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Inhibition of Return and the Hemifield Asymmetry Prediction

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**DANKE!**



Hier mein Geheimnis. Es ist ganz einfach: Man sieht nur mit dem Herzen gut. Das

Wesentliche ist für die Augen unsichtbar.

*Antoine de Saint-Exupéry, Der Kleine Prinz.*



## **Zusammenfassung**

Die aktuelle Untersuchung befasst sich mit dem Gebiet der visuellen Verarbeitung. Das Hauptaugenmerk liegt auf dem mittlerweile klassischen Phänomen der Hemmung der Rückkehr (engl.: inhibition of return IOR). IOR beschreibt die Tatsache, dass visuelle Zielreize, die auf gleicher Position gezeigt werden wie zuvor ein Hinweisreiz, bei einem Zeitintervall (engl.: stimulus onset asynchrony, SOA) von mehr als 300ms, zu längeren Reaktionszeiten führen als es bei Zielreizen der Fall ist, die auf einer anderen Position gezeigt werden. Nachdem eine aktuelle Debatte darüber besteht, ob IOR automatisch auf exogene Aufmerksamkeitserfassung folgt, wurde dies in der vorliegenden Untersuchung überprüft. Es hat sich gezeigt, dass IOR und exogene Aufmerksamkeitserfassung nicht selbstverständlich als zwei Seiten einer Medaille betrachtet werden sollten.

Des Weiteren wurde aufgrund bekannter Asymmetrien in den nasalen und temporalen Halbfeldern des Gehirns angenommen, dass der IOR - Effekt für temporal präsentierte Hinweisreize unter monokularen Bedingungen stärker sein sollte, als für Hinweisreize, die im nasalen Halbfeld präsentiert wurden. Dies konnte in der aktuellen Untersuchung nicht bestätigt werden.

**Schlüsselwörter:** selektive visuelle Aufmerksamkeit, Cueing Paradigma, Aufmerksamkeitserfassung, Rückkehrhemmung, nasal-temporale Halbfeldasymmetrie.





## **Abstract**

The present study addresses the subject of visual processing. The focus is laid on the nowadays classic phenomenon of inhibition of return (IOR). IOR describes the fact that visual stimuli presented at a previously cued location take longer to be detected than visual stimuli on a different position, after a stimulus onset asynchrony (SOA) of more than 300ms. As there is a present debate whether IOR automatically follows exogenous capture of attention, this matter was further investigated in the present study, concluding that IOR should not be considered a hallmark of exogenous capture by unconscious cues.

Furthermore based on known asymmetries in the nasal and temporal hemifields of the brain it was assumed that, under monocular conditions, IOR for temporally presented cues should be stronger, than IOR for nasally presented cues; this could not be confirmed in the present study.

**Keywords:** selective visual attention, cueing paradigm, attentional capture, inhibition of return, nasal-temporal hemifield asymmetry



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## **1. Introduction**

Our daily life consists of actions we take based largely on visual information given by our environment. Hence vision could probably be considered our most important modality as every action we take is a reaction to what we see. We process this information constantly, mostly without even realizing, although the amount of visual information presented by our visual environment is by far greater than we can actually process. Consequently automatic information processing helps us to separate relevant information in our environment from irrelevant distractors. Therefore we are able to focus on particular things, while looking for them. It could for example be a certain fruit in the supermarket, the familiar face of a friend waiting at the railway station or the missing keys on the living room table. To perform a successful search it is for example important to be able to let one's gaze wander around the surroundings instead of constantly staring at the same place. By continuously staring at the same place, how would we be able to find what we are looking for? This scenario almost implies the necessity of a mechanism helping us to process what our rich visual environment offers and to conduct visual search behavior. One could consider inhibition of return (IOR) as a hereby advantageous effect. This inhibitory effect following a shift of attention away from a cued area, leads to a less efficient processing of the target than at another – not cued – location (Posner & Cohen, 1984).

In the following IOR will be further examined with the aid of a search paradigm adapted from Mulckhuyse, Talsma and Theeuwes (2007).

### **1.1 Attention processes**

In order to be able to decide which of the available objects is to be selected, attention is required to carry out this selection process.

According to M. Carrasco: “Attention allows us to selectively process the vast amount of information, with which we are confronted, prioritizing some aspects of information while ignoring others by focusing on a certain location or aspect of the visual scene.” (Carrasco, 2011, p. 1484). Therefore attention can be considered the foundation of visual search as we perform it daily, helping to select relevant information without deliberate effort.

But to understand how we precisely select what we are looking for, the focus will be laid on selective attention, which generally refers to the set of operations that determine which of several possible inputs will be analyzed (Behrmann & Haimson, 1999). In the context of

visual search, selective visual attention is described as the ability to select information that is relevant for a response from other competing information, in a visual scene (Kahneman & Treisman, 1984).

A summarized definition would be: “Visual attention is the selection mechanism by which some visual events are prioritized, whereas others are excluded from processing” (Theeuwes, Olivers & Belopolsky, 2010, p. 872).

As previously mentioned, we only process a small amount of all the information offered by the surroundings, which determines our further interaction with the environment. Meaning that of all present information, relevant information has to be selected constantly to ensure efficient and undisturbed acting. Classical paradigms of selective attention trying to explain its working mechanisms were conducted in the field of auditive selective attention, including Cherry’s (1953) paradigm of dichotic listening, Broadbent’s (1954) split-span paradigm, Treisman’s attenuation theory (1964), as well as Deutsch and Deutsch’s (1963) theory of late selection, the latter three are schematically depicted in Figure 1.

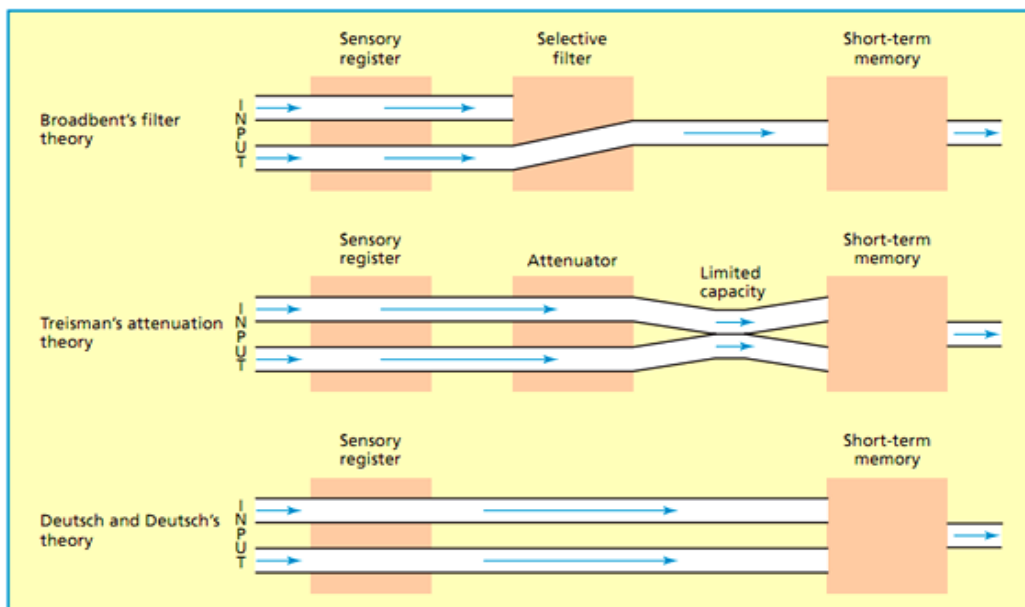


Figure 1. Schematic comparison of classic filter theories (<https://wiki.ucl.ac.uk>, 24.02.2012), showing the different bottlenecks of information processing proposed by three different models.

In summary C. Cherry analyzed the “cocktail party” effect, where the ability to follow a conversation in a room full of talking people, was examined, with the result, that physical differences (e.g. speaker location, voice intensity, sex of the speaker) were necessary to

maintain attention to a chosen message, while unattended information receives no processing. D. Broadbent's studies resulted in similar findings, as physical characteristics of stimuli are crucial for whether or not the stimuli were allowed to pass a filter, or remain in a buffer for later processing, after two stimuli were presented at the same time. This filter is supposed to prevent overloading the limited capacity mechanism beyond it. Furthermore Treisman found that sometimes a word that was presented on the unattended channel has a "breakthrough". Questioning Broadbent's theory of early processing, she proposed the idea of the filter reducing or attenuating the analysis of unattended stimuli, arguing for a more flexible location of the bottleneck as Broadbent had claimed, whereas Deutsch and Deutsch (1964) proposed a full analysis of all stimuli before processing, with the most important information determining the response (for an overview see Müller & Krummenacher, 2007 or Eysenck & Keane, 2005). The focus on selective visual attention was laid later, with research aiming to describe object-based vs. space-based attentional selection, as for example in Posner's cueing paradigm (see chapter 3) and Erikson and Erikson's flanker task (see chapter 1.5).

Visual attention is examined by means of visual search tasks, which typically are laboratory-based, displaying a number of discrete and separated items. Subjects are asked to search for pre-defined targets among a varying number of non-target distractors. The reaction time (RT) is measured to indicate the presence or absence of the target (Findlay & Gilchrist, 2003).

## **1.2 Object-based vs. space-based attentional selection**

Models of attentional visual selection can be divided into space-based and object-based models: whereby space-based models focus on how spatial properties, as the location or proximity of stimuli, can affect the selection process, whereas object-based models emphasize how objects and groups affect selection (Macquistan, 1997).

In order to describe how space limits the distribution of attention metaphors such as "spotlight", "zoom lens" or "gradient", are often used (Lamy & Tsal, 2000).

Evidence for spatial attention mostly comes from spatial cueing studies (Soto & Blanco, 2004), such as described in chapter 3.

Posner's cueing paradigm causes a proband to direct attention to a certain location while ignoring other positions. A second example for space-based attentional selection would be Erikson and Erikson's flanker task (1974), which was conducted in order to determine how

a human subject selects one out of a number of equally potent visual stimuli for his/ her response. For this purpose circular displays of letters with targets appearing at a known location (indicated by a black bar cue) were used. Those displays were of three kinds:

- compatible displays where the target letter was flanked by letters identical to the target or another letter with the same response assignment
- incompatible displays with the target letter flanked by letters of the opposite response assignment
- neutral displays showing distractor letters that shared feature similarity

Results showed increasing reaction times (RTs), when targets were flanked by distractors of another target class (Erikson, 1995). Major findings signify that attentional selectivity is not able to eliminate effects of extraneous stimuli completely, meaning that visual selection is not able to infinite selection based on limited capacity of simultaneous processing. Consequently it is necessary to decide which information is processed or inhibited, leading to higher reaction times as this selection process needs time. Easy spatial discrimination of targets leads to faster reaction times (Erikson & Erikson, 1974). Spatial attention is oriented endogenously to task relevant stimuli or can be exogenously captured by salient stimuli (Chica, Bartolomeo & Lupiáñez, 2013). Summarized typical findings in studies addressing spatial attention show that responses are faster and more accurate when stimuli are presented at cued locations, in comparison with uncued locations (Soto & Blanco, 2004).

Proof for object-based information is the consistent finding that invalidly cued targets are responded to faster, when they appear in the same object as the cue rather than in an uncued object, equally distant from the cued location (Shomstein & Yantis, 2002) (e.g. Brown, Breitmeyer, Leighty & Denney, 2006; Soto & Blanco, 2004; Lamy & Tsal, 2000; for an overview of experimental studies). Major findings state that attention can be split among multiple moving objects which do not occupy a connected region of space. Furthermore cueing effects can be modulated by object-based factors and the extent of response-competition can be influenced by the grouping of targets and distractors, overriding the effects of the distance between stimuli under certain conditions (Soto & Blanco, 2004).

Although object-based and space-based attention, are two individual modes, they can cooperate to influence the allocation of attention (Logan, 1996). Marotta, Lupiáñez, Martella and Casagrande (2012) in turn argue that the mode of attention is influenced by the present cue: “attention is nonspecifically directed to nearby objects when a noninformative arrow is



used as a cue, whereas it is selectively directed to a specific cued location when noninformative eye gaze is used”.

### **1.3 Overt and covert shifts of attention**

In order to further understand how relevant information is selected from our environment it seems necessary to describe the process with which we pay attention. During the inspection of a visual scene, periods of fixation are interrupted by fast ballistic movements of the eyes, called saccades. Via these goal-directed eye movements the fovea is brought to “interesting spots” of the visual scene. Foveation is considered the basic function of saccades, as adequate object recognition requires foveal representation of the to-be-recognized object (Deubel & Schneider, 1995). According to Findlay and Gilchrist (2003) covert attention is the ability to pay attention to part of the visual array without moving the eyes. The ability to saccade and foveate part of the visual array is known as overt attention and is conducted without any effort. Thus shifts of visual attention can occur without eye movement, improving the sensitivity to areas outside the fovea. Attention shifts precede the eye movement and are a method of selecting areas of the visual field, which will be foveated next (Posner & Driver, 1992).

