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automatized process in endogenous orienting of attention in
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RESUMO

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Considera-se que a orientação da atenção ocorre pelo menos de duas formas distintas, i.e., exogenamente (ou orientação reflexiva) ou endogenamente (ou orientação voluntária). No entanto, evidências sugerem que a orientação endógena da atenção poderia envolver tanto processos voluntários como também processos automatizados. O principal objetivo dos três estudos aqui relatados foi diferenciar, comportamental e eletrofisiologicamente, o curso temporal da orientação endógena da atenção envolvendo processos voluntários e automatizados. Os experimentos foram delineados para investigar os efeitos da orientação voluntária da atenção evitando-se a possibilidade de automatização usualmente observada após apresentação contígua repetitiva de uma pista com um alvo. Para isso, foram criadas duas variantes da tarefa clássica de Posner. No primeiro capítulo a tarefa consistia em apresentar um estímulo visual relevante entre a apresentação da pista e do alvo para evitar a contiguidade desses estímulos. Os resultados indicaram que a orientação voluntária da atenção parece ocorrer somente em intervalos de tempo mais longos do que 150 ms enquanto que a orientação automatizada ocorre em intervalos de tempo tão curtos quanto 150 ms. Na tarefa do segundo capítulo a pista simbólica era modificada a cada tentativa sendo necessário uma nova interpretação de seu significado espacial e evitando, assim, a apresentação repetitiva de uma só pista seguida do alvo em um local. Observou-se que quando há um conflito na interpretação da pista a orientação voluntária da atenção é prejudicada, porém ainda podendo ocorrer em intervalos de tempo de 250 ms. Esse prejuízo na orientação da atenção estaria relacionado com uma diminuição da decodificação do alvo na memória visual operacional demonstrado pelos resultados eletrofisiológicos. De modo distinto, no capítulo três, foi investigado o curso temporal necessário para processos automatizados e voluntários da orientação da atenção utilizando

diferentes tipos de pistas como flechas, formas geométricas associadas a direcionamentos da atenção no espaço, e uma pista de escolha a qual o sujeito era livre para escolher qual lado orientar sua atenção. Foi observado que o curso temporal da orientação da atenção é similar para processos envolvendo pistas associadas a locais e pista de escolha, e podem ocorrer em intervalos de tempo de 200 ms. Porém, a orientação da atenção automatizada por um aprendizado de longa duração como o caso das flechas apresenta um curso temporal muito mais curto. Assim, os resultados indicam que a orientação da atenção voluntária mesmo sem a interferência de processos automatizados pode ocorrer em intervalos de tempo mais curtos do que o esperado. Isso se daria devido a uma facilitação da realização da tarefa, a qual estaria relacionada com contingências bem estabelecidas na tarefa e a presença de muitas repetições permitindo que mecanismos de aprendizagem reforcem o desempenho. A partir dessas evidências, uma hipótese teórica foi estruturada em torno da ideia de que as distinções de uma orientação endógena automatizada (rápida e fácil) ou voluntária (lenta e custosa) estariam relacionadas ao fortalecimento da associação entre a pista e o local indicado que varia em um continuum a partir de mecanismos de reforço que dependeriam da função dos componentes da memória operacional e sua conexão com a memória de longo prazo.

Palavras-chave: Orientação endógena da atenção. Voluntária. Automatizada. Tarefa de Posner

ABSTRACT

JORDÃO, E. M. A. Is it possible to dissociate a voluntary process from a automatized process in endogenous orienting of attention in humans? 2019. 118f. Thesis (PhD) - Biosciences Institute, University of São Paulo, São Paulo, 2019.

Orienting of attention is considered to occur at least in two distinct ways, i.e. exogenously (or reflexive) or endogenously (or voluntary). However, evidence suggests that endogenous orienting of attention could involve both voluntary and automatized processes. The main objective of the three studies reported here was to differentiate, behaviorally and electrophysiologically, the temporal course of a voluntary process from an automatized process involved in endogenous orienting of attention. The experiments were designed to investigate the effects of voluntary orienting of attention when avoiding the possibility of an automatization usually observed after repetitive contiguous presentation of a cue and a target. For this, two variants of the classic cueing task were created. In the first chapter the task consisted of presenting a relevant visual stimulus between the cue and target presentation to prevent the contiguity of these stimuli. The results indicated that voluntary shift of attention appears to occur only at time intervals longer than 150 ms while automatized orienting occurs at times as short as 150 ms. For the task on the second chapter the symbolic cue was different for each trial requiring a new interpretation of its spatial meaning, and thus avoiding repetitive presentation of a single cue followed by the target at a location. It was observed that when there is a conflict in the interpretation of the cue the voluntary orienting of attention is impaired, but may still occur at a time interval of 250 ms. This impairment in shifting attention would related to a decrease in target decoding in working visual memory demonstrated by electrophysiological results. Moreover, chapter three investigated the time course required for automatized and voluntary orienting of attention processes using different types of cues such as arrows, geometric shapes associated with direction of attention in space, and a choice cue to which the subject could freely choose which side to direct her attention to. It was observed that the time courses of orienting

