were previously considered separate – autism, "Asperger's syndrome", childhood disintegrative disorder and pervasive developmental disorder not otherwise specified. According to APA guidelines, people with ASD tend to have communication deficits, to respond inappropriately in conversations, misreading nonverbal interactions and to have difficulties to build friendships adequate to their age. Other characteristics of this disorder are the high dependence on routines, the intense focus on inappropriate items and the increased sensibility to changes in their environment, demonstrating superior skills on the processing of fine details.

These numerous impairments in social attention could be suggestive of a lower probability to be misdirected by magician's social cues. It has been demonstrated that individuals with autism have social-attention difficulties, spending less time looking at a face and eye regions of a visual scene and more time looking at objects (Kuhn et al., 2010). They compared individuals with ASD with typically developing individuals (TD) while watching a video recorded magic trick: the vanishing ball illusion. There were 15 patients with "Asperger's syndrome" in comparison with 18 TD, ensuring that all participants obtained Full Scale QI scores above the average range (QI>80), and normal visual acuity. The expected results were based on the scientific findings stating that people with ASD have a higher capacity for processing details on a scene and less probability to be misdirected by social cues; therefore, they would be more efficient at detecting the ball. The results were obtained through eye tracking measurements and a questionnaire – Box 2.

Box 2.

The Vanishing ball illusion is an ancient magical trick, being performed by innumerous magicians over the years. One of the first descriptions on the scientific literature was the execution of the trick and posterior evaluation on a children group (Triplett, 1900). The method of execution used on the ASD group was similar to the one already tested on a previous experiment (Kuhn et al., 2006). The magical trick was performed by a magician, throwing a ball up in the air and catching it twice before a third fake throw, when he just pretend to throw the ball, hiding it in his hand. On the fake throw, the magician also looks at the imaginary ball, he makes exactly the same gestures and direct his eye gaze like he had done on the first two times.

The results weren't as expected, the ASD group were more susceptible to the vanishing-ball illusion than the TD control participants, challenging the idea that adults with ASD have general social attention difficulties. They were misdirected by the magician's social cues and looked instantly to the face, and were similar to the control group on the global time spent looking at the face and eyes. Nevertheless they exhibited a subtle delay in directing their first saccade to the face and had problems to allocate attention at the ball. It is important to look to all the experience context. It was a complex task, where it was needed to fixate a moving ball against a background of social cues, including the magician's eye and body movements. People with ASD may not be able to set up attention faster enough to fixate a small moving ball even though in principle, top down strategies based on prior expectations and social cues are available to them.

They were capable to anticipate that a ball that had previously been throwed, should be in the air again, and relying on the magician social cues, they deducted its trajectory.

There is not a better conclusion about this study than the one given by Kuhn et al. on their paper *"Magic can change expectations about autism, and autism can also change expectations about magic"*.

Conclusion

After analyzing some of the innumerous points of this matter, it can be concluded that the hypothesis of using magic tricks/illusions to study attention mechanisms is valid and reproducible. Although not fully understood, it has a huge potential, waiting to be properly managed. Cognitive neuroscience, through magic trick studies, must ally itself with imaging techniques, connecting both areas' knowledge in order to achieve better results. Applying similar methodologies, as the ones exemplified, on large population's studies, and not just in ASD, it could open new doors to different approach fields, combining magic with science, creating countless possibilities to obtain well-founded results. For instance, as a different and complete approach, it could be possible to investigate how the brain actually is or not activated by functional MRI, allied with eye tracking, while a group of people with ASD observe a magic trick.

The art of illusion is a very antique one, and without exposing its secrets it will continue entertaining the masses, helping science to achieve different results and conclusions. Many obstacles may appear due to the subject's complexity, but with rightful methodologies and background study, new data can be obtained and shed light to complex neurochemical networks underlying attention in both health and disease, with promising results for clinical applications..

References

Ascanio,A.,& Etcheverry, J. (2000). La magia de Ascanio,Vol.1.Madrid: Editorial Páginas.

Ballard, D. H., Hayhoe, M. M., & Pelz, J. B. (1995). Memory Representations in natural tasks. *Cognitive Neuroscience* 7, 66-80.

Baron-Cohen, S. (1994). How to build a baby that can read minds: Cognitive mechanisms in mindreading. *Cahier s de Psychologie Cognitive* 13, 513–552.

Baron-Cohen, S. (1995). The eye direction detector (EDD) and the shared attention mechanism (SAM): Two cases for evolutionary psychology. In C. Moore & P. J. Dunham (Eds.), Joint attention: Its origins and role in development (pp. 41–59). Hillsdale, NJ: Erlbaum.