While covert attention can be deployed to more than one location simultaneously (“parallel”) eye movements are sequential (“serial”) and can – at a given time – only be directed to one location. The general opinion indicates that covert attention precedes eye movements and although the effects of covert and overt attention on perception are often similar, this is not always the case. In everyday situations covert attention is routinely executed, for instance when searching for objects or crossing a street. It enables monitoring the environment and guides eye movements (overt shifts of attention) to salient and/or relevant information in the visual environment (Carrasco, 2011).

Hunt and Kingstone (2003a) answered the question of whether both eyes and attention are attracted to salient external stimuli because the two forms of orienting are linked by a common neural architecture or due to the fact that they are each – independently – activated by abrupt onsets. Findings predicate that attention and eye movements are independent whether they are activated reflexively or volitionally. According to Beauchamp, Petit, Ellmore, Ingeholm and Haxby (2001) it has been demonstrated that a cortical network of visuospatial and oculomotor control areas is active in both, overt and covert shifts of spatial

attention. Whereupon more neural activation can be observed during overt shifts of attention than during covert shifts of attention, which is considered as the additional activity associated with saccade execution.

#### **1.4 Conscious vs. unconscious perception of cues**

The identification of objects and their relation to the spatial environment are conducted either by rapid saccadic eye movements or by covert shifts of attention with limited processing capacity. Which input is preferentially processed is decided by shifting the processing focus from one location to another in a serial fashion. Only a small fraction of present visual stimuli reaches the level of processing that influences human behavior (Itti & Koch, 2000).

Not all visual stimuli are processed in a way we are aware of, unconscious processing is the alternative. According to Merikle and Cheesman (1987) subliminal perception can be easily demonstrated and is a valid phenomenon, if perceptual awareness is measured in terms of subjective criteria. The term “unconscious” is used for inputs that do not reach awareness, even when attended to (Lamme, 2003). Nevertheless fully masked, hence unconscious stimuli can still influence perceptual and behavioral processes (van Gaal & Lamme, 2012). Unconscious perceptual processes redescribe sensory data into every representational form and to the highest level of description that is available to the organism, providing records of each resultant representation and activating relevant structures. Conscious perception however requires a constructive act matching perceptual hypotheses against information gained from records, structuring and synthesizing that information recorded from different domains (Marcel, 1983).

The discussed distinction between conscious and unconscious experiences is captured by a subjectively-defined awareness threshold, providing a basis for establishing qualitative differences that distinguish conscious from unconscious perceptual processes. Therefore based on a distinction between subjective (*subjective threshold*: level of discriminative responding at which observers claim not to detect or recognize perceptual information on a better than chance level of performance) and objective (*objective threshold*: level of discriminative responding corresponding to chance level of performance) recognition thresholds, a boundary between conscious and unconscious perceptual processes should be defined, in terms of subjective thresholds (Cheesman & Merikle, 1986).

Imperceptible high-frequency chromatic flicker stimulation is used to investigate subliminal visual processes, as human perception of chromatic flicker is known to be limited. Two equiluminant colors alternating at frequencies of 25 Hz or higher can only be perceived as one fused color (Lu, Cai, Shen, Zhou & Han, 2012). The critical flicker frequency of a visual stimulus is, according to Miller, Anderson and Simonson (1965), the rate of delivery of a train of photic pulses above which the brightness of the target is steady and below which it is undulatory, hence flicker occurs. A subliminal frequency-specific flicker cue (at 50 Hz) causes faster reaction times and increased sensitivity to targets presented to previously cued locations (Bauer, Cheadle, Parton, Müller & Usher, 2009).

Conscious and unconscious processing modes are highly interdependent with influences in both directions. Nowadays technology provides the possibility to control the presentation of visual stimuli precisely. The focus of research lies on the influence of unconsciously perceived stimuli on information processing (Kiefer et al., 2011). It is currently debated how the brain's visual system causes subliminal vision and subliminal attention. A possible explanation is that the processing along the visual system's parvocellular projection, from the retina to the cortex, is reflected by forms of unconscious vision. Alternatively a partly contrast-elicited attentional capture reflection of subliminal attention, mediated by midbrain structures (e.g. the superior colliculus, SC) is under discussion (Fuchs & Ansorge, 2012a).

Stimulus properties that could in principle capture attention can be distinguished in stimuli that differ substantially, in one or more simple visual attributes, such as color, orientation or motion, from their backgrounds named (feature) singletons and abrupt visual onsets. It was shown, that peripheral cues draw attention whether they are informative about the location of a target or not, whereas central cues only influence the deployment of attention when they are informative of a targets location, which might be caused by their abrupt onsets (Egeth & Yantis, 1997).

Abrupt visual onsets capture visual attention, resulting in a processing advantage over items lacking an abrupt onset (Jantis & Yonides, 1984). Furthermore a peripheral cue produces two effects upon the information processing system. Firstly it summons a movement of attention which enhances efficiency in the processing of information at a targets' location and secondly it causes a temporary inhibition (Posner, Cohen, & Rafal, 1982). Even if a peripheral cue is not consciously perceived, the classic biphasic effect of facilitation followed

by inhibition is clearly observed (Mulckhuysen, et al., 2007). McCormick (1997) found that the attention of an observer can be directed without subjective awareness of the attention-capturing stimulus. Support for the assumption that exogenous orienting is an automatic process, not requiring conscious awareness, whereas endogenous orienting is a controlled and strategic process, was found.

A response to a centrally located cue would be allocated by endogenous attention whereas visual stimuli with an abrupt onset capture attention exogenously (McCormick, 1997). According to Fuchs, Theeuwes and Ansorge (2012) there is an ongoing debate as to whether unconscious or subliminal stimuli attract attention in a purely exogenous and automatic way or if they are perceived in a top-down contingent or conditionally automatic way. Several studies have shown that a subliminal cue influences the distribution of spatial attention depending on the task relevance of the cue (Lu, et al., 2012).

Although it seems contradictory that abrupt onset cues that are not perceived can capture attention studies indicate that exogenous spatial attention can be dissociated from consciousness. It is supposed that attentional engagement to subliminal spatial cues is dissolving more rapidly than attentional engagement to supraliminal spatial cues (Mulckhuysen & Theeuwes, 2010b). Simons and Chabris (1999) state on the matter, that only objects and details that receive focused attention are perceived and remembered, as we often do not detect large changes in scenes and objects (“change blindness”) or without attention we may not even perceive objects (“inattentive blindness”).

### **1.5 Bottom up vs. top down processing of attention**

Several theorists have stated that there are two major attentional systems responsible for processing the visual information that we constantly receive. Thereby one attentional system has been described as voluntary, endogenous or goal-directed (top-down) whereas the other system is considered to be involuntary, exogenous, or stimulus-driven (bottom-up) (Eysenck & Keane, 2005). Growing evidence supports the distinction between exogenous and endogenous orienting, such as the evidence for corresponding differences between shifts generated by peripherally presented cues, which are typically exogenous, versus centrally presented cues that are known to be endogenous (Folk, Remington & Johnston, 1992).

Imagine you arranged to meet a friend at the subway platform before going to the movies together. It is rush hour and you are looking around desperately for a sign of her

among all those strangers. What do you know about her? That she is blond! So you would automatically focus your attention on the stimuli blond and female, fading out everything else to avoid distraction (brunettes, redheads, caps, hats, baldes, etc) in order to discover your friend. This would be an example for an endogenous, goal-directed search. If there would suddenly emerge two ticket inspectors you would involuntarily recognize them, even though you actually, concentrate on searching your friend. Those ticket inspectors now somehow got your attention, probably without even being blond or female and you start looking for your ticket. Hence those unexpected, abrupt appearing ticket inspectors captured your attention exogenously or stimulus-driven, which is the second possibility for a stimulus to find its way to your awareness. So there are two ways to reach visual awareness, the first would be the fast bottom-up mechanism that selects stimuli based on their saliency. The second mechanism is the slower top-down mechanism, which directs the “spotlight of attention” under cognitive, volitional control (Itti & Koch, 2000). The following Figure 2 shows the functional components of attention whereat the focus should be laid on bottom-up and top-down processing.

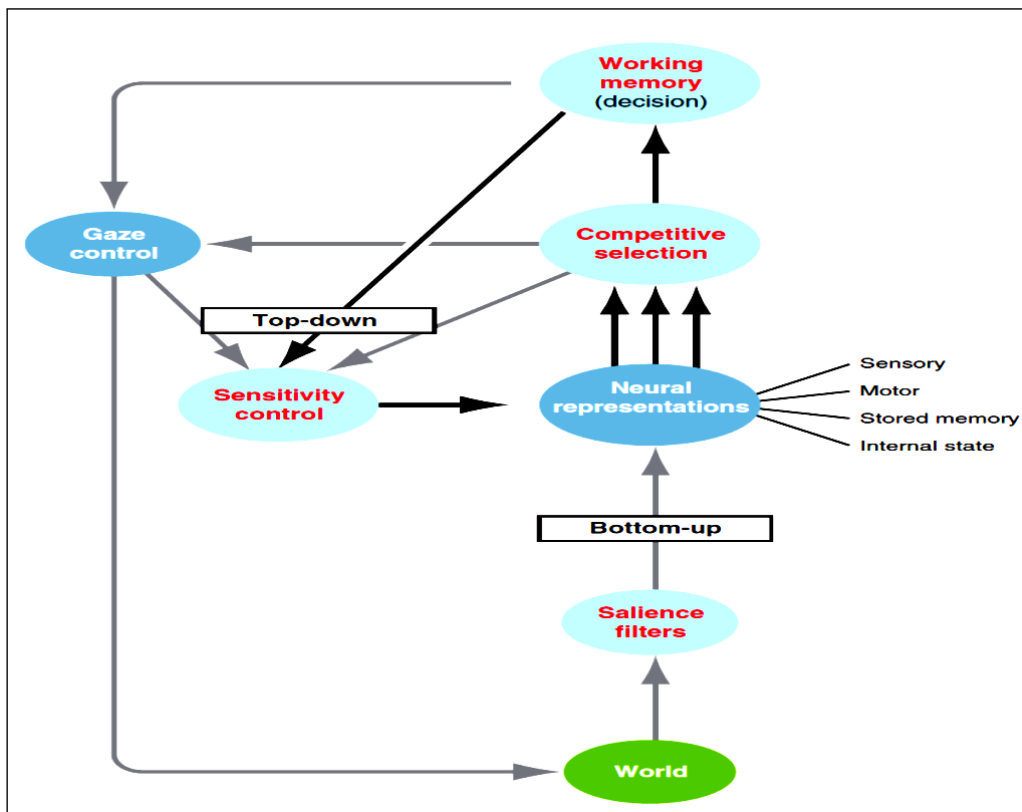


Figure 2. Schematc illustration of attention processing (Knudsen, 2007), showing how information presented in the environment, is processed through bottom-up and top-down mechanisms, leading to neural representations.

Processes contributing to attention are shown in red. Information coming from the environment (in green) is transduced by the nervous system and processed by salience filters, responding differently to relevant or irrelevant stimuli. Various hierarchies of neural representations encode information about the world, such as movements. Representations with the highest strength are selected to enter the processing circuitry that underlies working memory. Working memory can direct top-down signals, modulating the sensitivity of representations. Eye movements can be directed by working memory and competitive selection. Voluntary attention involves working memory, top-down control and competitive selection which operate as a recurrent loop. In summary top-down control is regulating the relative signal strength of information coming from the environment based on immediate goals and past experience. Bottom-up control automatically enhances responses to salient stimuli (Knudsen, 2007).

Nowadays there is an ongoing debate in the literature of visual research, on which way visual awareness is reached. Hunt and Kingstone (2003a) found that even as top-down and bottom-up control of attention differ greatly they access and control the same independent covert and overt attentional systems. In terms of the functioning of exogenous and endogenous attention Chica and colleagues (2013) commented that exogenous attention produces effects at early processing stages, affecting stimulus enhancement, external noise reduction and perceptual processing based in object coordinates, while endogenous attention affects external noise reduction, perceptual processing based on spatial coordinates and additionally influence later stages of processing.

Li, Gratton, Yao and Knight (2010) provide evidence for parietal and frontal cortices being involved in the control of bottom-up and top-down attentional processing.

### **1.5.1 Bottom up processing**

A stimulus is considered salient if it can be detected efficiently in visual search. Saliency is displayed by contrast of a basic visual feature dimension such as: color, orientation or motion (Yantis & Egeth, 1999). Saliency is also referred to as the bottom-up attraction of exogenous attention (Zhang, Zhaoping, Zhou & Fang, 2012). According to Folk et al. (1992) the allocation of exogenous attention is uniquely sensitive to dynamic discontinuities in visual information, by what shifts elicited by such discontinuities are involuntary, assuming that conditions are of spatial uncertainty.

Following Itti and Koch (2000) most models of visual search are based on the concept of a saliency map that encodes the saliency or conspicuity of objects in the visual environment. Particular locations in a scene are selected on basis of their importance or local image cues. The idea of a two-dimensional map (saliency map) encoding the saliency of visual objects in the environment was established. Based on competing neurons the winning location hereby represents the most salient stimuli. Being deliberately brought into the focus of attention or winning the neuronal competition for saliency brings a visual stimulus to higher levels of awareness. Inhibiting this location will automatically lead to focusing on the next most salient location. The input from different independent feature maps can be combined in order to determine the next location that is to be attended. Electrophysiological measurements provide evidence for several neuronal maps, in the pulvinar, the SC and the intraparietal sulcus, particularly encoding the saliency of visual stimuli.