attention are similar for processes involving cues associated with locations and choice cue, and may occur at time intervals as short as 200 ms. However, an automatized orienting of attention triggered by arrow cues has a much shorter time course. Thus, the results indicate that voluntary orienting of attention even without the interference of automatized processes can occur at shorter time intervals than the expected. This would be due to a facilitation of task performance related to a well-established contingencies in the task and the presence of many repetitions allowing learning mechanisms to reinforce processes involved on the task. From these evidences, a theoretical hypothesis was structured around the idea that the distinctions of an automatized endogenous orientation (fast and effortless) or voluntary (slow and effortful) would be related to the strengthening of the association between the cue and the indicated location that varies on a continuum from reinforcement mechanisms that would depend on the function of working memory components and their connection to long-term memory.

Keywords: Endogenous orienting of attention. Voluntary. Automatized. Visuospatial cueing tasks

1. Introduction

Picture yourself hiking on a trail in the amazon. It is a very dense forest, with tall trees, lower bushes, plants with thorns, army-ants on the ground, mosquitoes flying, you hear different birds communicating, and you see one or two tiny and colorful frogs jumping in the middle of the trail. If you are a biologist, or anyone who enjoys nature, you can get overwhelmed with so much information that you want to perceive. But suddenly you hear a loud noise on your right side. You turn around, try to see what it was, but nothing. After a few minutes, with no clue of what it was, you decide to keep walking. However, for the rest of the trail you won't be so interested in all things you encounter along it. Because, now, you are paying attention to your right side almost all the time waiting for another loud noise to happen. That's when you stumble in a tree root.

This brief story describes how attention is relevant to trivial tasks that we conduct in daily life, and how perception, memory and attention are intricately related. Attention is important to perceive sensory information. If a regular information is not attended, likely it will not be processed by the nervous system and will not be perceived. An example is the tree root that you stumble when you were not attending to the ground. However, if an information is attended, or a source of information is attended, then it will probably be processed as a priority in detriment of other information, as exemplified by your right side location after you heard the loud noise. This is also a good example of a relevant relationship involving attention and memory. After the loud noise, your right side location became a relevant source of information, perhaps because of fear or pure curiosity. Therefore, directing your attention to this location will happen often. This expectancy-dependent control of where attention is located is considered a voluntary process. Think about how many times you orient your attention to relevant locations when driving. As a novice driver you probably took longer to get to places, checked your mirrors, were very careful with pedestrians and traffic lights. However, after a few months driving you probably did all those things much faster, and even without being completely aware of them. Is it possible that your control of orienting of attention involved voluntary processes of each component of driving at the beginning, but after a lot of repetitive training it became automatized.

These questions permeate this thesis. The studies presented here investigated how voluntary, slow and effortful, and automatized, fast and effortless, processes contribute for endogenous orienting of attention from behavioral and electrophysiological perspectives.

1.1. Selective attention

According to Anne Treisman (1969), “attention can be defined as the selective aspect of perception and response”. In this sense, selective visual attention can be regarded as a set of processes that prioritize sensory processing of one or a few task-relevant items in a scene while also inhibiting irrelevant or distracting stimuli. The underlying assumption for this idea is that because the central nervous system has a limited capacity for sensory and/or response processing, in order to deal with the abundance of simultaneous information provided by the environment one requires selective mechanisms that facilitate processing of some information and/or inhibits processing of other information (Broadbent, 1982; Treisman, 1969; Theeuwes, 1992). Theories of selection are mainly concerned with how this selection occurs. One relevant aspect that received a lot of attention was in which moment of sensory processing the selection occurs.

Broadbent (1958) tested performance of humans in recollecting auditory and visual items of information presented simultaneously. He observed that performance was superior when the subjects adopted a strategy of attending and recalling all the items on one sensory modality, and then all items on the other sensory modality. He argued that because the two simultaneous stimuli were separated in sensory terms they could both be processed forming a representation internally without loss of data. However, for that to happen, stimuli had to be further processed from a first memory-stage to a later information processing going through a filter. To efficiently recall all items this filter would select items for the next stage of processing based on sensory properties of the input. Thus, for instance, visual items would be selected for further processing while auditory items would stay in a buffer storage until they could also be processed. From this and other studies, Broadbent theorized that when the system is overloaded there would be a “filter” that would relieve the system by limiting the transfer of information from a peripheral memory stage to later stages of processing. This proposal is considered part of the “early selection” theories of information processing. Afterwards, Treisman (1960) showed that even when attending to one stream of items, recollection of items from the other stream and of the same sensory modality could happen if their meaning were relevant for the current task. This led researchers (e.g., Deutsch & Deutsch, 1963) to propose and support a “late selection” theory of information processing, that suggests that selection occurs later in the internal processes after all stimuli reaching the senses had been fully processed. However, one well accepted view of selection is that some features of unattended information are processed and influence responses when those features are congruent with the current information being attended. Therefore, information not receiving

priority for processing is attenuated but can reach full processing (or be prioritized) when relevant for the task being conducted (Treisman, 1964).