Bayliss, A.P., Frischen. A., Fenske, M.J., & Tipper, S.P.(2007). Affective evaluations of objects are influenced by observed gaze direction and emotional expression. *Cognition* 104, 644—53.

Bayliss, A.P., Paul, M.A., Cannon, P.R., & Tipper, S.P. (2006). Gaze cuing and affective judgments of objects: I like what you look at. *Psychon Bull Rev.* 13(6), 1061—66.

Beanland, V. & Pammer, K. (2011). Minds on the blink: The relationship between inattentional blindness and attentional blink. *Atten Percept Psychophys* 74, 322–330.

Berger, H. (1929). "Über das Elektrenkephalogramm des Menschen." *Archiv fuer Psychiatrie und Nervenkrankheiten* 87, 527–570.

Biederman, I., Mezzanotte, R.J., & Rabinowitz, J.C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive Psychology* 14, 143–177.

Blackmore, S.J., Brelstaff, G.,Nelson, K.,& Troscianko, T. (1995). Is the richness of our visual world an illusion? Transsaccadic memory for complex scenes. *Perception* 24, 1075–1081.

Castelhano, M.S., & Henderson, J.M. (2008).The influence of color on the activation of scene gist. *Journal of Experimental Psychology: Human Perception and Performance* 34, 660–675.

Chabris, C.F., Weinberger, A., Fontaine, M., & Simons, D.J. (2011).You do not talk about Fight Club if you do not notice Fight Club: inattentional blindness for a simulated real world assault. *Perception* 2, 150–153

Cho, M. W., & Choi M. Y (2013). A Model for the Receptive Field of Retinal Ganglion *Cells. Neural Networks* 49, 51–58. Elsevier.

Corbetta, M., & Shulman, G. L. (2002). Control of Goal-Directed and Stimulus-Driven Attention in the Brain. *Nature Reviews Neurosci.* 3, 201-215.

Dawson, G., Meltzoff, A., Osterling, J., Rinaldi, J., & Brown, E. (1998). Children with autism fail to orient to social stimuli. *Journal of Autism and Developmental Disorders* 28, 479 – 485.

Descartes, R.(1649). "Les Passions de L'âme". Le Gras, Paris.

Desimone, R. (1996). Neural mechanisms for visual memory and their role in attention. *Proc. Natl Acad. Sci. USA* 93, 13494–13499.

Desimone, R., & Duncan, J. (1995). Neural Mechanisms of Selective Visual Attention. *Annual Reviews Neurosci*. 18, 193-222.

Desimone, R., & Ungerleider L. G. (1989). Neural Mechanisms of Visual Processing in Monkeys. *Handbook of Neural Psychology*, vol.2, ed. F. Boller, J. Grafman, pp. 267- 299. New York: Elsevier.

Drew, T., & Vogel, E.K. (2008). Neural measures of individual differences in selecting and tracking multiple moving objects. *J. Neurosci.* 28, 4183–4191.

Drew, T., McCollough, A.W., Horowitz, S.T. & Vogel, K.E. (2009) Attentional enhancement during multiple-object tracking. *Psychon. Bull. Rev.* 16, 411–417.

Driver, J., Davis, G., Ricciardelli, P., Kidd, P., Maxwell, E., & Baron-Cohen, S. (1999). Gaze perception triggers reflexive visuospatial orienting. *Visual Cognition* 6, 509–540.

Eimer, M. (2014) The neural basis of attentional control in visual search. *Trends in Cognitive Sciences.* Cell press.

Eimer, M., & Grubert, A. (2014) Spatial attention can be allocated rapidly and in parallel to new visual objects. *Curr. Biol.* 24, 193–198.

Emery, N. J. (2000). The eyes have it: The neuroethology, function and evolution of social gaze. *Neuroscience & Biobehavioral Review* 24, 581–604.

Eriksen, C.W., & Yeh, U. (1985). Allocation of attention in the visual field. *Journal of Experimental Psychology: Human Perception and Performance* 11, 583-597.

Felleman, D. J., & Van Essen D. C. (1991). Distributed Hierarchical Processing in the Primate Cortex. *Cereb. Cortex 1, 1 – 47.*

Frischen, A., Bayliss, A.P., & Tipper, S.P.(2007). Gaze cueing of attention: visual attention, social cognition, and individual differences. *Psychol Bull* 133(4), 694—724.