The question of how the different maps can be combined is addressed in a study of Itti and Koch (2000). A vision algorithm to reproduce human performance on search experiments was calculated, based on the primate visual system. The model does not include any top-down control of attention but is limited to the bottom-up system of attention processing and hence focusing on the saliency of visual stimuli. In addition the focus lies on the localization of the stimuli that are to be attended and thus does not include their identification. Assumptions regarding the neuronal expression of attention are that visual input is represented in early visual structures, in form of iconic topographic feature maps. To construct those representations center-surround computations of every feature at different spatial scales and the within-feature spatial competition for activity are considered. A single map combines the information of the feature maps representing the local saliency of any one location with respect to its neighborhood. The maximum of a saliency map is defined as the most salient location at a given time also determining the next location that is to be searched. Furthermore the saliency map contains internal dynamics which enable the perceptive system to scan the visual input in order of decreasing saliency.

With this model salient targets are well detected in natural and artificial scenes. As performance in demanding target detection tasks is superior to human performance it is suggested that top-down influences play a significant role in the deployment of attention and top-down cues might bias attentional shifts in ways that might not be appropriate. As the

model operates in a purely bottom-up way it is believed that such high-level knowledge might interfere with optimal performance.

The bottom up theory of attention indicates that unconscious abrupt onsets are highly salient and therefore capture attention via the SC (Fuchs & Ansorge, 2012b). Attentional capture is referred to as objects receiving priority in processing independently of the volitional goals of the observer. The irrelevant singleton paradigm provides evidence for bottom-up attentional capture. Thereby participants are supposed to search for a particular feature singleton, the target, while at some trials an irrelevant feature singleton, the distractor, is also present. The present distractor leads to an extended reaction time during the search for the target, leading to the conclusion that the irrelevant salient singleton captures attention automatically. Subsequently the argument that attentional capture is basically bottom-up and not affected by volitional top-down control was produced (Belopolsky, Schreij & Theeuwes, 2010).

### **1.5.2 Top-down processing**

The contingent capture hypothesis indicates that the capture of attention is never stimulus driven (bottom-up) but always contingent with the settings of the observer (top-down), therefore only stimuli matching the top-down control settings will capture attention while others will be ignored (Theeuwes et al., 2010). Therefore the effectiveness of a nonpredictive cue is related to its physical similarity to the target and the capture is greater the more similar the cue is to the target. Hence cues involving a sudden onset are effective if the target is defined by a sudden onset, but less effective if the target is defined by color (Prinzmetal, Taylor, Barry Myers & Nguyen-Espino, 2011). If a nontarget shows target-defining features, they can capture attention which leads to impairments in the detection of the actual target (Serences, et al., 2005).

In a series of experiments Folk and colleagues (1992) found that the involuntary orienting of attention to a stimulus is contingent if a stimulus shares feature property that is critical to the performance of the target task (contingent involuntary orienting hypothesis). Conditions, under which abrupt luminance changes over time do not involuntarily summon attention, were found. Top-down control over attentional capture also involves the degree to which attention is spatially focused before a salient irrelevant stimulus is presented (Folk, Leber & Egeth, 2002). In accordance with those findings Folk and Remington (1998) have



furthermore proved that no evidence of spatial attentional capture is shown, by an irrelevant distractor of a different color, when searching for a singleton target defined by a particular color. The spatial cueing paradigm suggests that top-down attentional sets determine the selection priority. The main function of a top-down attentional set is proposed to be the controlling of the disengagement of attention from an irrelevant distractor (Belopolsky et al., 2010).

According to Ansorge, Horstmann and Scharlau (2011), contingent capture of attention requires the fulfillment of three conditions as defined in contingent capture experiments. The first condition concerns the researcher, who has to have a motivated hypothesis about the content of the search templates used by the participants, normally ensured by the task and the corresponding instructions. The participants can, for example, be asked to search for targets defined by one particular feature. If the target can be detected by more than one of its characteristics, the researcher's assumption about the content of the search templates could be wrong, and search templates could vary across participants or time.

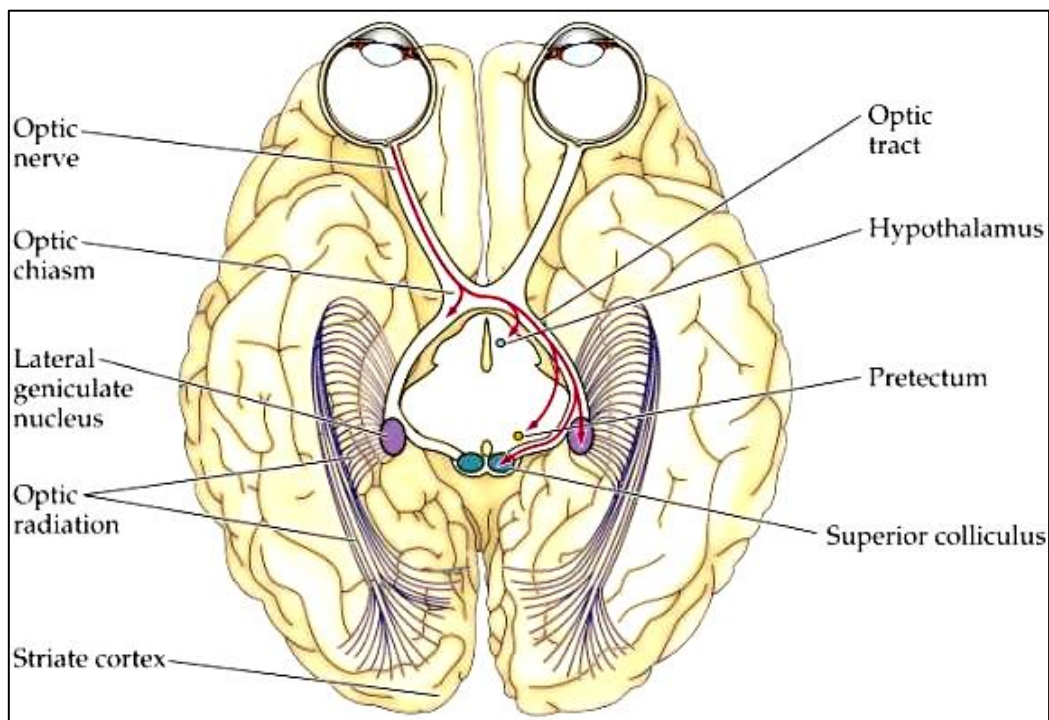
The second and third condition addresses the use of irrelevant distractors, as there are "matching cues" with templates matching the feature of the target and "non-matching cues", without a template matching feature. The cues must be fully irrelevant for the task and should not inform about the likely target position. Otherwise participants could search intentionally for the cues, additionally to their intentional search for relevant targets. In order to demonstrate contingent capture the participants' orientation towards matching cues and not the non-matching cues, needs to be shown. Which would confirm that the search template for a target feature is also a necessary precondition of the capture by the matching cue, with the same feature.

The ongoing debate does not always side with either top-down or bottom-up mechanisms for visual perception, but referring to Egeth and Yantis (1997) there has been mounting evidence revealing an almost invariable interaction of the two systems, whereby the images as well as the expectations and goals of the observer determine the attentional consequences. This interplay between voluntary attentional control settings, as for example, prior knowledge about a target's location or color and the degree to which a visual stimulus matches the voluntary control settings, leads to the deployment of attention (Serences, et al., 2005).

## 2. Visual processing

According to Gottlieb (2007) the process of rapid visual selection is known as selective attention and the eye movements used to scan the environment as saccades or rapid eye movements. The control of spatial orienting through attention or saccades is depending on a network of dorsal stream areas including the frontal eye field (FEF) and the superior colliculus in the midbrain. A major function of the SC is controlling eye and head movements in order to determine gaze direction. In the neural circuitry of the retina fluctuating patterns of light are transformed into a pattern of neural activity in retinal ganglion cells. This pattern is then transmitted along the optic nerve to the brain (Bruce, Green & Georgeson, 2003).

Figure 3 shows an overview of structures involved in visual processing in order to provide a figurative basis of relevant structures.



*Figure 3.* Schematic overview of brain structures relevant for visual processing (<https://www.knowhowcompany.com>, 24.02.2012). Information travels from the retina over the optic nerve and the optic tract to the striate cortex, passing the lateral geniculate nucleus (LGN) and the superior colliculus (SC).

Axons of retinal ganglion cells constitute the optic nerves projection to the optic pretectum in the midbrain, maintaining the same topographic relationship as the receptive fields of the retina. The cells in the pretectum are arranged in layers called retinotopic maps.

Similar projections go to the SC, which contains cells sensitive to moving stimuli that are arranged in a number of layered retinotopic maps of the contralateral visual field. A major projection from the retina goes to the dorsal part of the lateral geniculate nucleus (LGN) in the thalamus. The projecting axons terminate at synapses with the LGN cells, which are also arranged in layers. Each layer contains a retinotopic map of half of the visual field, in which those in the right LGN contain maps of the left visual field and those in the left LGN contain maps of the right visual field.

The LGN contains six major layers of cells, whereby three receive input from one eye and the other three receive input from the other eye. Each layer maps the contralateral visual field, the lower two and the upper four layers differ in cell size. The lower layers consist of large cells called the magnocellular layers. Most magnocellular retinal ganglion cell axons project to the magnocellular (M) layers and the SC. The second type, called the parvocellular (P) layers, receive input from all P ganglion cells. Their main differences lie in color opponency, contrast sensitivity and linearity. P pathways carry information about patterns of light at all spatial frequencies and at low and medium temporal frequencies. Additionally they transmit information about luminance contrast at high frequencies and about chromatic contrast. M pathways are transmitting information about patterns of light at high temporal and low spatial frequencies.

Axons from the LGN then form optic radiations and project to the visual cortex in the outer layer of the cerebral hemispheres. The visual processing is dominated by the projection to the LGN in the thalamus. Phylogenetically, this pathway is newer than the pathways projecting to the brainstem and the hypothalamus. The so called geniculostriate pathway refers to the major pathway from the retina to the striate cortex via the LGN as shown in Figure 3. The term retinotectal pathway refers to projections of visual information from the retina to the SC. Other ganglion cells run axons to the hypothalamus, the tegmentum, the pulvinar nucleus and the ventral LGN (Boothe, 2002; Bruce et al., 2003).

Visual processing is additionally illustrated in a simplified Figure 4 displaying the dorsal and the ventral streams from the retina to the cortices, showing a path to the posterior parietal cortex that leads through the SC and the pulvinar. Secondary and higher order processing of visual information takes place in the inferior pulvinar, the striate visual cortex and particular higher-order cortical areas referred to as extrastriate cortex. Visual information that has passed the LGN and arrives at the cortex is processed in the area primary visual

cortex (V1). This information is then further processed in the extrastriate cortex. Extrastriate areas can be divided into two streams, basically known as the “what” and the “where” stream. The “what” stream travels ventrally to the inferotemporal cortex and is involved in discriminating between objects, whereas the “where” stream projects dorsally to the posterior parietal cortex and is involved in locating objects (Snowden, Thompson & Troscianko, 2006).

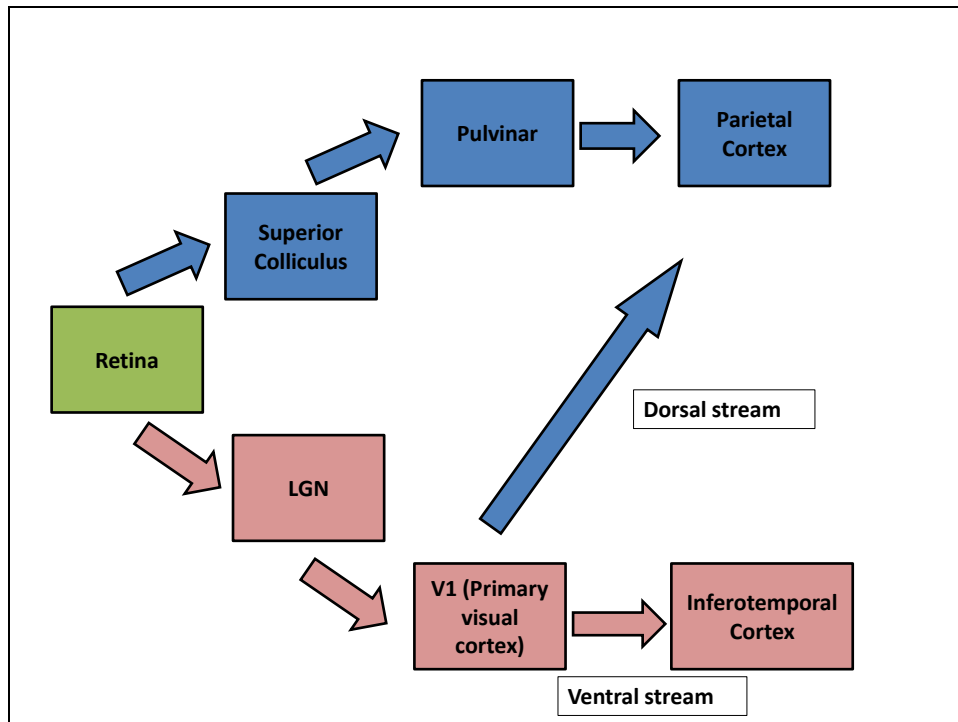
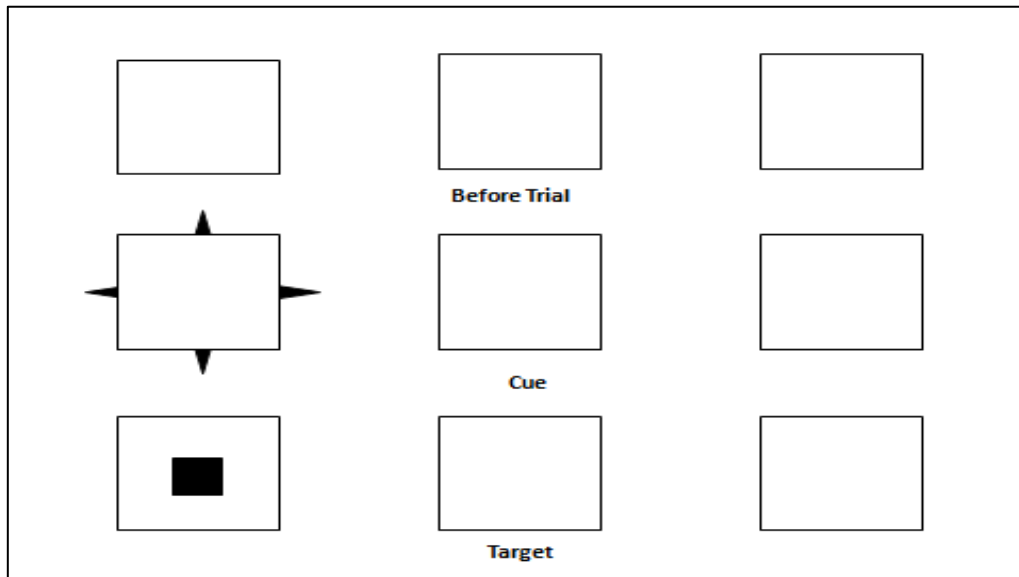