In consonance with this latter view, the “feature-integration” theory (Treisman & Gelade, 1980) for visual selective attention tries to explain how the nervous system deals with two or more objects in a visual input. According to this proposal, a pre-attentive stage of processing discriminates simple features in parallel, without focal attention. This explains why there is no set size effect, i.e. the increase amount of distractors does not increase target detection latencies, in a visual set with single-feature distinct target among distractors. However, when the target does not have a single-feature distinction from distractors, its detection latency increases linearly with set size. Thus, the theory proposes that integration of a conjunction of features into a single combined unit can only occur serially, one item at a time, in the attentive process. This serial process involving each item being scanned one at a time is congruent with the effect of set size when target is not salient and a conjunction of features requires processing. However, other models oppose to this view. For instance, Desimone & Duncan (1995) favored the notion of a parallel processing system with selection occurring at later stages by a limited capacity system. Other models and theories also tried to make sense of data related to visual selective attention, favoring the notion that both processing mechanisms are involved, running in parallel at early stages and serially at later stages (Theeuwes, 1993; Luck & Hillyard, 1990; Tamber-Rosenau & Marois, 2016).

Control of orienting of visual attention is also a major aspect under investigation. According to the proposal of automatic and controlled processes of selection introduced by Schneider & Shiffrin (1977), “automatic processing is generally fast, parallel, fairly effortless, not limited to short-term memory capacity, not under direct subject control, and performs well-developed skilled behaviors” (p. 269). This type of processing would occur after extensive training involving consistent pairings of stimuli over many trials. In visual search tasks, for instance, when target and non-target are constant remaining the same from trial to trial, the speed of search does not depend on the set size. In contrast, “controlled processing is often slow, generally serial, effortful, capacity limited, subject regulated, and used to deal with novel or inconsistent information” (p. 269). Usually, controlled processing is required when targets and non-targets change from trial to trial (or in the beginning of the search task), thus with instructions guiding search and non-targets interfering with search. In this case, increase in the number of items results in decreased speed of processing. Further, the authors suggest that a complex combination of both processes would be present in all tasks. Many studies involving different attentional tasks, some of which will be reported here, have

employed similar frameworks to explain distinctions between different perceptual and response processes.

Spatial attention plays an important role in visual attention. Not only 'what', but also 'where' objects are selected from are subjected to specific processes. An object or its visual scene is better detected and processed if presented at an attended location while processing of stimuli outside the focus of attention is worst (Eriksen & Hoffman, 1972; Posner, 1980). This can be revealed experimentally by orienting attention to a particular location and comparing the response to a stimulus presented at this location relative to a stimulus presented at another location. Consistently, the response to the attended stimulus is faster and more accurate than the response to the unattended stimulus. Further, as mentioned above, evidence shows that orienting of attention can also involve voluntary or automatic processes.

Sherrington, in 1906, described reflex and volitional actions in "The integrative action of the nervous system", as it follows:

"Yet it is clear, in higher animals especially so, that reflexes are under control. Their intrinsic fatality lies under control by higher centres unless their nervous arcs are sundered from ties existing with those higher centres. In other words, the reactions of reflex-arcs are controllable by mechanisms to whose activity consciousness is adjunct. By these higher centres, this or that reflex can be checked, or released, or modified in its reaction with such variety and seeming independence of external stimuli that the existence of a spontaneous internal process expressed as "will" is the naive inference drawn. (...) It is urgently necessary for physiology to know how this control—volitional control—is operative upon reflexes, that is, how it intrudes and makes its influence felt upon the running of the reflex machinery. How is the cough, or eye-closure, or the impulse to smile suppressed? How is the convergence of the eyeballs, innately associate to visual fixation of a near object initiated voluntarily without recourse to fixation on an object? (...) No exposition of the integrative action of the nervous system is complete, even in outline, if this control is left without consideration. Reflexes ordinarily outside its pale can by training be brought within it (...) Volitional movement can certainly become involuntary, and, conversely, involuntary movements can sometimes be brought under subjection to the will." [p. 388-389]

Although his considerations relate to control of action, it seems possible to extend this idea for the control of spatial attention. Because orienting, shifting or deploying attention is commonly regarded as a movement of the attentional focus even without an actual muscle movement (Posner, 2016). Definitions and conceptualizations of what is voluntary or automatic seldomly fall into the problem of being vague by using other unclear concepts like "conscious" or "intentions" for something voluntary, and "unconscious" or "unintended" for

automatic (Kimble & Perlmutter, 1970). Therefore, a rather more neurophysiological, and thus mechanistic, approach to these concepts will be adopted for the most part of the discussions mentioned here.

