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Unconscious attentional orienting to exogenous cues: A review of the literature

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ABSTRACT

The present paper reviews research that focuses on the dissociation between bottom-up attention and consciousness. In particular, we focus on studies investigating spatial exogenous orienting in the absence of awareness. We discuss studies that use peripheral masked onset cues and studies that use gaze cueing. The results from these studies show that the classic biphasic pattern of facilitation and inhibition, which is characteristic of conscious exogenous cueing can also be obtained with subliminal spatial cues. It is hypothesized that unconscious attentional orienting is mediated by the subcortical retinotectal pathway. Moreover, a possible neural network including superior colliculus, pulvinar and amygdala is suggested as the underlying mechanism.

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1. Introduction

In everyday life it is essential to select visual information that is important for us to help us to accomplish the goals we want to achieve. Attention is the mechanism by which we select objects, events or locations in the environment. Directing attention in a voluntary way according to our goals and intentions is referred to as top-down or endogenous attentional orienting. For example, when typing a line of words on a computer we direct our attention to the screen, the keyboard and the mouse to accomplish the task of typing. However, sometimes we automatically orient our attention to objects or events in the environment even though we had no intention to do so. For example, a bird flying passed the window will capture attention even though our intention was to attend to the computer screen. Directing attention in an involuntary way irrespective of our goals and intentions is referred to as bottom-up or exogenous attentional orienting (Egeth & Yantis, 1997; Theeuwes, 1992, 1994a, b, 2004).

Objects that are known to capture attention exogenously are, for example, feature singletons. Singletons are salient because they possess a feature, such as motion, orientation or color that is different from the rest of the scene, such as a single red rose in a field of green grass (e.g., Itti & Koch, 2000; Theeuwes & Godijn, 2002). Particularly salient is an object that is suddenly presented against a static background of no-changing objects. Such objects are known in the literature as abrupt onsets or luminance transients (Yantis & Jonides, 1984) and they have the ability to capture attention automatically (Egeth & Yantis, 1997; Schreij, Owens, & Theeuwes, 2008; but see Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994). Because abrupt onsets are highly salient, one intuitively assumes that people are always aware of an abrupt onset. However, inattentional blindness studies found that people often do not consciously perceive highly salient objects or events when their attention is focused on a different task (Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, 2005; Rees, Russell, Frith, & Driver, 1999; Scholte, Witteveen, Spekreijse, & Lamme, 2006; Simons & Chabris, 1999). Moreover, even when attention is spread across the display in a search task, abrupt onsets are not always perceived consciously (Belopolsky, Kramer & Theeuwes, 2008; Theeuwes, Kramer, Hahn, & Irwin, 1998). In these oculomotor capture studies, people were not only unaware of the presentation of the abrupt onset but sometimes even of the erroneous saccades they made to the onset. This latter finding suggests that exogenously attending to a stimulus is not automatically followed by awareness of that stimulus. Therefore, exogenous attention may be a process that is independent of awareness and intentions. Instead, it may be driven by a system that automatically activates an orienting response. To examine these automatically triggered exogenous orienting processes, the present review focuses on studies that addressed attentional *orienting* in the absence of awareness. More specifically, we address studies that investigated exogenous spatial attention by using exogenous cues presented subliminally. Note that we will focus on the orienting response based on irrelevant cues that do not posses any information related to the task. This is in contrast with priming studies in which the prime (or cue) possesses information which is relevant for the response. For instance, these studies have demonstrated that masked prime stimuli can influence responses to a target by means of semantic or motor priming (e.g., Ansorge & Neumann, 2005; Dehaene et al., 1998; Eimer & Schlaghecken, 1998; Jaskowski, van der Lubbe, Schlotterbeck, & Verleger, 2002). Other studies have focused on the orienting response to masked target stimuli. For instance, in an ERP study, Woodman and Luck (2003) showed that a masked target is identified by the visual system and triggers a shift of attention. The aforementioned studies have in common that they investigated automatically triggered response processes caused by the "unconscious" identification of subliminal stimuli, for example, the shape of a stimulus. This review focuses on the initial spatial orienting response not caused by the identification of a stimulus, but solely caused by the "unconscious" detection of subliminal stimuli. Ideally, these stimuli – exogenous cues – do not share any features with the target, do not convey any information about the upcoming target location and they do not activate any automatic process related to the response to the target. They only trigger an automatic orienting response to its location.

2. Exogenous attention

There are several findings in the literature that indicate that exogenous orienting is different from endogenous orienting. First, the time-course of orienting is different. Whereas endogenous attentional orienting is relatively slow to develop, exogenous attentional orienting is fast and occurs within 100 ms (for review, see Egeth & Yantis, 1997). Second, once attention is shifted to a location, endogenous attention is sustained and can last for a longer period of time at the attended location whereas exogenous attention is transient and may rapidly dissolve from the attended location. Because in exogenous orienting the cue has, typically, no predictive value of where the target will appear, there is no incentive on part of the observer to keep attention at the cued location because it is not relevant for the task. Third, exogenous orienting shows a typical biphasic pattern in which attentional facilitation is followed by inhibition. This latter finding is called inhibition of return (IOR; for review, see Klein, 2000) and is assumed to be a mechanism to increase efficiency in visual search by preventing attention from returning to the previously inspected locations (Klein, Munoz, Dorris, & Taylor, 2001). It is important to note that IOR only occurs when attention is captured exogenously (Godijn, & Theeuwes, 2004; Posner, & Cohen, 1984; Pratt, & McAuliffe, 2002). However, when an endogenous eye movement is made or has to be prepared to a location, IOR also occurs (Rafal, Calabresi, Brennan, & Sciolto, 1989). This finding signifies the tight relation between oculomotor programming and exogenous orienting of attention (see also Corbetta et al., 1998).