Figure 4. Simplified schematic illustration of the dorsal and ventral streams to the cortices (Snowden, Thompson, & Troscianko, 2006). Information passes from the retina either to the SC, the pulvinar and then to the parietal cortex (dorsal stream), or from the retina to the LGN, the primary visual cortex (V1) and the inferotemporal cortex (ventral stream).

### 3. The cueing paradigm

In 1984 Posner and Cohen conducted experiments showing an inhibitory effect later known as inhibition of return. Thereby a peripheral visual cue that did not predict the location of a subsequent target produces an orienting of attention. Facilitating the detection of targets in the cued area, it is followed by a shift of attention away from the cued location, leading to a less efficient handling of targets at this location compared to targets at other (not cued) locations. The paradigm used to demonstrate the inhibitory effect consists of three boxes as shown in Figure 5. In the first row subjects were to fixate the central box; the brightening of the outline of one randomly selected peripheral box for 150 ms then initiates the trial (second

row), followed by a bright target in one of the boxes, either 0, 50, 100, 200, 300 or 500 ms after the brightening (third row), requiring a response by pressing a single key.



*Figure 5.* Schematic demonstration of Posner's and Cohen's basic paradigm (Posner & Cohen, 1984), with the first row before the trial, to fixate the central box. In the second row the trial is initiated by a peripheral brightening of the outline of one of the boxes. The third row shows a small, bright target in the center of one of the boxes.

For the first 150 ms a reaction time (RT) advantage was shown for targets that appeared at the cued side, which was replaced by an inhibition of the target RT on the cued side compared to the uncued side, after about 300 ms.

Posner's and Cohen's pioneer work in this field has shown that the already known cueing effect or facilitation effect, which is described as facilitation in detecting a target's location when presenting a single abrupt-onset briefly before the target with a stimulus onset asynchrony (SOA), of 200-300 ms at the same position (SP) as the target, reverses after about 300ms. If one presents a cue with a cue-target SOA of less than 300 ms at one of two possible target positions, the response to the target on the SP as the cue is facilitated through attentional capture, which is shown in faster reaction times compared to targets on a different position (DP). When using SOAs of more than 300 ms, the RTs to targets shown on the DP are faster in comparison to targets shown on the SP as the cue presented before, which is nowadays called IOR (Fuchs & Ansorge, 2012b).

#### 4. Inhibition of return

The afore described inhibitory effect nowadays known as IOR has undergone extensive research since its discovery. It is now described as: “When responding to a suddenly appearing stimulus, we are slower and/or less accurate when the stimulus occurs at the same location of a previous event than when it appears in a new location.” (Lupiáñez, Klein & Bartolomeo, 2006, p. 1003) and knowingly following the facilitation effect the two are also referred to as a classic biphasic effect. IOR is observed when a peripheral cue precedes a target and eye movements are prohibited during the trial, or when an eye movement is endogenously executed to a peripheral location and back to the center before the target appears (Chica, Rafal, Klein & Hopfinger, 2010).

##### 4.1 On the signification of IOR

The IOR effect seems to be caused by the orienting of attention towards a location and the subsequent removal of attention from that location, discouraging attention to reorient back to the originally attended location. An initial response to a peripheral visual stimulus facilitates the processing of that stimulus, probably because of a reflexive shift of attention towards the source of visual stimulation. But if identified as a not task-relevant event, attention disengages from the stimulus which can be measured in a delayed responding to subsequent stimuli presented at the originally cued location, describing a prototypical example of IOR (Klein, 2000). Supporting evidence for this foraging facilitator proposal of IOR comes from a critical observation of IOR in a variety of human foraging tasks by Wang and Klein (2010).

Chao (2009) on the other hand, calls attention to the fact that discrimination between serial and parallel search tasks is hereby of importance. In a serial search task attention has to be paid to each potential target in a serial manner in order to detect the relevant stimulus, repeated examining of a certain location causes increase of reaction time. But in a parallel search task targets can be detected at a feature level, consequently there is no need to focus serially on potential targets and a mechanism preventing observers from returning to a certain location is not necessary. Evidence contradictory to the foraging facilitator hypothesis additionally came from Smith and Henderson (2011) who found that return fixations occurred significantly more often than would be expected if IOR would facilitate foraging.

Furthermore the presence of temporal IOR does not necessarily mean that IOR also has spatial consequences decreasing the probability of return.

According to Posner and Cohen (1984) the IOR effect evolved to maximize the sampling of our visual environment as new targets are in favor for future eye movements, or possibly IOR favors the release of attention from a spatial position so that the concentration on a single position does not get out of control. Reasoning therefore has similarly come from Sapir, Soroker, Berger and Henik (1999), who state that it is important for an organism to limit the duration of attention contributed to one stimulus, in order to maintain the ability to scan and detect potentially meaningful events at other locations. Results from experiments conducted by Krüger & Hunt (2012) give evidence that IOR reflects an inhibitory tagging mechanism that is able to orient attention, during active, overt scanning of the visual environment to new locations.

A different benefit of IOR could be the fact that distractors cause less interference due to IOR, as shown by Theeuwes and Godijn (2004). The purpose of inhibition is that inhibited locations no longer compete for selection, therefore irrelevant distractors compete less when presented at inhibited locations than when presented at non-inhibited locations and orienting is biased towards new locations.

#### **4.2 Anatomic correlates of IOR**

There has been evidence provided for the assumption, that the SC is playing an important role in IOR. The SC is a part of the visual system primarily involved in visual reflexes and reactions to moving stimuli located in the midbrain of the human brain (Carlson, 2007). Individuals with damage to the SC have, for example, shown reduced or no IOR whilst a hemianoptic patient with damage in the visual cortex but an intact SC showed IOR to cues presented in his blind field (Klein, 2000). It appears moreover that in tasks involving eye movement, the facilitation is produced at the level of the superior colliculus (Posner, Cohen & Rafal, 1982). Sapir and colleagues (1999) also demonstrated that IOR is generated within the midbrain SC with the aid of a patient with a unilateral lesion restricted to the dorsal midbrain. The midbrain visuomotor pathways are providing all vertebrates with mechanisms for rapid, reflexive orienting to abrupt environmental changes. Those visual pathways have become involved in strategic search and endogenous control. Advantages of orienting automatically to new sensory signals in the visual periphery do not disregard the importance of an organism's

ability to limit the duration of attention to one stimulus, in order to maintain scanning the environment. Sapir and colleagues (1999) state additional evidence for the generation of IOR in the SC by examining patients with midbrain degeneration due to progressive supranuclear palsy (PSP). Research showed that IOR is abnormal under these conditions. Furthermore IOR is present in patients with hemianopia, a condition where only the extrageniculate pathways are available for the processing of visual information. Third, IOR is present in newborn infants, in whom the geniculostriate pathways are not yet developed. In addition retinotectal mediation is suggested due to the asymmetric generation in temporal and nasal visual fields.

Dorris, Klein, Everling and Munoz (2002) found that even trained monkeys showed IOR similar to that observed in humans. They concluded that the primate SC participates in the expression of IOR even though it is suggested that the SC is not the site of inhibition, but receives reduced input from upstream structures in response to previously cued targets.

Prime and Ward (2006) consider the “real neural architecture” (RNA) model as evidence for the contribution of the FEF and the SC in the generating of IOR. In this model the ventral pulvinar nucleus of the thalamus contains a salience map pooling information from several brain areas, including various visual cortical processing areas, the SC, the frontal and parietal eye fields (PEF) and the prefrontal cortex. Focal states of attention emerge from the interaction of all inputs in the ventral pulvinar taking the form of a localized “beam” of neural activity. This “beam” spreads from the ventral pulvinar via reciprocal connections to various processing areas. IOR is explicitly represented by a loop from the FEF and PEF through the SC to the ventral pulvinar, reducing the salience of a previously explored location in order to enable other locations in the visual field to compete for focal attention as depicted in Figure 6.



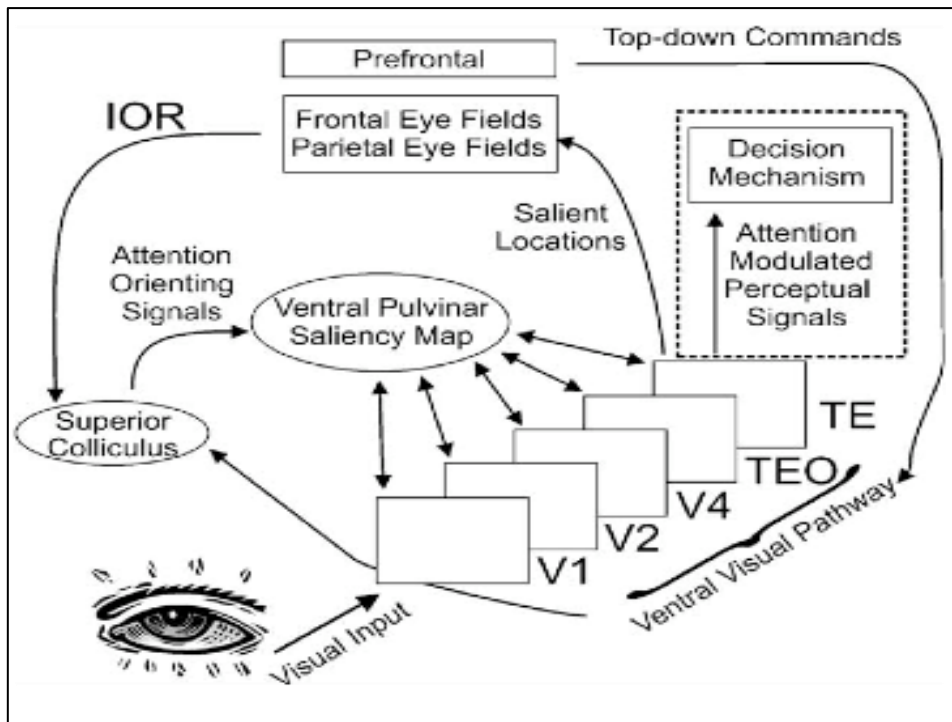


Figure 6. “real neural architecture“ (RNA) model by Prime & Ward (2006), depicting how IOR is possibly generated in the frontal eye fields (FEF) and the SC. Visual input travels from the eye to the ventral visual pathway and the SC creating a saliency map.

Moreover it is proposed that IOR is a behavioral byproduct of a mechanism operating by biasing attention away from previously cued locations through programming the contralateral voluntary eye movements in the FEF ipsilateral to the cue, also serving to enhance visual processing in contralateral locations (Ro, Farnè & Chang, 2003).

#### 4.3 Mechanism and functioning of IOR

Regardless of how attention is drawn back to the center (via task demands - endogenously or exogenously via luminance change) the inhibitory effect of the prior cue is observed in relatively long cue-target intervals (Taylor & Klein, 1998). Following Rafal, Calabresi, Brennan and Sciolto (1989) IOR is activated when attention is summoned by an exogenous signal as well as when attention is deployed endogenously together with eye movements.

Wang and Klein (2012) found that IOR could be observed provided that a saccadic response to a cue was required. IOR was not generated by the peripheral cue under the condition that fixation should be maintained to process the central digit.