1.2. Visuo-spatial orienting of attention

Orienting of attention will be considered to occur in two main forms: one reflexive (termed exogenous orienting or bottom-up) and the other voluntary (termed endogenous orienting or top-down). These two forms of attention were experimentally dissociated and have proper and conspicuous characteristics (Posner & Cohen, 1984). In a seminal study reported in 1980, Posner used either symbolic stimuli (arrows presented close to the fixation point) or peripheral stimuli (abrupt changes in the luminance of lines surrounding the place for later target presentation) to indicate, either validly (correctly) or invalidly (incorrectly), the likely location for appearance of an impending visual target. All along the task, the subjects gazed in a single fixed location; thus, attention was oriented covertly. The idea was to investigate how orienting of attention validly and invalidly towards cued locations would affect target detection, minimizing the contribution of either sensory or motor aspects. By measuring the reaction time (RT) and/or accuracy to the target presentation it seemed possible to quantify the benefit promoted by valid cues and costs promoted by invalid cues associated to orienting of attention.

Studies using this basic experimental arrangement, referred here as classical cueing task, allowed characterizations of how shifting attention in a visuo-spatial area is controlled [Posner & Cohen, 1984; Jonides, 1981; Muller & Rabitt, 1989; see Klein (2009) for review]. Exogenous orienting of attention is triggered a salient stimulus, usually a brief change in luminance in the lines composing a square surrounding the place where the target is to be presented, called peripheral cue, usually located at 70° to the left or the right of the fixation point, in the horizontal plane, followed by the target stimulus, which may appear at the same location (when the cue is valid) or at opposite location (when the cue is invalid). For endogenous attention, a symbolic cue (also named central cue, e.g., an arrow or a geometric figure) typically presented close to the fixation point indicates the likely target location. In both cases, the time interval between the beginning of the cue and the beginning of the target (Stimulus Onset Asynchrony or SOA) is varied from trial do trial thus delimiting the time interval available for orienting of attention (Chica *et al.*, 2014). Moreover, a relevant condition of the task is relative to the predictiveness of cues along trials, i.e. how informative they are about the actual location of the target. A non-predictive condition consists of 50% of

trials with cues indicating target location correctly or incorrectly, which means no informative relationship between cue and target. When this frequency is different from 50% (e.g. 80% of trials with cues indicating correctly the location of target) then the task condition is predictive, i.e. cues are informative about the likely target location. is considered to delimit the time provided for orienting of attention processes to occur (Chica *et al.*, 2014). Combinations of cue nature (either symbolic or peripheral), cue predictiveness (either predictive or non-predictive) and cue validity (either valid or invalid), all associated with the SOA, have provided means to characterize different processes of orienting of attention (see Luck & Vecera, 2002, for review).

For instance, symbolic non-predictive cues does not induce any validity effect (i.e. the reaction time in invalid trials minus the reaction time in valid trials) because cue-target relationship would not be informative, thus the subject would not know or use the direction that the cue is indicating. In contrast, predictive symbolic cues reduce RT for valid cued targets as compared to invalid cued targets at SOAs longer than 300 ms, with a long lasting period of a few seconds. The explanation for the presence of validity effect only at longer SOA is that symbolic cues need to be interpreted in order to orientation to occur properly. Therefore, it would involve slow and effortful processes related to endogenous orienting of attention (Jonides, 1981; Muller & Rabbitt, 1989). Peripheral cues are related to distinct behavioral results. Even when peripheral cue is non-predictive valid cues reduce reaction times to the target as compared to invalid cues, usually at SOAs as short as 50 ms (Castro-Barros *et al.*, 2008). This fast effect is ascribed to exogenous capture of attention by the peripheral non-predictive cues. However, this positive validity effect is observed only until SOAs of 300 ms. SOAs longer than 300 ms produce higher reaction times for valid as compared to invalid cued targets, i.e. negative validity effect, an effect termed as Inhibition of Return - IOR (Posner *et al.*, 1985). This effect is explained as a prioritization of unattended locations in detriment of locations already attended recently without meaningful events (Posner & Cohen, 1984). These results are interpreted as the involvement of a fast and effortless processes, related to exogenous orienting of attention, at SOAs shorter than 300 ms. In contrast, for peripheral predictive cues a positive validity effect is also observed at short SOAs. However, positive validity effect in this condition endures for SOAs longer than 300 ms, but decrease greatly at SOAs longer than 500 ms (Posner *et al.*, 1982). This suggests that for peripheral predictive cues there would be the involvement of an exogenous orienting process at early stages which allows a fast response to cued target, and an endogenous attentional process at late stages which allows the maintenance of attention at cued location even for longer SOAs (Chica *et al.*, 2014). In summary, when a salient stimulus

appears in the periphery of the visual field it automatically or reflexively (tens of milliseconds) captures attention to that location regardless of whether that stimulus carries any information relevant to the task. In contrast, a symbolic cue (e.g., a geometric figure) engages voluntary, top-down orienting of attention only when it is informative (predictive condition) about the target location, requires effort and takes longer times (hundreds of milliseconds).