Friesen, C. K., & Kingstone, A. (1989). The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. *Psychonomic Bulletin & Review* 5, 490–495.

Hannon, E. M., & Richards, A. (2010). Is inattentional blindness related to individual differences in visual working memory capacity or executive control functioning? *Perception* 29, 309– 319.

Hayhoe, M. M., Bensinger, D. G., & Ballard, D. H. (1998). Task constraints in visual working memory. *Vision Research* 38, 125-137.

Henderson, J. M. (2008). Eye movements and visual memory. In S. J. Luck & A. Hollingworth (Eds.), *Visual memory* (pp. 87–121). Oxford, UK: Oxford University Press.

Henderson, J. M. (2003). Human gaze control during real-world scene perception. *Trends in Cognitive Sciences* 7, 498–504.

Henderson, J. M., & Hollingworth, A. (1999). The role of fixation position in detecting scene changes across saccades. *Psychological Science,* 10, 438-443.

Henderson, J. M., Malcolm, G. L., & Schandl, C. (2009). Searching in the dark: Cognitive relevance drives attention in real-world scenes. *Psychonomic Bulletin & Review* 16, 850–856.

Hernández-Peón, R., Scherrer, H., & Jouvet, M. (1956). Modification of electrical activity in the cochlear nucleus during attention in unanesthetized cat. *Science* 123, 331–332.

Hillyard, S. A., Hink, R. F., Schwent, L. V., & Picton, W.T. (1973). Electrical signs of selective attention in the human brain. *Science* 182, 177–180.

Hood, B. M., Willen, J. D., & Driver, J. (1998). Adult's eyes trigger shifts of visual attention in human infants. *Psychological Science* 9, 131–134.

Hubel, D. H., & Wiesel, T. N., (1963). The visual cortex of the Brain. In *Scientific American Offprints*, Vol. 209, nº 5, pp. 54-63. New York: W. H. Freeman and Company.

Husain, M., & Stein, J. (1988). Rezso Balint and his most celebrated case. *Arch. Neurol*. 45, 89–93.

Hyman Jr, I.E., Boss,S.M., Wise,B.M., McKenzie, K.E., & Caggiano,J. M. (2010). Did you see the unicycling clown? Inattentional blindness while walking and talking on a cell phone. *Appl.Cogn.Psychol.* 24, 596–607.

Hyman Jr, I. E., Sarb, A.B., & Wise-Swanson, M. B. (2014). Failure to see money on a tree: inattentional blindness for objects that guided behavior. *Frontiers in Psychology* 5, 356.

Irwin, D. (1996). Integrating information across saccadic eye movements. *Current Directions in Psychological Science* 5, 94-100.

Irwin, D., & Gordon, R. (1998). Eye movements, attention, and trans-saccadic memory. *Visual Cognition* 5, 127-155.

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research* 40, 1489–1506.

Itti, L., & Koch, C. (2001). Computational modelling of visual attention. *Nature Reviews Neuroscience* 2, 194–203.

James, W. (1890*). "Principles of Psychology."* Holt, New York.

Jonides, J. (1981). Voluntary versus automatic control over the mind's eye's movement. *In J.B. Long & A.D Baddeley (Eds.), Attention and Performance IX* (pp. 187-203). Hillsdale, NJ: Lawrence Erlbaum Associates Inc.

Kleinke, C.L. (1986). Gaze and eye contact: a research review. *Psychol Bull* 100, 78—100.

Kuhn, G., Amlani, A.A., & Rensink, R.A. (2008). Towards a science of magic. *Trends in Cognitive Sciences* 12, 349–354.

Kunh, G., Kourkoulou, A. & Leekam, R.S. (2010). How Magic Changes Our Expectations About Autism. *Psychol. Sci* 21, 1487–1493.

Kuhn, G., & Land, M.F. (2006). There's more to magic than meets the eye. *Current Biology* 16, 950‑951.

Kuhn, G. & Martinez, M. L. (2012). Misdirection- past, present, and the future. *Frontiers in Human Neuroscience* 5, 172.

Kuhn, G. & Tatler, B.W. (2005). Magic and fixation: now you don't see it, now you do. *Perception* 34, 1155–1161.

LaBerge, D., Carlson, R. L., Williams, J.K., & Bunney B.G. (1997). Shifting attention in visual space: tests of moving-spotlight models versus an activity-distribution model. *Journal of Experimental Psychology: Human Perception and Performance* 23(5), 1380-1392

Lamont, P. & Wiseman, R. (1999). *Magic in Theory*. Hermetic, Seattle.