The mechanism that produces IOR is presumably promoting goal-directed behaviour by limiting the capacity for non-predictive visual onsets repeatedly gaining control over orienting (Taylor, 2007). Satel and Wang (2012) and Wang, Satel and Klein (2012) proposed two separate mechanisms of IOR in the oculomotor system. A sensory mechanism, representing the observation that a peripheral visual onset moderates following peripheral onsets at the same spatial location during the beginning of processing, meaning that a reduction of visual input in the SC occurs after repeated visual stimulation, with the consequence that saccades to targets appearing at a previously stimulated retinotopic location will have longer latencies than those at a location that was not already stimulated before. The second mechanism is called “motor mechanism” representing the affection of a saccades’ execution on the latency of a following saccade, as the execution results in asymmetric activation in the SC. Both mechanisms are supposed to correspond to IOR effects following covert exogenous orienting and overt endogenous orienting. As various other mechanisms of IOR, as for example a deficiency in processing due to inhibition of attentional orienting were discussed, Taylor and Klein (1998) conclude that the motor view is most likely to capture diverse findings as a whole. Namingly this mechanism is able to account for increased saccadic and manual latencies to previously cued locations the biasing of saccade direction in absence of perceptual effects, the occurrence of IOR for unilaterally presented targets and the occurrence of IOR for nonspatial target discriminations under the condition of unilateral target presentation. Taylor (2007) on the other hand states that the hypothesis of a motor bias of IOR can only be upheld under conditions of natural viewing as there are stronger contributions from motor effects when the eyes are free to move compared to attentional facts related to IOR when the eyes are prohibited from moving. Support therefore also comes from Hunt and Kingston (2003b), suggesting that manual (attention-based) and saccadic (motor-based) IOR should be further investigated in isolation as well as in relation to each other, as two qualitatively different systems of IOR.

Another model aiming to explain the functioning of IOR involves the intermediate layer of the SC (iSC) which receive and integrates sensory and cortical inputs from prefrontal, parietal and temporal areas. It has been shown that target induced neural activity in the iSC is reduced stronger for previously cued than for previously uncued target-locations, which is highly correlated with saccadic reaction times (SRTs) to targets. As neural activity is not directly suppressed in the iSC following a cue, IOR is not caused by active inhibition of

recently stimulated iSC sites, but by a reduction in the strength of subsequent input signals to these neurons, labelled short-term depression (STD) of sensory input (Satel, Wang, Trappenberg & Klein, 2011).

Although exogenous attentional orienting and inhibition of return are similarly affected by attentional control settings, the occurrence of inhibition of return does not always covary with the occurrence of exogenous attentional orienting (Gibson & Amelio, 2000), as claimed contradictory to Mulckhuysen et al. (2007) and further investigated in the following.

### **5. The nasal-temporal asymmetry of the hemifields in connection with IOR**

As all vertebrates, humans have midbrain circuits that enable reflexively orienting the eyes, towards salient events occurring in the visual periphery, known as the visual grasp reflex. This reflex must be integrated with cortical mechanisms that are involved in strategic search under voluntary control (Berger, Henik & Rafal 2005). The following Figure 7 depicts a schematic representation of how visual information is processed in the human brain with a focus on contralateral processing.

Visual information is processed ipsilateral but also contralateral to the visual input, meaning that for each eye there are axons from the nasal hemiretina, which receive input from the temporal hemifield, cross at the optic chiasm and project contralaterally. The temporal hemiretina, receiving input from the nasal hemifield projects ipsilaterally (for a more detailed description of involved structures see chapter 2).

Inherently the spatial density of photoreceptors in the periphery of the human retina is asymmetrical for the nasal and temporal hemiretinae (Grigsby & Tsou, 1994). The mean distance between photoreceptors is slightly higher for the nasal than for the temporal visual field and therefore higher in the temporal than the nasal hemiretina (Fahle & Schmid, 1988).

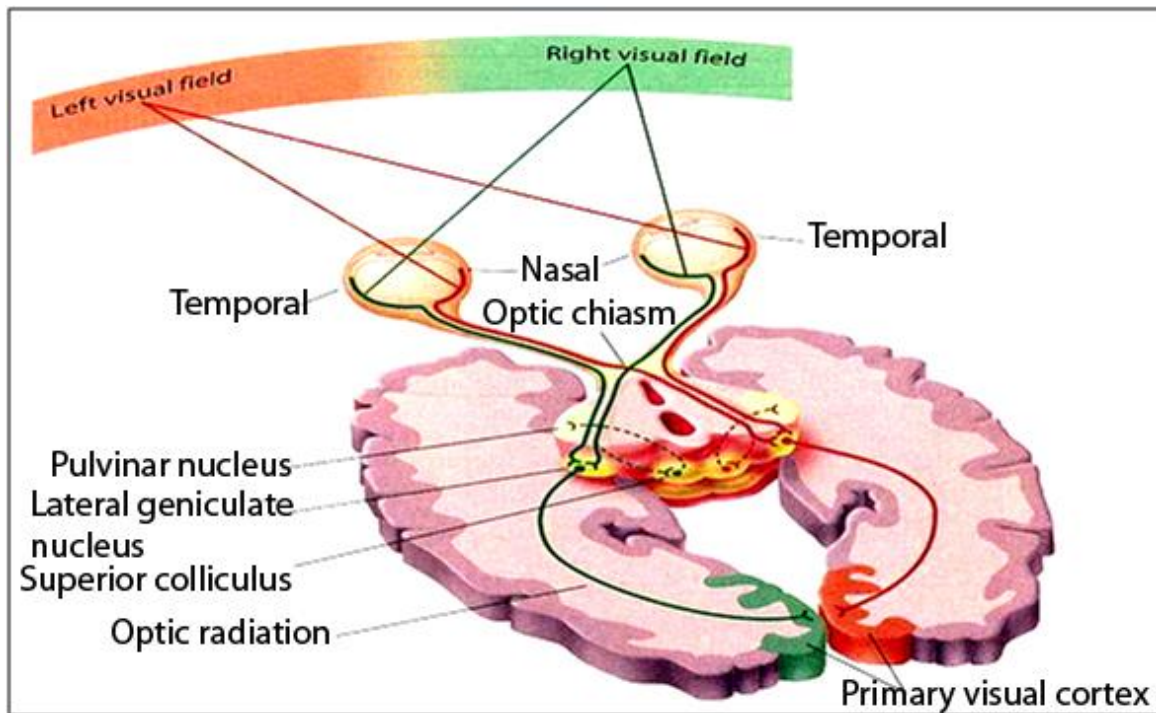


Figure 7. Schematic depiction of contralateral processing in the visual fields (<https://wiki.ucl.ac.uk>, 24.02.2012), showing visual input from the left visual field travelling to the right visual cortex and vice versa.

In various experiments, under monocular viewing conditions, several behavioral naso-temporal asymmetries (NTA) have been shown (Bompas, Sterling, Rafal & Sumner, 2008). As the extrageniculate pathway is a phylogenetically older pathway – compared to the geniculate pathway – retinal projections to the superficial layers of each SC receive input mainly from the contralateral hemifield. If monocular viewing conditions are given, information from the temporal and the nasal hemifield project to the LGN and the SC (Michael & Gálvez-García, 2011). As fibers from the retina leaving the optic tract project to the SC and crossed fibers are most numerous the temporal visual field is dominantly represented in the SC and it has been found that IOR is generated asymmetrically in temporal and nasal visual fields (Sapir, Rafal & Henik, 2001). IOR is greater for stimuli presented monocularly in the temporal hemifield, caused by stronger collicular representations than in the nasal hemifield (Klein, 2000). Each SC predominantly receives input from the contralateral visual field, with greater representations from the temporal hemifield (nasal hemiretina) than from the nasal hemifield (temporal hemiretina) of the open eye. Consistent with the connectivity of the retinotectal pathway the significant IOR effect shown by Taylor and Klein (1998) was stronger for targets presented in the temporal hemifield than for targets presented in the nasal hemifield.

Furthermore it was found that unconscious processing is stronger for the temporal than for the nasal hemifield with enhanced activity in the SC for stimuli presented in the temporal hemifield compared to stimuli presented in the nasal hemifield (Mulckhuyse & Theeuwes, 2010a).

As those nasal and temporal differences are related to asymmetries in the visual pathways (Paradiso & Carney, 1988) and the actual impact on IOR is still under discussion, the matter should be further considered in the following experiment, aiming to make a small contribution to the elucidation of relevant connections between the nasal-temporal asymmetry of the hemifields and IOR.

## **6. Hypotheses**

Basically this study was conducted to test whether automatically exogenous capture is necessarily followed by IOR and furthermore if IOR for temporally projected cues is stronger than for nasally projected cues. IOR is supposed to follow after an automatic exogenous capture of attention by subliminal cues, due to one of the earliest activated midbrain structures while processing: the superior colliculus (Mulckhuyse et al., 2007). But following Fuchs and Ansorge (2012b, p. 1): “Inhibition of return is no hallmark of exogenous capture by unconscious cues”, which shall be further investigated within this study. Thus the first hypothesis: “Automatic exogenous capture by unconscious cues, is necessarily followed by IOR” will receive attention in the further procedure.

Posner and Cohen (1984) already report that under monocular conditions the direction of the eye movements is biased in favor of the temporal visual field. In addition thereto IOR could be shown for cues in the temporal hemifield but not for those presented in the nasal hemifield (Mulckhuyse & Theeuwes, 2010a).

Therefore as a second hypothesis: “Under monocular conditions IOR for cues presented in the temporal hemiretina is stronger, than for cues presented in the nasal hemiretina, due to the hemifield asymmetries” is further investigated.

In order to test those hypotheses the study from Mulckhuyse and colleagues (2007) was replicated under monocular conditions, which made it possible to test the nasal and temporal hemifields of each eye separately.

By monocular conditions the use of an eye-patch alternating on both eyes is meant. According to Bertini, Leo and Ládavas (2008) the use of an eye patch gives a simple way to

isolate the temporal and the nasal hemifield, as when patching a single eye, the contralateral hemifield becomes temporal and the ipsilateral field nasal.

For the experiment 16 volunteers were asked to perform a subliminal cueing task and a cue report task. The assignment was to detect a target in form of a small black dot, appearing at different positions on the screen, giving the examiner the opportunity to identify IOR by analyzing error rates and reaction times on the tasks.

Up to the present several studies at the University of Vienna failed to replicate the findings of Mulckhuyse et al. (2007), under similar experimental conditions. On account of this adaptations are in the following limited to the eccentricity of the cues. The discs were shown either,  $10^\circ$  to the left, or to the right of the center of the screen, whereas they were presented  $6.7^\circ$  to the left or to the right of the center of the screen in the original study. This alteration was made in order to allow a precise measurement of the nasal and temporal projection differences.

## **7. Method**

### **7.1 The Mulckhuyse Paradigm**

The study of Mulckhuyse and colleagues (2007) aimed to prove, that an abrupt onset cue, which is not consciously perceived, can cause the classic biphasic effect of facilitation followed by IOR. It is suggested that the subliminal cue captures attention exogenously as IOR is not observed following endogenous shifts of spatial attention.

Therefore the following experiment was conducted: sixteen volunteers were to execute a subliminal cueing task and a cue report task, the procedure is depicted in Figure 8.

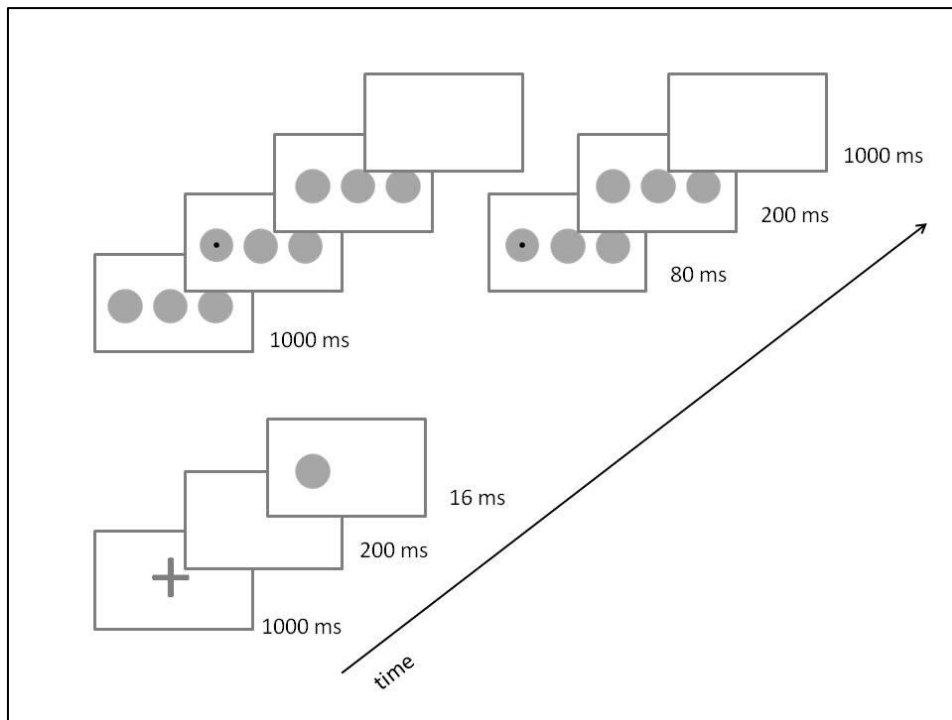


Figure 8. Schematic figure of the Mulckhuyse Paradigm; sequence of a long SOA condition trial on the left, and a trial with short SOA on the right, adapted from Mulckhuyse, Talsma & Theeuwes, 2007.