Interestingly though, evidence have been reported demonstrating that fast and effortless orienting (related to automatic processes) may also occur when symbolic non-predictive cues are used (e.g., Friesen & Kingstone, 1998; Ristic *et al.*, 2002; Tipples, 2002; Ristic & Kingstone, 2012). These studies revealed that symbolic non-predictive cues, like representations of eye-gaze and arrows, induce validity effects even at SOAs as short as 100 ms. Similar results have been reported when using small numbers (1 or 2) as cues indicating the impending target in the left and bigger numbers (8 or 9) indicating the impending target in the right (Fisher *et al.*, 2003). One well accepted interpretation of these effects is that some symbols are repeatedly associated with a spatial location throughout an individual's life rendering, after a long repetitive training, an automatic orienting of attention particularly for overlearned spatial symbols (Fisher *et al.*, 2003; Dodd & Wilson, 2009). In addition, Ristic & Kingstone (2012) suggest that there would be a third form of orienting of attention that would be neither exogenous nor endogenous, but would be an "involuntary attentional response that became automated after repeated exposure to environmental contingencies" (p. 256). In these cases, instead of "automatic" orienting, the term "automatized" orienting of attention will be used, in order to distinguish this kind of endogenous (automatized) orienting from exogenous, automatic orienting, thus emphasizing the learned nature of these associations by repetitive training.

In this context, it seems reasonable to speculate about what would be the amount of training for an initially directionally neutral symbolic cue to induce endogenous automatic orienting of attention when repeatedly associated with a spatial location. Dodd & Wilson (2009) and Guzzon *et al.* (2010) explored this question by associating initially neutral cues, e.g., textures and colors, respectively, with a location in space. Before and after the training they tested performance of subjects on a cueing task using the same trained stimuli as cues. For Guzzon *et al.* (2010) study the training sessions consisted of 160 trials in each day, 5 consecutive days per week, along 3 weeks. They used a predictive task (80% of valid trials) condition with four different SOAs (50, 100, 150 and 200 ms) for pre and post-test. It is important to note that the pre-test consisted of 552 trials which could already be accounted as training for cue-target association. A small validity effect was observed at the SOA of 200 ms for the pre-test. In contrast, for the post-test, larger validity effects were present not only

at the SOA of 200 ms, but also at a smaller SOA of 150 ms which did not show validity effect for pre-test. These results show that training improved the ability to orient attention by texture cues with no initial directional meaning. Furthermore, Dodd & Wilson (2009) showed results from an elegant study where pre and post-tests used non-predictive cues instead of predictive cues which eliminate the interference of a possible training from pre-test session. The training session consisted of 800 trials in one experiment and 1200 trial in another, where two colour cues were associated with a target location in 100% of trials. They observed that, after training with 800 trials, even with a non-predictive condition there was a small but significant validity effect at 100, 500 and 800 ms SOAs. After 1200 trials at training session, the validity effect at the same SOAs were larger than the ones observed with 800 training trials.. Together, these results indicate that repeated associations of initial non-directional symbolic cues and spatial locations can induce attentional effects similar to exogenous orienting with validity effect at short SOA (100 ms) for non-predictive cues, but also similar to endogenous orienting with no IOR at long SOA (800 ms).

Olk *et al.* (2014) investigated the occurrence of validity effects by using different types of symbolic cues including arrows, numbers and colors, with, respectively, strong, intermediate and weak spatial biases according to cultural contingencies. For instance, while arrows are culturally directional, therefore should produce automatized orienting of attention towards the indicated location, colors are not thus depending on the associations built along task performance. There were two conditions using numbers as cues. In the first condition the numbers 1 and 2 were used as symbolic cues to directed attention to left and right, respectively. Thus, the left location was associated with a smaller number and the right location was associated with the bigger number. In the second condition, the numbers 9 and 3 were used to directed attention to the left and right, respectively. Thus, the left location was associated with the number 9 and the right location with the number 3, because these are their locations in a clock watch. These cues were presented at SOAs of 100, 450 and 800 ms from the target. Even though all cues produced validity effects at all SOAs, larger cueing effects on reaction times and accuracy were observed when using arrow cues in comparison to numbers and colors. However, there was a slower and worse performance when using the numbers 9 and 3, as compared to colors and numbers 1 and 2. Another hypothesis they investigated was if there was a correlation with the size of cueing effects and speed of direction judgement for each type of cue. No correlations were found indicating that a fast speed to decode the direction of a cue is not associated with a larger cueing effect. Therefore, the reflexive-like orienting effects observed for overlearned spatial cues like arrows would not be related to the efficiency of processing the cue itself.