Although much research has shown that salient stimuli can capture attention in a pure exogenous or stimulus-driven way (for review, see Theeuwes, in press), it is still an ongoing debate to what degree these salient stimuli have to match top-down attentional control settings (e.g., see Eimer & Kiss, 2008; Hickey, McDonald, & Theeuwes, 2006). Top-down attentional control settings depend on the task at hand. For example, when a task is to search for a color target, the feature color will be part of the attentional set whereas other features, such as shape, will not. Consequently, irrelevant but salient color cues will capture attention while other salient cues, such as an onset cue, will not (e.g., Folk et al., 1992, 1994). This form of attentional capture is called contingent capture. A related type of top-down attentional control setting can be to search for singletons. For example, if the target is defined by a shape singleton, all other singletons, such as an irrelevant color singleton, will also capture attention (Bacon & Egeth, 1994; Leber & Egeth, 2006).

Although the ongoing debate regarding the extent to which salient stimuli capture attention in a purely stimulus-driven way or in a top-down manner is not yet resolved, recent studies have started to focus on differences in the time-course of attentional engagement between the two forms of attentional capture. The idea is that when attention is captured by an *irrelevant* salient stimulus (an onset cue while searching for a color target) attention rapidly dissolves from that location. Subsequently, when there is a gap between cue and target onset of about 150 ms (as in the Folk paradigm) attention has already shifted back from the distractor when the target is presented. As a consequence no attentional capture effects will be measured. However, when attention is captured by a *relevant* stimulus (an onset cue while searching for an onset target) attention lingers longer at the distractor location and capture effects will be measured (Belopolsky, Schreij, & Theeuwes, 2010; Mulckhuyse, van Zoest, &

Theeuwes, 2008; Pratt, & McAuliffe, 2002; Schreij et al., 2008; Theeuwes, Olivers, & Belopolsky, in press; but see Chen & Mordkoff, 2007; Folk, & Remington, 2006; Lamy, & Egeth, 2003). In this review, we will consider both the task relevance of a cue as well as the time-course of attentional disengagement as a result of the task relevance of a cue.

3. Neurophysiology of exogenous attention

Neuroimaging research investigating spatial attention has demonstrated the involvement of a frontoparietal attention network modulating visual processing at different stages in the stream of visual processing. The dorsal frontoparietal network is associated with endogenous attention while the ventral frontoparietal is associated with exogenous attention (for review, see Corbetta, Patel, & Shulman, 2008). It has been suggested (Corbetta, & Shulman, 2002) that the ventral network functions as a "circuit breaker" of ongoing selection in the dorsal network to shift attention toward the salient event. However, recent research showed that activation of the ventral network is correlated with orienting to behaviorally relevant stimuli rather than to salient (irrelevant) stimuli (Corbetta et al., 2008). Therefore, ventral network activation is rather associated with contingent capture than with pure exogenous attentional capture (Serences, et al., 2005).

An attention network that is associated with exogenous capture in non-human primates consists of the superior colliculus (SC; Bell, Fecteau, & Munoz, 2004; Dorris, Klein, Everling, & Munoz, 2002; Fecteau, & Munoz, 2005; Munoz, 2002), the frontal eye fields (FEF; Schall, & Thompson, 1999; Shipp, 2004; Thompson, & Bichot, 2005) and the lateral intrapariatal area (LIP; Colby, & Goldberg, 1999; Gottlieb, Kusunoki, & Goldberg, 1998; Kusunoki, Gottlieb, & Goldberg, 2000) that projects to the FEF and the intermediate layers of the SC (Munoz, & Everling, 2004). Much research emphasizes the role of the SC in exogenous attentional selection (Bell et al., 2004; Fecteau, & Munoz, 2005). For instance, Fecteau, Bell, and Munoz (2004) showed in a neurophysiological study that non-predictive salient cues producing attentional capture were correlated to enhanced target-related signals in the SC. This enhanced signal originated from the summation of target-related activity and residual cue-related activity. Moreover, when the cue was predictive of the upcoming target location, top-down activation increased the pre-target activation which enhanced the target-related activity even more. This resulted in stronger attentional capture but, importantly, reduced IOR effects. This latter finding is in line with the notion that IOR only occurs when attention is captured exogenously (Godijn & Theeuwes, 2004; Klein, 2000; Posner & Cohen, 1984). The essential role of the SC in IOR is also demonstrated in patient studies. These studies showed that damage to the SC reduces or eliminates the occurrence of IOR (Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988; Sapir, Soroker, Berger, & Henik, 1999). However, neurophysiological research also showed that when IOR occurs the neurons in the SC are not themselves inhibited but rather receive a reduced input from other brain regions representing the inhibited location, such as the parietal cortex (Dorris, Taylor, Klein, & Munoz, 1999; Klein, 2000). It has been suggested that the "inhibitory tag" generated in the subcortical retinotectal pathway is transmitted via the pulvinar to the parietal cortex to be encoded in spatiotopic coordinates (Danziger, Fendrich, & Rafal, 1997).