The subliminal cueing task consisted of five blocks with 40 trials in which each condition consisted of 40 trials, randomly presented during the experiment. 20% catch trials (trials where no target is shown) were included in the task to avoid the participants' anticipation. A non informative cue was used in the trials, which started with a black fixation cross, which stayed at the screen center for 1000 ms and then disappeared for 200 ms. Then the cue, a disc consisting of a grey filled circle ( $1.9^\circ$  in diameter, with a luminance of  $12.7 \text{ cd/m}^2$ ) was presented for 16 ms either  $6.7^\circ$  to the left or the right of the screen center. This was followed by two more discs of the same size and luminance as the first one. In the "long SOA" condition the target stimulus then appeared after 1000 ms, whereas in the "short SOA" condition the target stimulus appeared simultaneously with the onset of the latter two discs.

The sudden onset of the first disc was expected to attract attention and therefore serve as a cue. As the two other placeholders followed immediately, the impression of a simultaneous appearance of the three discs was caused, by what the cue was expected not to be perceived consciously.

The appearing target was a small black dot, presented either in the right or the left disc. It was remaining for 80 ms and after another 200 ms the discs disappeared as well,

leaving only the gray background (with a luminance of  $4.6 \text{ cd/m}^2$ ) for 1000 ms more before the next trial began.

The cue report task, consisting of four blocks of 20 trials including 20% catch trials was identical to this, with the only exception that the trial ended when the participants gave a response.

The volunteers were seated at a 75 cm distance to the monitor, their heads positioned on a chinrest and with the instruction to remain fixated to the center of the screen. The space bar was to be pressed as soon as the target was detected. Practice trials were included in the experiment, giving feedback if the participants had given the right answers. When the subliminal cueing task was completed it was evaluated whether the volunteers were able to perceive the earlier onset of one of the discs, when instructed to do so. For this purpose the following task was to ignore the target and instead specify which of the discs - left or right – was presented first, by pressing the “z” or the “m” key. Half the trials started with the left disc being presented an instant earlier than the right one, half the trials started with the right disc. Mulckhuysen et al. (2007) came to the following results: the cue report task revealed a mean detection performance of 50% and was not significantly above chance level. For the subliminal cueing task a significant main effect of SOA (short and long) and a significant interaction effect of SOA and cue validity (cued location vs. uncued location) on detection time was shown. Further analysis indicates a facilitation effect at the short SOA as detection times at the cued location were faster than at the uncued location. This effect was reversed at the long SOA as detection times were slower for the cued location than for the uncued location.

Therefore the for peripheral cueing paradigms typical cueing effect was shown even with a not consciously perceived cue. Even though other studies reported ambiguous results on the matter, the biphasic effect of facilitation followed by inhibition was observed. Current findings therefore implicate that subliminal cues can cause exogenous attentional orienting. Since this was the first study to illustrate those results using subliminal cues the study was replicated in order to further investigate the biphasic effect.



## 7.2 Participants

Twenty participants, mostly students, who had not participated in a similar study before took part in the following experiment. The experiment took place in the test-room K6 of the Faculty of Psychology at the University of Vienna, between the 22.03-26.03.2012.

Twelve of those participants were female and eight were male with a mean age of 24.1 years and an age range from 19-51. All participants had normal or corrected-to normal vision, tested with a "Nahsichtleseprobe nach Nieden" before the beginning of the experiment. The volunteers were recruited with help of RSAP (computer based recruiting system of the faculty of psychology of the University of Vienna) and signed a letter of agreement, ensuring their participation on volunteer basis, before the beginning of the experiment. Participation was either on a pure voluntary basis or rewarded with course credit for various courses. All volunteers' first language was German and therefore understanding the instructions was no problem.

## 7.3 Apparatus

The experiment was conducted via six computers, where the stimuli were presented on 19-inch TFT screens with a resolution of 1024 x 768 pixels and a refresh rate of 60 Hz. An Experiment Builder software (SR Research) was used to control the stimulus presentation. The monitors were placed in the middle of six desks, parallel to the volunteers' viewing direction. A stable position of the participants' heads, the same distance to the monitor and a similar sitting position of every participant was assured by chinrests attached at a 64cm distance of the monitor, in order to help standardize the experiment. The volunteers were seated in front of the monitors with their head positioned on the chinrest. They were additionally instructed to remain fixated on the center of the screen.

## 7.4 Stimuli and Procedure

As mentioned before the conducted experiment was adapted from Mulckhuyse et al. (2007). Cues (discs with a luminance of 12.7 cd/m<sup>2</sup>, consisted of a gray filled circle, 1.9° in diameter) and small black dots as targets ( $l = 2.7 \text{ cd/m}^2$ , 0.38° in diameter) were presented on a gray background ( $l = 4.6 \text{ cd/m}^2$ ), with a 10° distance of the two outer discs to the left or right of the center. This adjustment was made to adapt the procedure to the aforementioned retinotopy of the naso-temporal retinotectal projection asymmetry. Cues were presented

equally likely at the same (SP) or different (DP) position as the target. In 20% of the trials no target was shown (catch trials). Those were included in the procedure to avoid anticipation.

Monocular viewing conditions were established by using an eye patch. The placement of the patch over the left or right eye was fully balanced over participants; hence half of the participants started the experiment with the patch on the right eye, whereas the other half started with the patch on the left eye. In addition, the position of the patch was switched after the first half of the trials of each condition.

Before the start of the experiment data of the participants' age, gender, handedness and information about their eye-sight specifically if they were wearing glasses or contact lenses was noted. Proximately the participants were asked to turn off their mobile phones and an oral instruction containing the task demands was given. Subsequent the volunteers were to take their seats in front of the monitors. Thereupon the lights were turned off, whereby the only remaining light was provided by desk lamps behind each monitor. During the whole testing the door of the room remained closed, which had been ensured by a sign outside the door. This measure was taken to guarantee an undisturbed working environment for the volunteers.

Participants were requested to read the instructions shown on the monitors and then, clarifying all further questions, start with the practice trials. The practice trials included feedback informing the subjects whether they had given the right responses to the tasks or not, to ensure that the assignment of tasks was understood by all participants. Any questions following the practice trials were answered by the instructor and it was pointed out to the volunteers that further questions would be answered anytime by the test-instructor. After the instruction was finished, practice trials were completed and all questions were answered, all participants, which were six at a time, started the actual trials on the computers in front of them simultaneously, to assure a procedure as standardized as possible over all subjects. It took the volunteers about 20 minutes to complete the experiment itself and they were asked to remain on their seats until everybody was finished.

The experiment consisted of two different conditions: first, a subliminal cueing task was conducted, followed by a cue report task.

### 7.4.1 Subliminal cueing task

The subliminal cueing task consisted of four blocks of 60 trials during which the eye patch had to be switched after 120 trials. The shown cue was not informative of the location of the upcoming target. Each trial started with a black fixation cross centered on the screen which stayed on for 1000 ms. After 200 ms the fixation cross disappeared for 200 ms whereby one of the discs was presented. The presented disc was shown for 16 ms on the right or left side of the screen. This first disc was followed by two more discs of the same size and luminance by what the resulting display contained three discs positioned in a straight line with their centers separated by  $10^\circ$ . The target stimulus appeared either simultaneously with the onset of the latter two discs (short SOA condition) or after an SOA of 1000 ms (long SOA condition). This target consisted of a small black dot that could appear inside either the left or right disc. The target stimulus was presented for 80 ms whereas the discs disappeared after another 200 ms and the gray background was presented for 1000 ms again before the next trial began.

The participants were instructed to press the space bar as soon as they detected the target and to not press it when they could not see it. There was no information given about the temporal difference in onset of one of the discs. A block of practice trials to demonstrate the following process was conducted at the beginning of the experiment. A written notification was shown if participants pressed the space bar before the presentation of the target, or if they responded too late.

The procedure of the short SOA condition with simultaneously appearing discs and target is shown in Figure 9, in a valid trial (a valid trial describes a trial where the cue and the target appear at the SP, whereas in an invalid trial the cue and the target are presented at DPs). In the following Figure 10 the long SOA condition, with a target onset 1000 ms after the placeholder discs, also in a valid trial, is shown.

# IOR & THE HEMIFIELD ASYMMETRY PREDICTION

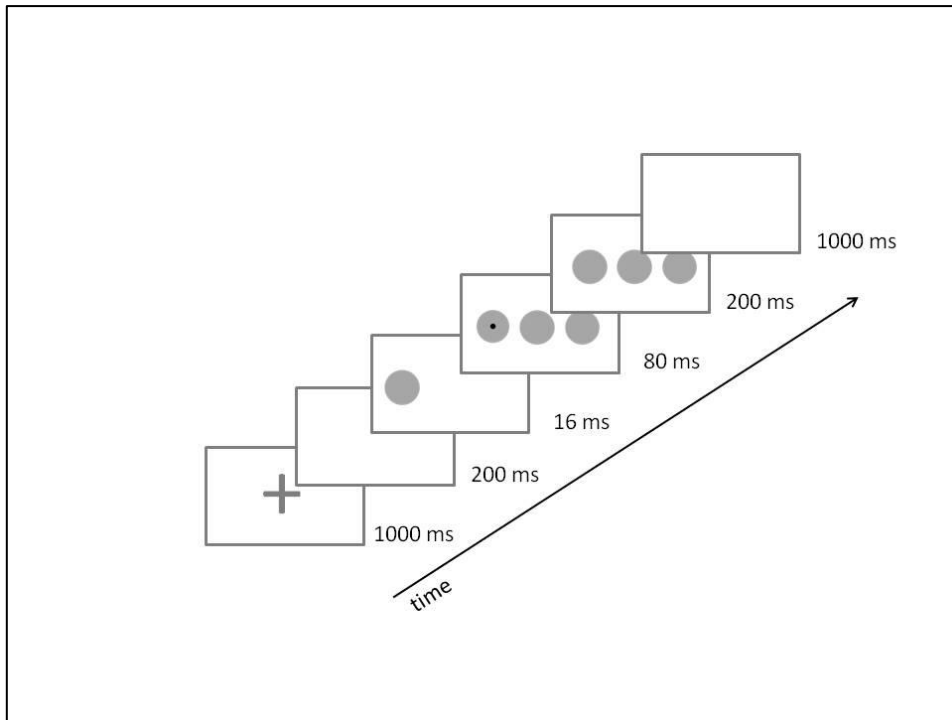


Figure 9. Schematic demonstration of the short SOA condition of the conducted experiment, showing the target simultaneously with the onset of the latter two discs, cued by a gray disc on the left side, in a valid trial.

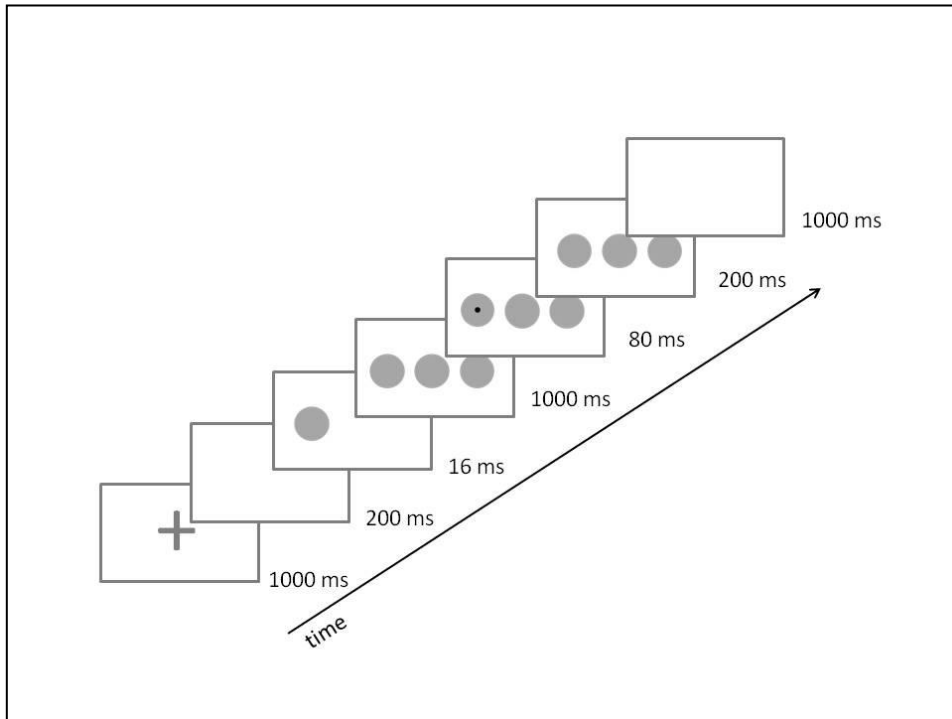


Figure 10. Schematic demonstration of the long SOA condition of the conducted experiment, showing the target after a SOA of 1000 ms, cued by a gray disc on the left side, in a valid trial.