In addition to these findings interesting studies presented a different approach to the issue involving a voluntary aspect of endogenous orienting of attention using symbolic cues. In order to evaluate the involvement of volition in endogenous orienting of attention, Taylor *et al.* (2008) instructed subjects to choose where to attend, in addition to submitting them to a classical cueing task. The authors then analyzed fMRI data to compare brain activity when the subjects had to choose where to attend to after a given cue and when they attended following symbolic orienting (instructional) cues. The results revealed distinct underlying networks in free choice orienting of attention as compared to instructional orienting. While free choice orienting of attention involved medial frontal areas including pre-supplementary eye field (pre-SEF) and anterior cingulate cortex (ACC), orienting of attention by instructional cues activated dorsal fronto-parietal areas including the frontal eye field (FEF). Bengson *et al.* (2015) investigated brain activity by using combined EEG and fMRI in order to compare brain activity during choice and instructional cues in a cueing task. Similarly to Taylor *et al.* (2008), they observed activation of the ACC and SEF associated with choice cues but indicating a unique activation of regions only for choice cues compared to instructional cues which comprises the middle frontal gyrus (MFG), anterior cingulate (ACC) and anterior insula (AI). Apparently, a cognitive function related to AI activity would involve categorization of cue as endogenously relevant so a decisional process could occur for execution of deployment of attention related to the dorsal attentional system. Further, MFG appears to be involved with working memory, and its activity is related to decision-making tasks and conflict detection, which seems to agree with the need to choose between sides. The EEG results revealed two components related to what the authors called willed attentional control which they point out are components that reflect a group of cognitive operations involved with this type of control including stimulus categorization, conflict perception and willful decision-making. Results from these studies indicate that distinct neural networks are activated when different cognitive processes are required in order to orient attention endogenously. They also suggest that volitional (or willed) orienting of attention can be distinguished from a voluntary/instructed orienting of attention by symbolic cues. However, this distinction is not clear from behavioral results. Only Taylor *et al.* (2008) showed a difference of reaction time and accuracy between type of cues with choice cue related to a poorer performance when compared to instructional cues. Bengson *et al.* (2015) did not revealed any behavioral difference between the types of cues. Therefore it would be interesting to know if a behavioral distinction could be observed when using an appropriate task design to evaluate the time course of processes involved on each type of cue.

On considering the results of the studies reported above it seems unavoidable to think about how knowledge concerning endogenous orienting of attention was built relying mainly in a task that requires many trials and in which a symbolic cue and the relevant target are presented repetitively. In a classical cueing task with a predictive condition a cue is informative about the impending target location meaning that its presentation (and symbolic meaning) in valid trials is followed by presentation of the target at a single location as indicated repetitively by the cue. That is, there is a relevant relationship between cue and target that is repeatedly strengthened by associations along the task. Therefore, overlearned or over trained associations involving symbolic cue and target location could result in automatized orienting of attention, then rendering possible that orienting effects observed in a classical cueing task are actually related to endogenous automatic processes resulting from repeatedly cue-target associations than to actual voluntary (or volitional) processes. It is still unclear whether and how voluntary and automatized processes are involved in endogenous orienting of attention. For instance, what would be the effects of orienting of attention if facilitation from cue-target associations is avoided? What are the cognitive processes underlying voluntary control of orienting of attention? If choice cue involves distinct neural networks as compared to instructional cues, then there would be a temporal difference related to the processes involved in decision-making relative to where to attend to in each trial?

1.3. Neural mechanisms involved in orienting of attention

Behavioral studies have revealed basic principles of processes related to visual attention. Even though behavioral measures provide relevant information to understand the organization of perceptual and cognitive processes such as visual attention, experimental approaches to the underlying neural mechanisms involved in those processes are of great interest to give additional understanding to how the nervous system deals with visual information. Neuroimaging and neurophysiological studies have also investigated processes of attentional control and showed neural correlates for reflexive and voluntary processes of orienting of attention (Corbetta & Shulman, 2002; Mangun, 1995; Posner & Petersen, 2012). Functional magnetic resonance imaging (fMRI) studies have shown the participation of distinct neural networks for voluntary (or top-down) and automatic (or stimulus-driven) control of attention (Corbetta *et al.*, 2000). Corbetta & Shulman (2002), in a review of the literature in this area, concluded that a dorsal frontoparietal network including the frontal eye fields (FEF) and the intraparietal sulcus exhibit sustained activity after an arrow cue indicates that

attention should be oriented towards a relevant location for detection of an impending target. This sustained activity in anticipation to the impending target indicates that this network participates in voluntary orienting of attention, although it was elicited by arrow cues thus possibly involving an automatized process. In contrast, a ventral frontoparietal network seems to be more related to a reflexive orienting of attention. The temporoparietal junction (TPJ) cortex and the ventral frontal cortex (VFC) are activated when orienting occurs towards an unexpected sensory event, outside the location of preferential processing, and without a preparatory cue.

However, despite this distinction of networks for control of attention, there seems to be a general agreement that there is a relevant, but still unclear, interaction between them when orienting attention towards sensory stimuli. It seems that a highly predictive symbolic cue (100% valid), which is considered to involve a voluntary process, greatly influence the sensory salience of stimuli at a point of extinguishing the effect of abrupt onset, considered to trigger a reflexive orienting process, on performance of target detection (Yantis & Jonides, 1990; Folk *et al.*, 1992). These results indicate that a reflexive orienting process related to abrupt-onsets can be influenced by the subject's attentional control. If reflexive orienting is characterized by an insensitivity to concurrent perceptual load and not subject to voluntary control, then these results put into question what are the conditions for a purely a reflexive or exogenous orienting of attention to occur. Posner (2016) argue that distinct but interacting brain systems for voluntary and reflexive control of orienting of attention allows investigation of the neural basis for volition.