4. Spatial cueing paradigm

The typical different time-courses of endogenous and exogenous attention can be measured in a spatial cueing task (Jonides, 1981; Posner & Cohen, 1984). In a spatial cueing task, a location is cued after which a target is presented either at the cued or at an uncued location. If a location is attended, the performance with respect to a target presented at that location is improved relative to the performance to a target presented at an uncued location. Usually reaction time and accuracy to the target are the dependent variables. To examine the allocation of endogenous spatial attention, typically, a cue is presented at fixation that indicates which location observers have to attend to (e.g., a location to the left or to the right of fixation). An endogenous cue can consist of an arrow (e.g., Jonides, 1981; but see Ristic, Friesen, & Kingstone, 2002; Tipples, 2002), a word (indicating "left" or "right") or a number that indicates the location on an imaginary clock (e.g., Munneke, Heslenfeld, & Theeuwes, 2008; Theeuwes & Van der Burg, 2007). Importantly, the endogenous cue predicts the upcoming target location in more than 50% of the trials, typically, around 80%. This gives observers an incentive to use the cue and shift attention to the cued location before the target is presented (Jonides, 1981). Consequently, because observers shift their attention to the indicated location, processing of the consecutive target presented at that location is facilitated; shorter reaction times and increased accuracy are found at validly cued locations relative to invalidly uncued locations. To examine the allocation of exogenous spatial attention, typically, a cue is used that is known to summon attention. Such exogenous cue can consist of the presentation of an abrupt onset or a luminance transient, such as brightening of a placeholder at or near the location where the target will appear (typically, in the periphery). Unlike the endogenous cue, the exogenous cue does not predict the location of the target. For example, when there are two potential target locations, the cue has a validity of 50%. In other words, there is no incentive for observers to attend to the cued location. However, abrupt onsets and luminance changes, typically, capture attention in a bottom-up fashion (Yantis & Jonides, 1984). As a result, after a short delay (short SOA) processing of the consecutive target presented at that location is facilitated. However, as mentioned before, when attention is captured exogenously the facilitation effect rapidly dissolves and the location gets inhibited. Therefore, at longer delays (long SOA) the opposite pattern is found; reaction time to the target at the cued location increases and accuracy decreases compared to the opposite uncued location.

Salience may not be the only way for objects or events to capture exogenous attention. Social relevant images such as diverted eye-gaze are also known to cause an exogenous shift of attention in the direction of the gaze (Driver et al., 1999; Friesen & Kingstone, 1998; Langton, Watt, & Bruce, 2000; but see Ristic et al., 2002; Tipples, 2002). Typically, these so-called gaze cuing studies make use of centrally presented faces or schematically drawn faces with their eye-gaze directed to a particular location. Even though the directional gaze cue does not predict the upcoming target location and there is no incentive for observers to deliberately direct their attention in the direction of the eye-gaze, cueing effects at that location are observed. Similar to peripheral onset cues, orienting in response to gaze cues is fast. Note, however, that unlike peripheral onset cues, the response is not transient but sustained. Typically, no IOR is found with gaze cues. Although not yet fully understood, it is suggested that this difference comes from the different underlying neural pathways in automatic capture of attention to abrupt onsets and automatic capture of attention by gaze. Whereas the former is often associated with the subcortical processes that underlie oculomotor behavior, such as the SC, the latter is more associated with cortical processing (Friesen & Kingstone, 2003).

5. Subliminal spatial cueing studies

One of the methods to present stimuli subliminally is backward masking. In backward masking a visual stimulus is presented very briefly and followed by a second visual stimulus, called the mask. Due to the mask, visibility of the first stimulus is abolished (Breitmeyer, 1984). The recurrent processing theory would state that information of the first stimulus is processed by the feedforward sweep but at the moment in time that this information is fed back to the lower visual areas, new information of the visual mask comes in and thereby disrupts the recurrent interactions that dealt with the first stimulus (Di Lollo, Enns, & Rensink, 2000; for an overview of theories on masking, see Breitmeyer & Ogmen, 2000, 2006). Backward masking is not the only method used to present stimuli subliminally; some studies manipulate contrast and luminance in such a way that stimuli are presented below subjective threshold (for methodology of unconscious perception, see Abrams & Greenwald, 2000; Cheesman & Merikle, 1984, 1986; Greenwald, Draine, & Abrams, 1996; Reingold & Merikle, 1988, 1990; Snodgrass, Bernat, & Shevrin, 2004).

5.1. McCormick (1997)

The aim of a study by McCormick (1997) was to provide more compelling evidence that exogenous attention is an automatic involuntary process. He reasoned that voluntary endogenous attention cannot be captured by stimuli that are not consciously perceived. In this study, peripheral cues were presented either above or below subjective threshold. To present the cues below subjective threshold, monitor brightness, monitor contrast and room luminance were adjusted. In addition, the cues were informative of the target location in the sense that the target appeared more often at the opposite location of the cue than at the cued location. Observers were explicitly told that they had to shift their attention to the opposite location of the cue. In this way the design allowed to obtain qualitative differences between processing of stimuli presented above and below subjective threshold (Cheesman & Merikle, 1986). That is, peripheral cues presented below threshold would solely induce an exogenous shift of attention while cues above threshold would instruct observers to shift attention endogenously to the opposite location. Immediately after each trial, observers were asked to indicate whether or not they had perceived the cue. Indeed, results from this study revealed that qualitative differences can be obtained between cues that were consciously perceived and cues that were not consciously perceived (Experiment 1 and 2). At the short SOA (500 ms), when observers perceived the cue, they were faster to respond to targets presented at the opposite site of the cued location. This indicated that they endogenously shifted their attention to the opposite site. However, when observers did not perceive the cue, they responded faster to targets that appeared at the cued location compared to the opposite location. This latter result suggests that the 'invisible' cues captured attention in an exogenous way. However, as mentioned before, true exogenous orienting should induce inhibition when the delay between cue and target presentation is extended. Therefore, McCormick also investigated cueing effects with a long cue target SOA (1000 ms, Experiment 3). However, no inhibitory effect was obtained. McCormick attributed the lack of IOR to the strategy of the observers to detect the cue. He reasoned that if observers did not immediately detect the cue they would have more time to divide their attention between the possible locations to search for it and, therefore, inhibition could not be measured at the cued location.

In conclusion, this study showed that peripheral cues presented below subjective threshold captured attention. However, no IOR was obtained at a long SOA. Possibly, the lack of IOR is due to the design of the experiment (the cues were task relevant). Therefore, it is not possible to conclude that attention was captured in a purely exogenous way.