### 7.4.2 Cue report task

Furthermore it will be examined whether participants were able to perceive the earlier onset of one of the discs, when instructed to do so. Therefore the cue report task, consisting of two blocks of 40 trials identical to the subliminal cueing task, with the exception that the trial ended when a response was given, was conducted. To examine whether this was possible, participants were asked to ignore the target in favor of indicating which of the discs, the left or the right, was presented an instant earlier than the other two discs by pressing respectively the - marked - „x“ or „,“ on the keyboard. The instruction included the lead to decide intuitional if one was not sure what disc appeared first. Whether the left or the right disc was the one presented first was equally balanced over all trials.

## 8. Results

In order to estimate the participants' objective consciousness of the cues,  $d'$  a measure of sensitivity, was calculated. According to Vermeiren and Cleeremans (2012) the  $d'$  measure of sensitivity can be calculated for each participant based on the z-scores for hit-rates (rightly reported cues) minus the z-scores for false alarm-rates (wrongly reported cues). A  $d'$  close to zero is then interpreted as a lack of conscious access. Thereby it was shown that the volunteers detected the cues significantly above chance level (mean  $d' = 0.46$ ,  $p < .001$  against  $d'$  of zero).

Out of 20 volunteers participating in the experiment, the results of 16 were further analyzed in the following, as four of them had already participated in a similar experiment. The analysis of the results was conducted via the statistical program SPSS where two different repeated-measurement ANOVAs were conducted. The method of a repeated-measurement ANOVA was chosen as it is testing differences between several means of the same people, in order to identify the effect of a manipulation and individual differences in performance (Field, 2005).

First, the participants' reaction times were examined so as to discover if presented cues led to covert shifts of attention which influenced the targets detection. Hereby faster responses to targets on a DP as the afore presented cue in comparison to a target presented on the SP would describe the IOR effect. Faster responses to targets on the SP as the afore presented cue, compared to a DP would imply the cueing effect.

Second, the participants' error rates were analyzed, as higher error rates for targets presented on the SP as the cues before, in comparison with targets presented on a DP, refer to IOR. Higher error rates for targets presented on a DP as the before shown cue, compared to the error rates on the SP, imply a cueing effect.

Additionally a stronger IOR effect for cues presented in the temporal hemifield, than for cues presented in the nasal hemifield was expected.

Two ANOVAs with the variables *cue position* (SP vs. DP), *hemifield* (nasal vs. temporal) and *SOA* (short vs. long)", on RTs and error rates (ER), were conducted. The analysis lead to the results presented in the following:

### 8.1 Reaction times

The trials with incorrect responses and the reaction times outliers (4.7%) were excluded. One participant had to be excluded from further analysis since no reliable reaction time mean could be calculated for one variable combination due to a high error rate (44% in target present trials).

Mauchley's test indicated that the assumption of sphericity had been violated for the main effects of *cue position*,  $\chi^2(0) = 0.0$ ,  $p < 0.01$ , *hemifield*,  $\chi^2(0) = 0.0$ ,  $p < 0.01$  and *SOA*  $\chi^2(0) = 0.0$ ,  $p < 0.01$ . Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ( $\epsilon = 1.0$  for all variables).

A significant main effect for the *cue position* [ $F(1,14) = 7.81$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.36$ ] was shown, with a mean reaction time of 381 ms for the SP and a mean reaction time of 388 ms for the DP condition. Post-hoc Bonferroni-adjusted *t*-tests indicate a significant difference between the SP and the DP condition ( $p < 0.05$ ).

A second significant main effect was found for *SOA* [ $F(1,14) = 191.37$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.93$ ], with an average reaction time of 414 ms for the short condition and a mean reaction time of 355 ms for the *long SOA* condition. Here the Post-hoc Bonferroni-adjusted *t*-tests also indicate a significant difference between the two conditions ( $p < 0.01$ ).

There was a significant interaction effect for *cue position* x *SOA* [ $F(1,14) = 14.45$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.05$ ], which is shown in Figure 11.

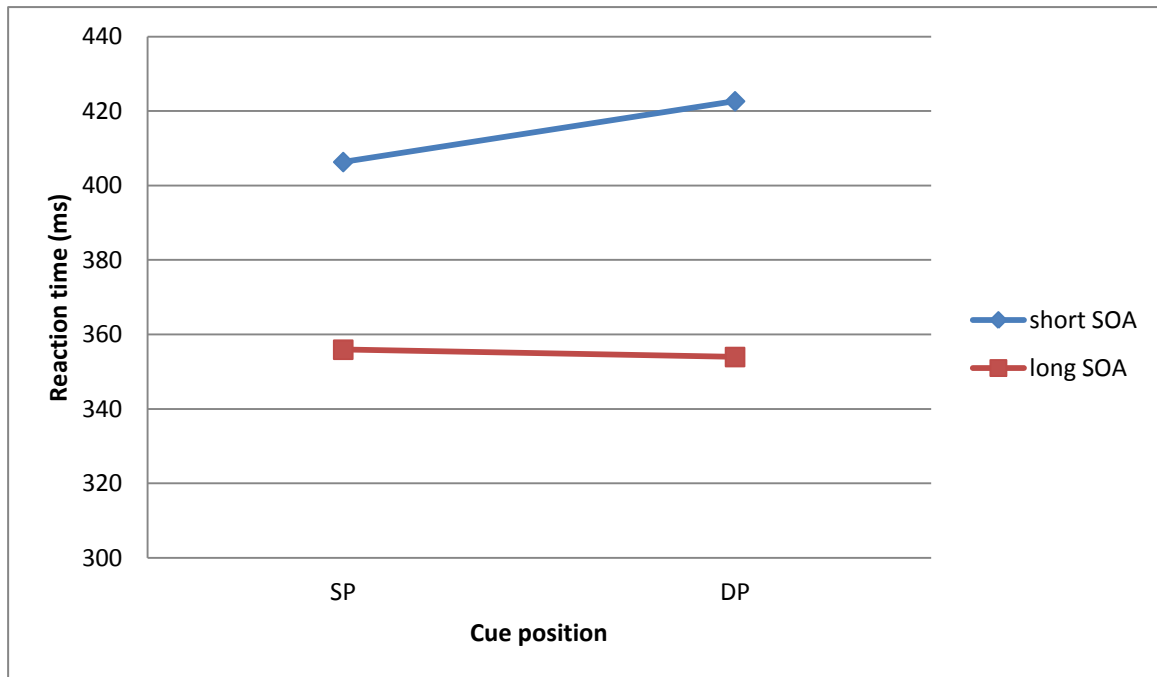


Figure 11. Depicted are mean reaction times (RTs) and cue positions of the mean of all participants, plotted separately for the short SOA condition (blue) and the long SOA condition (red).

This indicates that the *SOA* had different effects on the participants' performance depending on which of the *cue positions* was executed. Post-hoc Bonferroni-adjusted *t*-tests indicate a significant difference between the *SP* and the *DP* condition within the *short SOA* condition ( $p < 0.05$ ). As reaction times for *SP* (406 ms) were faster than reaction times for *DP* (422 ms), a cueing effect is pointed out.

At the *long SOA* there were no significant differences shown, depending on the *cue position* (mean reaction time: 354 ms,  $p > 0.05$ ).

For *SOA* x *hemifield* [ $F(1,14) = 173.91$ ,  $p < 0.01$ ,  $\eta_p^2 = 0.92$ ] another significant interaction effect occurred, results are schematically depicted in Figure 12.

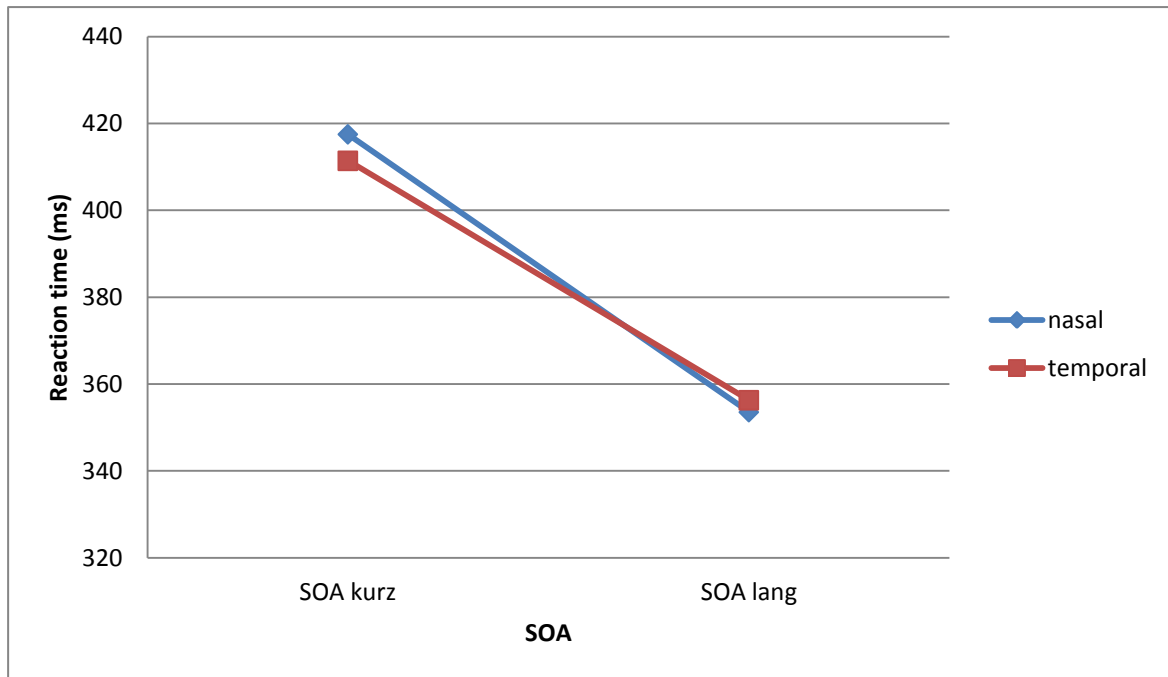


Figure 12. Depicted are mean RTs and SOA conditions of the mean of all participants, plotted separately for the nasal condition (blue) and the temporal condition (red).

This indicates that whether there was a *long* or a *short SOA* had different effects on the participants' performance depending the side of projection of the cue. Post-hoc Bonferroni-adjusted *t*-tests indicate a significant difference between the *short* and the *long SOA* condition depending on the *nasal* and *temporal* ( $p < 0.01$ ). Reaction times for the *short-nasal* (418 ms) and the *long-nasal* (354 ms) condition as well as for the *short-temporal* (411 ms) and the *long-temporal* (356 ms) condition, indicate a cueing effect.

## 8.2 Error rates

The second ANOVA, conducted with the dependent variable *error rates*, (mean error rate for target present trials = 11.9%, for target absent trials = 6.7%) showed two significant interactions. Mauchley's test indicated that the assumption of sphericity had been violated for the interaction effects of *cue position* x *hemifield*,  $\chi^2(2) = 28.97$ ,  $p < 0.01$ , *cue position* x *SOA* x *hemifield*,  $\chi^2(2) = 9.73$ ,  $p < 0.01$ . Therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ( $\epsilon = 1.0$  for all variables).

There was a significant interaction effect for *cue position* x *hemifield* [ $F(2,13) = 6.80$ ,  $p < 0.05$ ,  $\eta_p^2 = .51$ ], results are schematically depicted in Figure 13.



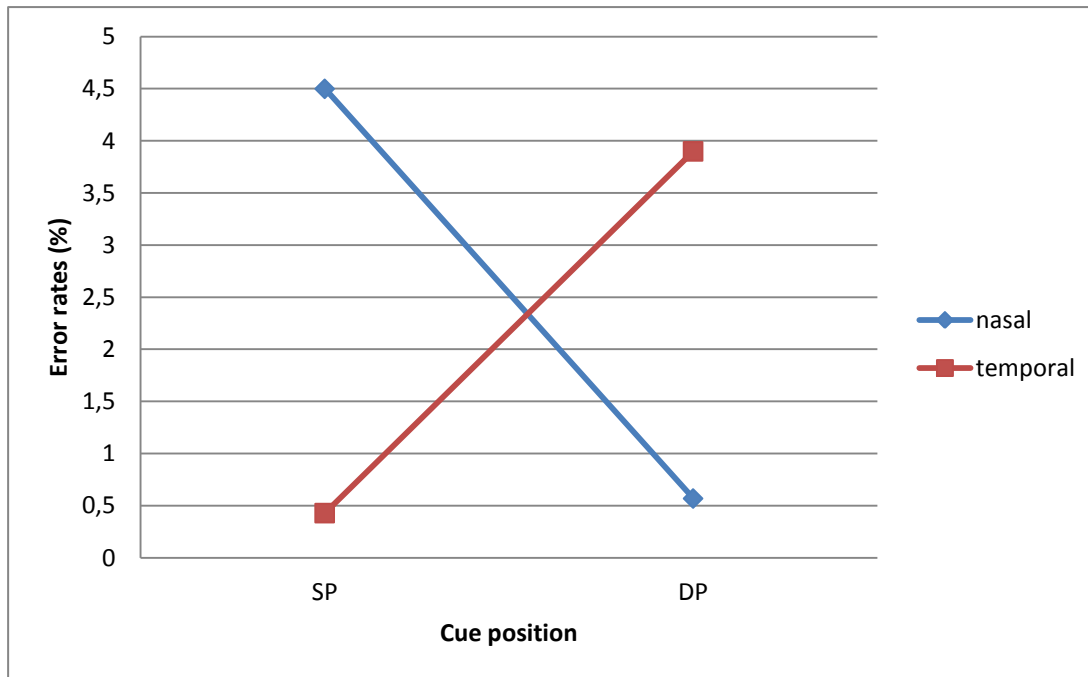


Figure 13. Depicted are mean error rates (ERs) and cue positions of the mean of all participants, plotted separately for the nasal condition (blue) and the temporal condition (red).