Langton, S R.H., & Bruce, V.(1999) Reflexive visual orienting in response to the social attention of others. *Visual Cognition* 6:5, 541-567.

Langton, S.R.H., Watt, R.J., & Bruce,V. (2000) Do the eyes have it? Cues to the direction of social attention. *Trends Cogn. Sci.* 4, 50–59.

Langton, S.R.H. (1996). Interference between gestures and words. Unpublished doctoral dissertation, University of Nottingham, Nottingham.

Leopold, A. D., & Rhodes, G. (2010) A Comparative View of Face Perception. *J Comp Psychol* 124(3), 233–251.

Loftus, G.R. (1985) Picture perception: effects of luminance on available information and information-extraction rate. *J. Exp. Psychol. Gen*. 114, 342–356.

Loftus, G.R., Kaufman, L., Nishimoto, T., & Ruthruff, E. (1992) Effects of visual degradation on eye-fixation durations, perceptual processing, and long-term visual memory. *Eye Movements and Visual Cognition: Scene Perception and Reading* (Rayner, K., ed.), pp. 203–226, Springer.

Leibnitz, G. W., (1765). Nouveaux Essais sur L'Entendement Humain, in R. E. Raspe (Ed.), "Oeuvres Philosophiques de feu M. Leibnitz." Screuder, Amsterdam & Leipzig.

Li, L., Miller, E. K. & Desimone, R. (1993).The representation of stimulus familiarity in anterior inferior temporal cortex. *J. Neurophysiol.* 69, 1918–1929.

Luck, S. J. (1998). Neurophysiology of Selective Attention. In H. Pashler ed., *Attention* (pp. 257- 295). East Sussex, UK: Psychology Press.

Mack, A., & Rock, I. (1998). Inattentional blindness. Cambridge, MA: MIT Press.

Macknik, S. L., King, M., Randi, J., Robbins, A., Teller, O., Thompson, J., & Martinez- Conde, S. (2008). Attention and awareness in stage magic: turning tricks into research. *Nat.Rev.Neurosci.* 9, 871–879.

Macknik, S. L. & Martinez-Conde, S. (2004).The spatial and temporal effects of lateral inhibitory networks and their relevance to the visibility of spatiotemporal edges. *Neurocomputing* 58–60, 775–782

Matsushima, A. & Tanaka, M. (2014). Differential Neuronal Representation of Spatial Attention Dependent on Relative Target Locations during Multiple Object. *J. Neurosci*. 34(30), 9963-9969.

Miller, E. K. (2000).The prefrontal cortex and cognitive control. *Nature Rev. Neurosci*. 1, 59–65.

Moore, C. (2008). The development of gaze following. *Child Development Perspectives, 2,* 66-70.

Moran, A. P. (2004). Sport and exercise psychology: a critical introduction. *Routledge*, UK.

Moran, A.P. (1996). The psychology of concentration in sports performers: A cognitive analysis, Hove: *Psychology Press.*

Morray, N. (1959). Attention in dichotic listening: Affective cues and the influence of instructions, *Quarterly Journal of Experimental Psychology* 11, 56-60.

Mundy, P., & Newell, L. (2007). Attention, joint attention, and social cognition. *Current Directions in Psychological Science* 16, 269–274.

Neisser, U. (1979). The control of information pickup in selective looking. In A. D. Pick (Ed.), Perception and its Development: A Tribute to Eleanor J. Gibson (pp. 201–219). Hillsdale, NJ: Erlbaum.

Oram, M.W., & Perrett, D.I.(1994). Responses of anterior superior temporal polysensory (STPa) neurons to “biological motion” stimuli. *Journal of Cognitive Neuroscience* 6, 99–116.

Pack, C. C., Livingstone, M. S., Duffy, K. R. & Born, R. T. (2003).End-stopping and the aperture problem: two dimensional motion signals in macaque V1. *Neuron* 39, 671–680.

Pack, C. C., Gartland, A. J. & Born, R. T. (2004). Integration of contour and terminator signals in visual area MT of alert macaque. *J. Neurosci*. 24, 3268–3280.

Pelphrey, K.A., Morris, J.P., Michelich, C.R., Allison, T., & McCarthy, G.(2005). Functional anatomy of biological motion perception in posterior temporal cortex: An fMRI study of eye, mouth, and hand movements. *Cerebral Cortex* 15, 1866–1876.