5.2. Lambert, Naikar, McLachlan and Aitken (1999)

In a subliminal spatial cueing study by Lambert, Naikar, McLachlan and Aitken (1999) an inhibitory effect at the long SOA was found (Experiment 2). In this study, perceptually faint peripheral cues were presented in each of the two outer corners of a box presented either to the left or right of fixation. These boxes served as placeholders in which the target could appear. The strength of the cues had three different magnitudes: they were either one, two or five pixels large. The observers were told that the cue was 80% valid and, therefore, informative of the upcoming target location. In a separate session, it was shown that none of the observers perceived the one pixel cue, 9 out of 12 observers were unable to perceive the two pixel cue and the five pixel cue was perceived above chance level. Of the cues that were not perceived (one and two pixels), the one pixel cue had no effect on spatial attention whereas the two pixel cue had a marginal significant effect on spatial attention. For the observers who were unaware of this cue, the results showed facilitation at the short SOA followed by inhibition at the long SOA. However, the aim of this study was to investigate implicit learning effects regarding the relation between cue and target. In Experiment 3 of their study, Lambert et al. showed that the 'invisible' cue had not captured attention exogenously but rather observers had learned the relation between cue and target in an implicit way. The biphasic pattern of facilitation followed by inhibition obtained in Experiment 2 could, therefore, not be attributed to unconscious exogenous orienting but rather to implicit learning. They reasoned that the results from Experiment 2, in which the pattern resembled exogenous orienting instead of implicit learning was due to the fact that implicit learning can have different time-courses depending on the nature of the relationship, the nature of the cue stimuli, levels of practice and the nature of the response.

In conclusion, this study showed that peripheral cues presented below subjective threshold induced attentional effects. However, these effects were obtained because of unconscious learning of the cue and target relationship and not because of unconscious exogenous orienting. In addition, it should be mentioned that IOR only occurs following exogenous attention while in their experiment the cue had a predictive value. Therefore, the inhibitory effect they obtained probably cannot be attributed to IOR.

5.3. Ansorge and Heumann, (2006)

In a series of experiments, Ansorge et al. investigated implicit learning effects, response priming and unconscious attentional cueing effects with visible and invisible spatial cues. To present the cues subliminally they used metacontrast masks. The cue appeared either at the left or right of fixation. The task of the participants was to respond to the location of the target (Experiment 1 and 3), or to the orientation of the target consisting of two bars (Experiment 2). The target was presented simultaneously with the masks but cleared after 34 ms while the masks stayed on the display. The cue detection task, indicating left or right, was performed in a separate task. In Experiment 1 the validity of the cue was congruent with the response to the target (i.e., a valid cue was congruent and an invalid cue was incongruent) and the results showed a validity effect for the visible cue as well as the masked cue. However, in Experiment 2, observers had to respond to the orientation of the target. The results showed that the validity effect was still present when the target was cued with a visible cue but not when the target was cued with the masked cue. In the latter case, the masked cue did not capture attention. In Experiment 3 the cues were predictive of the upcoming target location. Half of the observers performed a task in which the cue was around 66% valid (besides neutral and invalid trials), the other half a task in which the cue was around 66% invalid. The results showed that this information was used when the cue was visible; validity effects were stronger when the cue was 66% valid compared to 66% invalid. In contrast, when the cue was masked the probability information of the cue was not used because the validity effect was not significantly stronger when the valid cue was predictive for the upcoming target location. Based on these results, Ansorge et al. concluded that unconscious cue processing only has an effect when the information delivered by the masked cue matched the intention of the observer (for similar conclusions, see Ansorge & Neumann, 2005; Scharlau & Ansorge, 2003).

In conclusion, this study showed that peripheral cues presented below subjective threshold are processed up to a certain level but only affect reaction time if they contain information about the appropriate response. No evidence was found for an unconscious attentional effect or implicit learning.

5.4. Scharlau and Ansorge, (2003)

In a somewhat different set-up, Scharlau and Neumann (2003) investigated whether a phenomenon named perceptual latency priming (PLP) is due to bottom-up attentional capture, response priming or sensory priming. PLP refers to the faster perception of a stimulus that is preceded by a prime stimulus. This is measured in a temporal order judgment (TOJ) task. In a TOJ task, two targets, a diamond and a square are presented on an imaginary horizontal or vertical line with a slight temporal difference. One of the targets is preceded by the prime stimulus. The task of the observers is to judge which target was presented first. Commonly, the target that is preceded by the prime is perceived faster. In this study, the prime was masked by the target and could either be congruent (Experiment 1) or incongruent (Experiment 2) with the target. Congruent in this sense meant a smaller replica of the target and incongruent a smaller replica of the target with the alternative response. After participants had performed the TOJ task, detection of the prime was assessed. In the prime detection task, participants had to indicate whether a prime stimulus was present or absent (Experiment 1) or they had to identify the prime stimulus (Experiment 2). Results from the TOJ experiments showed that targets that were preceded by a masked prime were perceived faster, irrespective of congruency. These results are in line with the idea that the prime captured attention unconsciously, just as a subliminal spatial cue in a spatial cueing task. Because attention is shifted to the cued location, stimuli at that location are perceived faster. However, in Experiment 1 observers scored slightly above change in the detection task and in Experiment 2 not detection of the prime but identification was measured. Therefore, it is possible that in both experiments the primes were, at least to some extent, consciously detected.

In conclusion, this study showed that masked prime stimuli preceding a target stimulus induce perceptual latency priming in a TOJ task. Because the prime speeds up perception irrespective of the information it gives about the appropriate response, the results suggest that attention is unconsciously shifted to the primed location. However, result from the detection tasks do not refute the possibility that the primes were consciously detected to some degree.