This indicates that the *cue position* had different effects on participants' performance depending on the *hemifield* in which the cue was presented. Post-hoc Bonferroni-adjusted *t*-tests show significantly higher ERs for cues presented in the *temporal hemifield* in the *DP* (mean error rate = 26%) compared to the *SP* condition (mean error rate = 2.9%,  $p < 0.01$ ).

In contrast, results show higher ERs for cues presented in the *nasal hemifield* in the *SP* (mean error rate = 30%) compared to the *DP* condition (mean error rate = 3.8%,  $p < 0.01$ ).

This reveals a surprising result, as no significant IOR effect appears, which refutes the first hypothesis. Furthermore the sign of nasal IOR and temporal cueing appears contrary to expectations of nasal cueing and temporal IOR according to literature.

A second significant interaction effect occurred for *cue position* x *SOA* x *hemifield* [ $F(2,13) = 6.08$ ,  $p < 0.05$ ,  $\eta_p^2 = 0.48$ ], which is shown in Figure 14, indicating that the *cue position* had different effects on the participant's performance depending on the *hemifield* in which the cue was presented and the duration of the *SOA*.

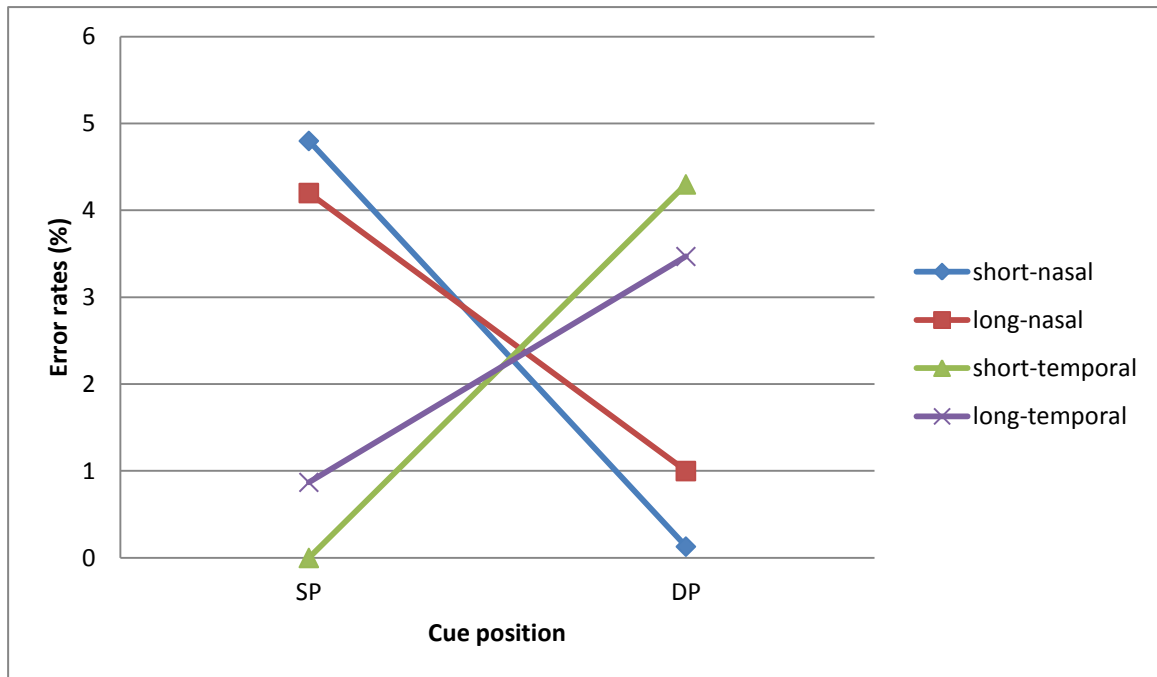


Figure 14. Depicted are mean ERs and cue positions of the mean of all participants, plotted separately for the short-nasal condition (blue), the long-nasal condition (red), the short-temporal condition (green) and the long-temporal condition (purple).

Post-hoc Bonferroni-adjusted *t*-tests show significantly higher error rates for cues presented in the *temporal hemifield* in the *DP* with a *short SOA* (mean error rate = 28,7%) compared to the *DP* condition with a *short SOA* in the *nasal hemifield* (mean error rate = 0,9%). There are also higher ERs for cues presented in the *temporal hemifield* in the *DP* with a *long SOA* (mean error rate = 23,14%), compared to the *DP* condition with a *long SOA* in the *nasal hemifield* (mean error rate = 6,7%).

In contrast, results show higher ERs for cues presented in the *nasal hemifield* in the *SP* with a *short SOA* (mean error rate = 32%), compared to the *SP* condition with a *short SOA* in the *temporal hemifield* (mean error rate = 0,0%). As well as higher ERs for cues presented in the *nasal hemifield* in the *SP* with a *long SOA* (mean error rate = 28%), compared to the *SP* condition with a *long SOA* in the *temporal hemifield* (mean error rate = 5,8%).

Consequently the results of the second ANOVA also indicate a nasal IOR and a temporal cueing effect.

## 9. Discussion and future prospects

The present study investigated the hypothesis whether exogenous capture of attention by unconscious cues is necessarily followed by IOR. Subsequent the second hypothesis, on the concern of whether the IOR effect is stronger for temporally presented cues compared to nasally presented cues, was examined during further procedure. The aim of the study was to further verify the results of Mulckhuyse et al. (2007), with an adaption of eccentricities, as previously executed experiments at the University of Vienna, failed to replicate the results of Mulckhuyse and colleges (2007).

For this purpose a subliminal cueing task and a cue report task were conducted. The assignment for the participants was to detect a target in form of a small black dot, appearing at different positions on the screen, after a subliminal cue and two placeholder rings were shown. This procedure was aiming to give the examiner the opportunity to identify IOR, by analyzing error rates and reaction times of the tasks.

The results indicate that neither does IOR automatically follow exogenous capture, nor are temporal cue projections leading to a stronger IOR effect than nasally presented cues, since no IOR effect was found in the present study. Mean reaction times for targets presented on a different position than previously shown cues were not significantly faster than for targets shown on the same position as previously presented cues.

Nevertheless findings indicate a tendency for a cueing effect for temporal presented cues and an IOR effect for nasally presented cues, without leading to significant results. These findings occurred contrary to the initially made assumptions of an IOR effect for temporally presented cues and a cueing effect for nasally presented cues, due to anatomical hemifield asymmetries.

It is assumed that subliminal cues were unconsciously perceived by the participants, as otherwise a cueing effect would also not have been shown. This finding of an overall cueing effect, hence shorter mean reaction times to a target presented at a previously cued location compared to a previously uncued location, is in accordance with the findings of Mulckhuyse et al. (2007), who also report cueing effects typically obtained in peripheral cueing paradigms, even though the peripheral cues were not consciously perceived. It is mentioned that the current study of Mulckhuyse et al. (2007) is the first to demonstrate the biphasic effect of facilitation and inhibition by subliminal cues, which leaves room for different assumptions,

such as the possibility that IOR does not necessarily follow exogenous capture of visual attention.

Given that the cues used in the present study were uninformative of the target location and did not resemble the target it is assumed that attention was captured exogenously, even though one could argue that the cue was part of an attentional set, as cues and targets were both defined by abrupt onsets (Mulckhuyse et al., 2007). Thus attention should, in the present study, be captured in a bottom-up manner as salience is displayed by contrast of a basic visual feature dimension such as: color, orientation or motion (Yantis & Egeth, 1999). The bottom-up theory of attention indicates that unconscious abrupt onsets are highly salient and therefore capture attention via the SC (Fuchs & Ansorge, 2012b), which also speaks in favor of bottom-up processing in the present study.

As Mulckhuyse et al. (2007) reported a significant IOR effect under the same conditions and a hemifield effect of IOR with similar conditions (Mulckhuyse & Theeuwes, 2010a) those conflicting results should be further investigated.

Divergent results could be based on the different eccentricity used in the present study as compared to the study of Mulckhuyse et al. (2007). It was shown that response times at cued locations increased significantly when stimulus eccentricity shifted from 15° to 20° leading to a much stronger IOR effect at more peripheral locations, in comparison to central and perifoveal regions (Bao & Pöppel, 2007). Therefore it seems possible that a systematical manipulation of stimulus eccentricity of cue and target could lead to a much stronger IOR effect in the peripheral visual field, than in regions close to the visual axis and should be regarded in further investigation, as in the present study the discs were shown either 10° to the left or to the right of the center of the screen.

One could say, according to Fuchs and Ansorge (2012b), that: “The absence of IOR after unconscious exogenous cueing in the present study certainly refutes the assumption of Mulckhuyse and Theeuwes (2010), that IOR would be a hallmark of unconscious exogenous capture” (p.7).

Furthermore it is possible that IOR and exogenous capture are brought about by dissociable cortical structures, and not by one shared sub-cortical structure, and therefore IOR and exogenous attentional capture might be less tightly coupled, leading to the possibility, that at least in some cases the IOR effect is not a necessary consequence of exogenous unconscious capture. If IOR and facilitation are the result of distinct mechanisms, perhaps

only exogenous attention occurs without awareness. IOR could be the result of a conscious strategy to orient towards novel locations and would not be observed when participants are not aware of the cue (Ivanoff & Klein, 2003). McCormick (1997) who concluded that subliminal peripheral cues could capture attention because target processing near the cue is facilitated, reports the typical facilitation effect, thought without reporting subsequent IOR. On the absence of IOR in McCormick's study (1997), Ivanoff and Klein (2003) argue that the requirement of actively searching for the cues, as participants were supposed to attend the location opposite to the cue that was more likely to contain the targets, lead to an attentional control setting. Hence this might have encouraged attention to remain engaged on the cued location, which would increase the overall facilitation effect and lead to an elimination or deferral of IOR. As mentioned above, one could argue that the abrupt onset defining both cues and targets could create an attentional set, which could be of help in the attempt to explain the findings of the present study.

Mulckhuysen and Theeuwes (2010a), who report an IOR effect for cues presented in the temporal hemifield and no IOR effect for cues presented in the nasal hemifield, clarify that the effect was not observed for all participants, as IOR displays large individual differences. The asymmetry effect was shown for 13 of their participants, who showed higher mean saccade latency in the validly cued condition compared to the invalidly cued condition at the long SOA when data was collapsed over both hemifields, the remaining nine participants showed no overall IOR effect. Examining the possible differences in IOR, based on whether a cue is presented temporally or nasally, Rafal et al. (1989) found that RTs were the same for temporal and nasal hemifields with an SOA of 50 ms, 150 ms and 300 ms. However for an interval of 500 ms detection RTs were slower at the cued location in the temporal hemifield than in the nasal hemifield, which should be considered for further research as the SOA in the present study was 80 ms for the short and 1000 ms for the long condition, both intervals were not in accordance with the study of Rafal and his colleagues. Maybe further trials with various time intervals will lead to more significant results.

As the LGN and the retinotopic cortical areas V1-V3 did not show any temporal-nasal differences and therefore differ from the SC (Sylvester, Josephs, Driver & Rees, 2006), it might be possible that not only the SC plays a role in the development of IOR, but structures that do not show the same asymmetry should be involved in further analysis, in order to review the absence of a stronger temporal IOR effect in our experiment.

As it was found by Maruff, Yucel, Danckert, Stuart and Currie (1999), that the presence and magnitude of inhibition and facilitation associated with orienting to non-predictive peripheral cues depends upon the temporal properties of both the cue and target and the SOA, this leaves a wide frame for further investigations with separate manipulations of the single experimental conditions.

A different approach might be to further consider the distribution between sexes within the participants as Colzato, Pratt and Hommel (2012) have shown that estrogen modulates IOR. In their study women in their follicular phase, which is associated with high estradiol levels and higher dopamine turnover rates, showed a more pronounced IOR effect than men.

Anyhow the biphasic pattern of early facilitation and late inhibition is not always observed in a peripheral cueing paradigm (Casagrande et al., 2012).

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## **12. List of abbreviations used**

DP	Different position
ER	Error rate
FEF	Frontal eye fields
iSC	Intermediate layer of the Superior Colliculi
IOR	Inhibition of return
LGN	Lateral geniculate nucleus
M	Magnocellular
ms	Milliseconds
NTA	Nasal-temporal asynchrony
P	Parvocellular
PEF	Parietal eye fields
PSP	Progressive supranuclear palsy
RNA	Real neural architecture
RT	Reaction time
SC	Superior Colliculi
SOA	Stimulus onset asynchrony
SP	Same position
SRTs	Saccadic reaction times
STD	short-term depression

### 13. Curriculum Vitae

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