Attention and working memory seem closely related processes since they both can induce top-down biases in visual cortex in the absence of sensory stimuli (Kastner & Ungerleider, 2000). Furthermore, in spatial cueing tasks, after a cue is presented, the information about the spatial location about where to attend to needs to be maintained in working memory for the task to be performed properly. Neuroimaging evidence indicates that distinctive areas in the frontal cortex are activated when the subject is performing a working memory task for objects relative to spatial location (Smith & Jonides, 1999). The superior frontal sulcus exhibits activation during performance of a spatial working memory task (Courtney *et al.*, 1998). This area is close to those activated in visuospatial attention tasks, like the FEF and the SEF. Kastner & Ungerleider (2000) reported extensive activations of the FEF and the SEF during performance of visuospatial attention tasks which could mean that areas actually involved in spatial working memory would not be distinct from those involved with attention, and thus activity related to attention and working memory would derive from partially overlapping areas in the frontal cortex.

In the late 1960s, electroencephalography (EEG) began to be used to provide measures of human brain activity that could be related to behavioral performance, for the study of perception and cognition. Numerous physiological studies of selective attention have been done in the past 40 years using this approach, especially in visual-spatial attention, revealing complex time course of neural activity related to voluntary (Van Voorhis & Hillyard, 1977; Mangun & Hillyard, 1991; Eimer, 1994; Mangun, 1995) and automatic (Hopfinger & Mangun, 1998) attentional orienting. The high temporal resolution of EEG allows recording of brain activity “millisecond-by-millisecond”, and signal processing of the EEG to extract event-related potentials (ERP) to specific stimulus/task categories, thus providing a powerful tool for studying the dynamic brain processes involved in perception and cognition in humans (Eimer, 2014; Luck, 2014).

ERP studies of visual selective attention revealed that when a target stimulus was presented at attended location (compared to when presented in unattended location) it evokes an increased amplitude in a series of visual ERPs recorded from electrodes on the scalp. This includes a positive component (P1) after approximately 80 ms of the target onset, followed by modulation of a negative component (N1) at about 120 ms after target, as well as additional longer-latency components (Van Voorhis & Hillyard, 1977; Mangun & Hillyard, 1987; Mangun & Hillyard, 1991; Eimer, 1994; Mangun, 1995). Because the earliest of these ERPs are sensory-evoked responses, their amplitude modulation by attention is considered to reflect the activation of sensory gain control mechanisms during orienting of attention towards likely target locations, which results in enhanced processing of the attended events and improved behavioral performance (Mangun, 1995; Eimer, 2014).

ERPs studies have also investigated the mechanisms and time course of engagement of brain systems involved in the top-down voluntary orienting of attention; the so-called “attentional control mechanisms”. In such studies, ERPs are recorded after the presentation of a symbolic cue but before the onset of the subsequent target stimulus (i.e., during the cue-to-target period). ERP components recorded from scalp sites contralateral to the location of the attentional shift were consistently observed in different experiments (Harter *et al.*, 1989; Nobre *et al.*, 2000; Hopf & Mangun, 2000). An early negative component, named Early Directing Attention Negativity (EDAN), was observed at posterior electrodes around 200 ms after cue onset (Harter *et al.*, 1989). It is hypothesized that this component would reflect initiation of voluntary shifts of visual attention (Hopf & Mangun, 2000). However, this relation has been challenged by the idea that this component could be a lateralized sensory response to an asymmetrical cue, like an arrow (Van Velzen & Eimer, 2003). Together, late ERPs components observed after cue onset were also related to covert

attentional control. A negative deflection, known as Anterior Directing Attention Negativity (ADAN), observed at anterior electrodes around 300 ms after cue onset, has been related to activation of frontal control processes involved in initiating shifts of attention (Nobre *et al.*, 2000). Finally, at occipital scalp electrodes, late positivity, named Late Directing Attention Positivity (LDAP), appears around 500 ms post-cue. The LDAP component is regarded as signs of preparatory activity in visual cortex (under top-down control) that will be involved in processing the visual targets, thus leading to attention-related enhancements of the upcoming target stimuli (Harter *et al.*, 1989; Hopf & Mangun, 2000).

Other studies have shown distinct ERPs when investigating voluntary orienting of attention. For instance, Woodman *et al.* (2009) did not find EDAN, ADAN or LDAP components after cue presentation. However, they used a visual search array with the cued target among distractors different from studies mentioned above. They found a lateralized negativity 200 ms before target presentation which was interpreted as a N2pc-like (N2-posterior-contralateral) component because of its latency range and scalp distribution. This N2pc-like component would be related to an anticipatory selection of target and suppression of distractors. Also, they argue that this contralateral negativity could have masked the LDAP component (contralateral positivity) due to the same distribution that they have.

Brignani *et al.* (2009) investigated eventual differences in ERP components when endogenous orienting of attention was triggered by different types of cues. They used overlearned symbolic cues like arrows and eye-gaze figures, and a neutral symbolic cue like textures to cue a target location. They aimed at investigating the topography and amplitude of components like P1, N1, P2 (a positive component at around 200 ms after stimulus presentation), and P3 (a positive component at around 300 ms), and also the EDAN component. In short, results showed differences in latency of P3, which is related to discrimination, categorization and decision making processes, between cues with a longer latency for texture cues indicating that it required more cognitive resources for its processing than the other cues. Results related to EDAN seem to corroborate the hypothesis that this component is more involved with relevant features of cue stimulus rather than attentional orienting as mentioned above.