5.5. Ivanoff and Klein (2003)

The idea that the absence of IOR in McCormick (1997) was due to the observer's strategy, as suggested by McCormick, motivated a follow-up study by Ivanoff and Klein (2003). They hypothesized that the design of the McCormick's study may have biased observers to search for the cue because it was informative of the upcoming target location. Moreover, after each trial observers had to report whether or not they perceived the cue. Therefore, unconscious orienting to the cue could have been contingent on the task, i.e., the requirement to report after each trial whether they perceived the cue. They reasoned that observers probably had an attentional set to look for the cue (cf. Folk et al., 1992). The contingent capture theory (Folk et al., 1992, 1994) states that at the early stage in visual processing, top-down attentional control settings induced by task demands are crucial for attentional capture to occur. In the subliminal cueing task by McCormick, the task demands of reporting the cue after each trial could, therefore, have induced an attentional set to search for it. To test this hypothesis, Ivanoff and Klein performed a study with masked peripheral cues that were uninformative of the upcoming target location and should, therefore, not induce an explicit attentional set to search for it. The study consisted of two experiments. In the first experiment, observers only performed the experimental task – a go/no go task – and in the second experiment, in addition to the experimental task they had to report after each trial whether or not they had detected the cue. When cue report was part of the task, the results were consistent with McCormick's study and with the attentional control set hypothesis; that is, facilitation at the short SOA and no IOR at the long SOA. In contrast, when cue report was not part of the task the results showed the opposite pattern; no facilitation at the short SOA though IOR at the long SOA. Ivanoff and Klein explained the lack of IOR in the cue report condition by a failure to disengage attention from the cued location. They reasoned that observers were unaware of orienting to the cued location but due to the attentional set to search for the cue their attention dwelled longer at the cued location (see also Babiloni, Vecchio, Miriello, Romani, & Rossini, 2006). In contrast, the lack of facilitation in the condition in which observers did not have to detect the cue was explained by rapid disengagement of attention. Ivanoff and Klein argued that due to rapid disengagement of attention, the early facilitation was combined with early IOR which led to similar RTs at cued and uncued locations.

In conclusion, this study shows that cues that are not consciously perceived can induce a shift of exogenous attention. When the cue was not part of the attentional set, IOR was found although not preceded by facilitation. However, an attentional set to search for the cue altered the temporal dynamics of exogenous orienting. When cue detection was part of the attentional set, facilitation is not followed by IOR.

5.6. Mele, Savazzi, Marzi and Berlucchi (2008)

Mele et al. (2008) conducted a spatial cueing study with subliminal cues but they came to a different conclusion than Ivanoff and Klein (2003). They performed a spatial cueing study with peripheral low luminance cues which were presented below subjective threshold and with high luminance cues presented above subjective threshold. The high luminance cues resulted in facilitation at the short SOA and IOR at the long SOA but the low luminance cues did not result in facilitation at the short SOA though it was followed by IOR at the long SOA (Experiment 2). In addition, in Experiment 4 they showed that observers responded slower at the long SOA to a low luminance cued location compared to a condition in which no cues were used, although no difference was observed between the conditions at the short SOA. This pattern of results is similar to the results of Ivanoff and Klein (2003) in the condition in which cue detection was not part of the task, i.e., lack of facilitation at the short SOA followed by inhibition at the long SOA. However, Mele et al. claimed that the obtained inhibition effect at the long SOA was the result of sensori-motor control as postulated by Eimer and Schlaghecken (1998) rather than the result of attentional modulation. Eimer and Schlaghecken (1998, 2003) showed that a subliminal prime that is not compatible with the response to the target induces an exogenous mode of response inhibition. Eimer and Schlaghecken argued that subliminal primes activate a response that is automatically inhibited by self-inhibitory circuits in motor control. In these experiments, subliminal primes were either compatible or incompatible with the response to the target. For example, arrows (prime and target) pointing to the right indicating a right hand response. This is in contrast to the spatial cueing task Mele et al. used in which the cue did not give any information about the target or the appropriate response to the target and thus exclusively captured attention in an automatic fashion. Although Mele et al. claimed that the self-inhibitory mechanisms were related to the fact that the cue and the target shared the same location (Harvey, 1980), this does not appear to be consistent with the idea of self-inhibitory response activation as proposed by Eimer and Schlaghecken (2003). It is not consistent because Schlaghecken and Eimer (2000) showed that benefits of incompatible primes are not present when they are presented in the periphery. In Mele et al. the cue and target were presented in the periphery. Therefore, a self-inhibitory response activation explanation is not convincing. However, the explanation for a negative compatible effect as a motor-inhibition account has been subject to debate (Lingnau & Vorberg, 2005; for review, see Sumner, 2007). Furthermore, the spatial cue in Mele et al. satisfied the criteria for exogenous cueing: the cue was the illumination of one of the placeholders in which the subsequent target was presented, the cue was uninformative of the target location and target location was irrelevant for the appropriate response to the target. Therefore, instead of self-inhibitory response activation, the rapid disengagement hypothesis of Ivanoff and Klein seems more fitting to explain a lack of facilitation at the short SOA when followed by IOR at the long SOA.

In conclusion, this study showed that spatial cues presented subliminally can induce a shift of exogenous attention resulting in inhibition at the cued location at the long SOA. Although Mele et al. (2008) do not attribute this effect to attentional mechanisms because of the absence of facilitation at the short SOA, it is most likely that attention was shifted to the cued location in an exogenous way. The explanation as proposed by Ivanoff and Klein (2003) could account for the lack of facilitation at the short SOA; that is, due to rapid disengagement of attention, the early facilitation was combined with early IOR. The idea that rapid disengagement of task irrelevant cues can conceal facilitation effects was tested in an ERP study with subliminally presented spatial cues (Ansorge & Heumann, 2006). The task relevance of the cue was systematically reduced by decreasing the match between features defining the cue and the target. Therefore, the attentional set to search for the cue dissipated and consequently, attentional capture as measured by reaction time was abolished. However, the PCN (Posterior Contralateral Negativity), an electrophysiological measure of the capture of visuospatial attention, showed that attention was captured by the cue even when the cue was task irrelevant. These findings suggested that the overt manual response lags behind the capture effect as shown by the PCN. Consistent with Ivanoff and Klein (2003) they concluded that subliminally presented task irrelevant cues capture attention in a bottom-up fashion but due to rapid disengagement, facilitation effects can be concealed.