Posner, M. I. (1980). Orienting of Attention. *Quarterly Journal of Experimental Psychology* 32, 1, 3–25.

Poulton, E. C. (1953). Two channel listening. *J. of Experimental Psychology* 46, 91–96.

Puce, A., Allison, T., Bentin, S., Gore, J.C., & McCarthy, G.(1998). Temporal cortex activation in humans viewing eye and mouth movements. *J. Neuroscience* 18, 2188—99.

Raymond, J. E., Shapiro, K. L., & Arnell, K. M. (1992). Temporary suppression of visual processing in an RSVP task: An attentional blink? *Journal of Experimental Psychology: Human Perception and Performance* 18, 849–860.

Rayner, K., Smith, T. J., Malcolm, G. L., & Henderson, J. M. (2009). Eye movements and visual encoding during scene perception. *Psychological Science* 20, 6-10.

Rayner, K., Li, X., Williams, C.C., Cave, K.R., & Well, A.D. (2007). Eye movements during information processing tasks: Individual differences and cultural effects. *Vision Research* 50, 2714–2726.

Rensink, R. A. (2007). The modeling and Control of Visual Perception. In Wayne D.Gray, ed., "*Integrated Models of Cognitive Systems*" (pp. 132-148). New York: Oxford University Press.

Rensink, R.A., O'Regan, J.K., & Clark, J.J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science* 8, 368–373.

Rousselet, G.A., Joubert, O.R., & Fabre-Thorpe, M. How long to get to the "gist" of real-world natural scenes? *Visual Cognition* 12, 852–877.

Seegmiller, J. K., Watson, J. M., & Strayer, D. L. (2011). Individual differences in susceptibility to inattentional blindness. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 37, 785–791.

Simons, D. J. (2000). Current approaches to change blindness. *Visual Cognition, 7,* 1-15.

Simons, D.J. (1996). In sight, out of mind: When object representations fail. *Psychological Science 7*(5), 301–305.

Simons, D.J., & Chabris, C.F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception,* 28, 1059–1074.

Simons, D. J., & Levin, D.T.(1997). Change Blindness. *Trends in Cognitive Sciences, 1*, 261-267.

Strayer,D.L., & Drews,F.A.(2007).Cell phone induced driver distraction. *Curr. Dir. Psychol. Sci.* 16, 128–131

Strayer, D. L., Drews, F.A., & Johnston, W.A. (2003).Cellphone-induced failures of visual attention during simulated driving. *J. Exp. Psychol. Appl.* 9, 23–32.

Thorpe, S.J., Fize, D., Marlot, C.(1996). Speed of processing in the human visual system. *Nature* 381, 520–522.

Treisman, A. (1964). The effect of irrelevant material on the efficiency of selective listening. *The American J. Psychology* 77, 533–546

Treisman, A., and Gelade, G. (1980). A feature integration theory of attention. *Cognitive Psychology* 12, 97–136.

Triesch, J., Ballard, D. H., Hayhoe, M.M., & Sullivan B. T. (2003). What you see is what you need. *Journal of vision* 3 (1), 9.

Triplett, N. (1900). The psychology of conjuring deceptions. *The American J. of Psychology* 11, 439‑510.

Troncoso, X. G. Macknik, S. L. & Martinez- Conde, S. (2007). BOLD activation varies parametrically with corner angle throughout human retinotopic cortex. *Perception* 36, 808–820.

.Tse, P. U. & Hsieh, P. J. (2007).Component and intrinsic motion integrate in 'dancing bar' illusion. *Biol. Cybern*. 96, 1–8.

Vickers, J. N. (2012). Neuroscience of the Quiet Eye in Golf Putting. In *International Journal of Golf Science* 1, 2-9.

Von Helmholtz, H. (1896/1989). "Physiological Optics" (1896—2nd German edition, translated by M. Mackeben, from Nakayama and Mackeben, *Vision Research* 29(11), 1631–1647.

Von Helmholtz, H. (1886/1962). "Physiological Optics, Vol. 3." (3rd editor) Translated by J. P. C. Southall. NewYork: Dover.

Wolff, C. (1734). "Psychologia Rationalis." *Renger*, Frankfort & Leipzig.

Yantis, S. (1998). Control of visual attention. In H. Pashler ed., *Attention* (pp. 223-256). East Sussex, UK: Psychology Press.

Yarbus, A.L. (1967). Eye movements and vision. New York: Plenum Press.

Zebrowitz LA, Montepare JM, Psychology. (2005). Appearance DOES matter. *Science* 308, 1565—6.