It is possible that distinct ERP results related to endogenous orienting of attention are due to the difficulty in comparing ERP components. Signal-averaging procedures used to isolate ERP components from EEG signal is a consistent way to observe a typified waveform related to an event. However, components mentioned here are considered small meaning that it is required a large number of trials (100 to 500) to observe reliable differences between groups or conditions (Luck, 2014). Furthermore, even though the paradigm used is very

similar, slight task feature modifications like cues, targets or temporal course could affect observed ERP components. Even so, the combination of behavioral and electrophysiological studies seems to bring advantages when investigating control of orienting of attention and underlying neural mechanisms, especially because of the millisecond-temporal resolution of EEG recordings. This allows comparison of fast cognitive processes like automatic and voluntary processes involved in orienting of attention.

2. Objective

The main purpose of this study was to investigate if there are distinctions between voluntary and automatized processes involved in endogenous orienting of attention. Three experiments were conducted in order to investigate the orienting of attention time course when involving a “truly voluntary” process in comparison to an automatized process.

The first experiment, involving a variant of the classical cueing task, was an attempt to avoid repetitive association between the symbolic cue and target location, using SOAs at 150, 300, 700 and 1000 ms, and thus evaluate endogenous orienting of attention when an automatized process of orienting of attention is avoided.

In the second experiment, a behavioral and electrophysiological study involving ERP components was conducted in order to investigate the neural mechanisms underlying a voluntary process of attentional control by using a variant of the classical cueing task that consisted of changing the symbolic cue in a trial-by-trial basis. This way it was expected that orienting attention by a novel cue on each trial could render behavioral and electrophysiological effects related to a more voluntary process.

The specific goals were (1) to investigate the temporal course of behavioral effects when orienting of attention is triggered by automatized or voluntary processes, and (2) investigate if classical ERPs components correlate with a truly voluntary endogenous orienting of attention.

The third experiment involved a temporal order judgement task combined with spatial cueing to investigate stimulus order perception when attention is oriented to a location by different types of cues including arrows, symbolic cues associated with a spatial location, and a choice cue that requires that the subject freely choose where to attend, that would involve automatized, or voluntary, or volitional orienting processes.

7. Conclusion and perspectives

The studies reported here investigated the involvement of voluntary and automatic control processes on endogenous orienting of attention. For this, temporal courses of what is considered to involve voluntary and automatic orienting of attention were explored behaviorally and electrophysiologically. The studies used variants of the classical cueing task in order to avoid the repetitive associations between presentation of symbolic cue and presentation of target at the cued location. Also, the speed of visual processing was explored when attention was shifted by different types of cues that would require distinct attentional control processes.

Results showed that inserting a relevant stimulus between cue and target presentation, thus avoiding cue-target associations, disrupted orienting of attention by extinguishing validity effect at 150 ms SOA. Also, other results showed that when cues are established in a trial-by-trial manner by a rule, in order to avoid repetitive cue-target associations, discrimination of target is decreased when attention is oriented by a cue that is conflicting with the rule. However, despite the interference, validity effect was observed at 250 ms SOA. Furthermore, the temporal courses for orienting of attention when using shape cues or choice cue are similar, and can occur at 200 ms SOA. Therefore, results demonstrate that endogenous orienting of attention can occur with a time interval as short as 200 ms even when implicit learning of cue-target associations are disrupted and more attentional resources are required.

Studies indicated that endogenous orienting of attention can occur in short time intervals even with high processing demands such as when direction of attention is guided by conflicting cues and choice cue. However, even though these high processing demands do not limit the temporal course of orienting of attention they do interfere with it causing a poor detection of target. Therefore, it seems that control of orienting of attention can be fast even when involving complex processing because of strategies based on repetitive experiences that would assist performance on cueing tasks.

The theoretical framework proposed here try to comprehend the results based on the idea that implicit and explicit learning mechanisms would form and reinforce representations of the association between cues and direction of attention. For that to occur it would require the function of working memory components such as the central executive and the episodic buffer which allow an interface with LTM. Therefore, voluntary and automatic control processes of endogenous orienting of attention are related with the strength of the

representations of cue-direction of attention that determine the performance of the cueing task.

Further studies could be conducted in order to elucidate and explore the ideas presented here:

- Investigate whether endogenous orienting of attention at 100 ms or 150 ms SOA would be disrupted completely for tasks like the ones presented in Chapter II and Chapter III
- Track the effects of orienting attention by blocks of trials for different types of cues to observe if the amount of trials would influence differently when orienting processes are controlled by stronger or weaker representations
- Volitional control of attention could be better explored by using choice cue when controlling for the influence of previous trials
- Investigate the effects of high working memory load on orienting of attention after training for acquiring stronger representations
- Vocal rehearsal could be used to understand how the phonological loop could interfere with strengthening of representation in a cueing task
- Understand how imagery training compared to visual training would influence performance in a cueing task

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