5.7. *Mele, Savazzi, Marzi and Berlucchi (2008)*

A recent study by Mulckhuyse confirmed the rapid disengagement hypothesis of Ivanoff and Klein. They reported facilitation and IOR in a spatial cueing task with subliminal peripheral cues. The cues they used were uninformative of the upcoming target location and assessment of cue awareness was performed in a second separate task performed after the main experiment. Therefore, observers could not have had an attentional set to search for the cue. The cue consisted of one of three placeholders: one in the centre, one to the left and one to the right. In different trials, the placeholder on either the left or right side was presented slightly before the other two placeholders. Observers were unaware of this temporal difference. Subsequently, after a short or a long SOA a target was presented either in the left or the right placeholder. The study showed that there were performance benefits at the short SOA for a target appearing within the placeholder that was presented slightly before the other two placeholders signifying early attentional facilitation. Accordingly, at the long SOA performance was worse at that location compared to the opposite location, indicating IOR. It was argued that in this study early facilitation was found because the SOA between cue and target was very short, i.e., only 16 ms. Because of the very short SOA, early facilitation was not overshadowed by an early onset of IOR, as was probably the case in Ivanoff and Klein (2003) and Mele et al. (2008). In Ivanoff and Klein the shortest SOA used was 105 ms; in Mele et al. the shortest SOA was 150 ms.

In conclusion, because Mulckhuyse et al. found the classic biphasic pattern of early facilitation followed by later inhibition, they concluded that unconsciously processed spatial cues can capture attention in a purely exogenous way.

5.8. *Mele, Savazzi, Marzi and Berlucchi (2008)*

Bauer, Cheadle, Parton, Muller, & Usher, (2009) performed an innovative version of a subliminal spatial cueing paradigm. Based on the hypothesis that synchronized gamma oscillations (40–70 Hz) in neural activity mediate attentional processes, they performed a series of experiments in which they presented subliminal gamma flickering stimuli to induce attentional selection. Gamma band synchrony is associated with top-down visual attention but Bauer et al. examined whether they could trigger attentional effects by externally evoking gamma band oscillations. The spatial cue in this paradigm consisted of one of three Gabor patches, which were presented on an invisible circle around fixation point. The cue flickered at a different frequency, i.e., 50 Hz (gamma band) or 30 Hz (below gamma band) than the other two patches. The other two patches flickered either at 100 Hz or 120 Hz, which is perceived as non-flickering and too high to evoke oscillatory responses. The task consisted of either detecting a spatial frequency change of one of the patches, a contrast modulation of one of the patches, or a dot probe detection task. Bauer et al. used the latter two tasks to ensure that the cue did not capture attention because it was task relevant in the sense that it shared features (temporal change) with the target. The target could be presented at the cued location (50%) or at one of the other two locations in one experiment. In a separate experiment, the cue was informative of the upcoming target location; it was presented opposite to the cued location in 80% of the trials. It is important to note that the 50-Hz flickering was not consciously perceived (detection at chance level) and, therefore, did not induce attentional selection based on other processes than temporal modulation. Results showed that observers were faster to detect the target at the gamma band cued location compared to the other two uncued locations, irrespective of the task of the observers (frequency change, contrast modulation or dot probe detection) or of the predictive value of the cue. This difference was not found for the below gamma band cued location. In addition, Bauer et al. also examined the time-course of subliminal gamma band induced attentional modulation and found the typical biphasic pattern associated with exogenous attention: facilitation at the short SOA and IOR at the long SOA. The authors concluded that an exogenous flicker cue that evokes gamma activity at that location acts as a mechanism similar to attentional enhancement.

In conclusion, subliminally presented synchronized gamma oscillations, normally associated with top-down attention, can induce a shift of exogenous attention. However, because the cue was not completely task irrelevant, it was valid above chance level (50% with three locations), the facilitation and inhibition effects cannot be totally attributed to exogenous attention.

5.9. *Sato, Okada and Toichi (2007)*

More evidence for the account that unconsciously perceived cues can induce an exogenous shift of attention comes from studies with subliminally presented gaze cues. Presented supraliminally, gaze cues trigger an exogenous shift of attention in the direction of the gaze (Driver et al., 1999; Friesen & Kingstone, 1998; for review, see Langton et al., 2000). In a study by Sato et al. (2007) the gaze cues – either schematic (Experiment 1) or photographs (Experiment 2) – were presented supraliminally or subliminally at fixation. The direction of the gaze (left or right of fixation) was not informative of the upcoming target location. The target consisted of a circle that was presented either to the left or to the right of fixation. In this study, they only examined facilitation effects at the short SOA. Observers had to indicate the target location by giving a manual response. To present the gaze cues subliminally, the cues were presented very briefly and masked with backward masks (Esteves & Ohman, 1993). In a separate session before the actual experiment started, threshold assessment of the cue was performed with different SOAs between cue and mask. Observers had to indicate whether they perceived the gaze cue and if so, they had to report the direction of the gaze cue. During the experiment, an SOA 10 ms shorter than the lower limit of cue detection in the separate task was used. The results of both spatial cueing tasks indicated that the supraliminally presented cues resulted in a facilitation effect at the cued location (direction of the gaze). Akin to the supraliminal cues, the subliminally presented gaze cues also induced an exogenous shift of attention leading to facilitation at the cued location.

In conclusion, this study shows that exogenous attention can be triggered by gaze cues that are presented subliminally. Targets presented at the location of the direction of the gaze are localized faster than targets presented at the opposite uncued location.

6. Conclusions

Table 1 summarizes the results and the methods used by the subliminal spatial cueing studies. As postulated by Ivanoff and Klein (2003) it seems reasonable that an attentional set to search for the cue alters the temporal dynamics of exogenous orienting. They claimed that when the cue is task relevant, attention stays engaged at the cued location. This would explain the lack of IOR in McCormick (1997). However, this explanation would require the assumption that the act of staying engaged at a location is an unconscious process although the attentional set to search for the cue is by definition a conscious process because observers were asked to look for it. Therefore, one would assume that after the initial unconscious orienting response to the subliminal cue – one is probably not aware of the shift of attention – attention would stay at the cued location because of the attentional set. Although this explanation seems plausible, it would suggest that one should also find facilitation at the long SOA. This was neither found in McCormick (1997) nor in Ivanoff and Klein (2003). Therefore, since there was no RT difference at the long SOA between cued and uncued locations, McCormick's explanation that attention is divided between the possible target locations seems to fit better with the data.

When the cue is truly exogenous, as in Ivanoff and Klein Experiment 1 (2003), Ansorge, Heumann, and Scharlau, Experiment 2 (2002) and Mele et al. (2008), the lack of facilitation can be attributed to rapid disengagement. The ERP study by Ansorge and Heumann (2006), in which they systematically manipulated the task relevance of the cue, indicated that attention can be captured in an exogenous way even though manual responses do not show evidence of attentional capture. This would be consistent with the explanation given by Mulckhuyse et al. (2007). They used a very short SOA between the subliminal cue and the target and were able to demonstrate a biphasic pattern of facilitation and inhibition, which is also characteristic of conscious exogenous attention.

7. Conscious and unconscious processing of visual stimuli

Most theories on consciousness are based on studies of visual perception because the neural correlates of the visual system are understood reasonably well (e.g., Crick & Koch, 1990, 2003; Dehaene, Changeux, Naccache, Sackur, & Sergent, 2006; Koch & Tsuchiya, 2007; Lamme, 2003, 2004, 2006). An important theory on consciousness has been put forward by Lamme (2003, 2004, 2006). Whereas other theories on conscious visual processing focus on neural synchronized oscillation (e.g., Crick & Koch, 1990, 2003; Tononi & Koch, 2008) or on activations of parieto-frontal network (Dehaene et al., 2006; for review, see Kanwisher, 2001), Lamme's theory focuses mainly on the temporal stages of neural processing. After a visual stimulus is presented, the information is fed forward (feedforward sweep) via the parallel pathways from lower to higher visual areas. However, the hierarchy of visual processing in the initial feedforward sweep is not that sharply defined. Higher visual areas, such as MT are activated at very short latencies by the feedforward sweep, possibly via the retinotectal subcortical pathway or via the quick magnocellular cortical pathway (Ffytche, Guy, & Zeki;, 1995; Lamme, 2001; Lamme & Roelfsema, 2000). At this stage visual processing is unconscious but it can trigger or modify behavior (Lamme, 2003). The theory proposes that subsequent recurrent processing through backward and horizontal connections will lead to visual consciousness.

Most current theories agree on the idea that attention can be dissociated from consciousness (Crick & Koch, 1990, 2003; Dehaene et al., 2006; Koch & Tsuchiya, 2007; Lamme, 2003, 2004, 2006). However, Lamme dissociates attention from consciousness by emphasizing that attention is the mechanism by which one transfers a visual stimulus from one conscious stage (phenomenal awareness) into the other conscious stage (access awareness). In his theory there is not much room for unconscious spatial orienting and specifically not for unconscious bottom-up attentional orienting to subliminal exogenous cues. Nevertheless, in his theory, the feedforward sweep can trigger a reflex-like response. If exogenous attentional orienting is comparable to a reflex-like response (Sokolov, 1963) that occurs before one becomes aware of the stimulus that triggers this response (Posner, 1980), feedforward processing could be the underlying

Table 1

	Method	Assessment of cue perception	Pure exogenous	Facilitation	IOR
McCormick (1997)	Low contrast/luminance cue 15 ms	After each trial	No: cues were task relevant	Yes	No
Lambert et al. (1999)	Low contrast/luminance cue 100 ms	Separate task after experimental task	No: cues were 80% valid	Yes	Yes
Exp 1 Ansorge et al. (2002) Exp 2	Backward masking	Separate task after experimental task	No: cues were task relevant	Yes	N/A
	Backward masking	Separate task after experimental task	Yes	No	N/A
Exp 1 Scharlau and Neumann, (2003) Exp 2	Backward masking	Separate detection task after experimental task	No: cues were task relevant	Yes	N/A
	Backward masking	Separate identification task after experimental task	Yes	Yes	N/A
Exp 1 Ivanoff and Klein (2003) Exp 2	Backward masking	No	Yes	No	Yes
	Backward masking	After each trial	No: cues were part of attentional set	Yes	No
Mele et al. (2008)	Low contrast/luminance cue 50 ms	Threshold assessment cue visibility beforehand	Yes	No	Yes
Mulckhuyse et al. (2007)	Temporal asynchrony onset cues	Separate task After experimental task	Yes	Yes	Yes
Bauer et al. (2009)	Gamma flickering cue	Separate task before experimental task	No: cues were 50% valid with three possible target locations	Yes	Yes

mechanism of exogenous attentional orienting, whether conscious or unconscious. Specifically in the case of orienting to masked stimuli only the feedforward information is processed. Therefore, it is possible that unconscious exogenous orienting may rely stronger on feedforward processing than conscious exogenous orienting.

8. Neurophysiology of orienting to subliminal spatial cues

In the feedforward sweep visual information rapidly reaches attentional areas such as SC, FEF and parietal cortex (Lamme, 2003; Lamme & Roelfsema, 2000). Note that this information is not only fed forward by the cortical pathway but also by the subcortical retinotectal pathway. This pathway is often denoted as the pathway that mediates visual processing in the absence of awareness in patient studies, for example, in studies with hemianopic patients (e.g., Danziger et al., 1997; Van der Stigchel, van Zoest, Theeuwes, & Barton, 2008). Hemianopic patients have a lesion in the cortical pathway of visual processing, which projects from the retina to the lateral geniculate nucleus (LGN) of the thalamus to the striate cortex, but the subcortical pathway is still intact. Some of the hemianopic patients show evidence of visual processing in their blind field which is referred to as blindsight (Weiskrantz, 1986). A blindsight patient can reliably report the stimuli in the blind field even though the patient is unaware of the presence of the stimulus. Exogenous attentional processing has also been demonstrated in blindsight. In this study (Kentridge, Heywood, & Weiskrantz, 1999), a patient with blindsight performed a spatial cueing task in which processing at the validly and invalidly cued locations in his blind field was compared. The results showed that the patient responded faster to validly cued targets in his blind field than to invalidly cued targets in his blind field. The same patient was scanned in an fMRI study by Sahraie, Weiskrantz, Barbur, Simmons, and Williams (1997). They found that subcortical structures and in particular the SC were activated in trials in which the patient reported no awareness of a visual event although his discrimination performance of this visual event was above chance.

The important role of the SC in unconscious attentional orienting was also demonstrated in a recent oculomotor study (Van der Stigchel, Mulckhuyse and Theeuwes (2009). In the study by van der Stigchel et al., observers had to make a vertical saccade while a subliminal spatial distractor was presented next to the saccade path. Typically, a visible distractor presented next to the saccade path will lead to deviations of the saccade (for review, see Van der Stigchel, Meeter, & Theeuwes, 2006; Van der Stigchel et al., 2009). These deviations are attributed to competition between distractor and target representations in the oculomotor network and specifically in the SC (McPeek, Han, & Keller, 2003). Van der Stigchel et al. (2009) showed that a subliminal distractor still affected the saccade deviation indicating that subliminally presented visual information evokes competition in the oculomotor system (but see Cardoso-Leite & Gorea, 2009).

It has been suggested that the essential role of the subcortical retinotectal pathway and the SC in particular in attentional orienting comes from the temporal-nasal asymmetry in this pathway. A temporal-nasal asymmetry effect becomes clear under monocular viewing conditions; visual stimuli in the temporal hemifield have stronger attentional effects than visual stimuli in the nasal hemifield (e.g., Ansorge, 2003; Dodds, Machado, Rafal, & Ro, 2002; Mulckhuyse & Theeuwes, 2010; Posner & Cohen, 1980; Rafal, Smith, Krantz, Cohen, & Brennan, 1990; Rafal, Henik, & Smith, 1991; Sapir et al., 1999; Simion, Valenza, Umilta, & Dallabarba, 1995; but see Bompas, Sterling, Rafal, & Sumner, 2008; Walker, Mannan, Maurer, Pambakian, & Kennard, 2000). An anatomical asymmetry in the retinotectal pathway could be responsible for the observed behavioral asymmetry effects in attentional orienting. The retinotectal pathway is essentially monocular and has more connections from the nasal hemiretina (corresponding to the temporal hemifield) to the contralateral SC than from the temporal hemiretina (corresponding to the nasal hemifield) to the contralateral superior colliculus. This anatomical asymmetry is evident in cats (Sherman, 1974; Sprague, 1966) but is, however, less apparent in monkeys (Williams, Azzopardi, & Cowey, 1995). Nonetheless, a recent fMRI study with humans showed enhanced activity in the SC for stimuli presented in the temporal hemifield compared to stimuli in the nasal hemifield while this effect was neither evident in the LGN nor in the visual cortex (Sylvester, Josephs, Driver, & Rees, 2007). Moreover, behavioral studies with hemianopic patients under monocular viewing conditions corroborate that unconscious processing via the retinotectal pathway is stronger in the temporal hemifield than in the nasal hemifield. In a study by Dodds et al. (2002), for example, a hemianopic patient performed a forced choice localization task with target stimuli presented either in the temporal blind hemifield or in the nasal blind hemifield. The results showed that the patient scored highly accurate in the temporal hemifield and at chance level in the nasal hemifield. More recently, this hypothesis was tested with healthy humans in a subliminal spatial cueing task under monocular viewing conditions (Mulckhuyse & Theeuwes, 2010). The design was a modification of the spatial cueing task Mulckhuyse et al. (2007) used. They used saccade latencies as the dependent variable because involvement of the SC is stronger in oculomotor IOR than in manual IOR. Two placeholders were presented to the left and the right of fixation indicating the possible saccadic target location. Next to the each placeholder a large filled circle was presented with a small temporal asynchrony between them. The circle that appeared first served as a spatial cue. Observers were unaware of the temporal difference between the onsets of the circles. Subsequently, after a short or a long SOA one of the placeholders changed color indicating the saccadic target location. Observers were asked to make a speeded saccade to this location. The study showed that at the short SOA saccade latencies were shorter to the location that was subliminally cued. However, this effect was not different across the temporal and nasal hemifields. At the long SOA there was a temporal-nasal asymmetry difference, but only for those observers who showed an overall IOR when data from both hemifields were combined. Although these results are consistent with retinotectal mediation in unconscious attentional orienting, the results are also consistent with the idea that the retinotectal pathway mediates sensori-motor priming (see also Ansorge, 2003). That is, in the paradigm used by Mulckhuyse et al. the cue simply could have primed the oculomotor system to make a saccade to that location. Consequently, when cue and target location are congruent, saccade latencies at the short SOA are faster to validly cued locations than to invalidly cued locations. Furthermore, the inhibitory effect at the long SOA could be explained as a negative congruency effect (NCE; see also Mele et al., 2008). However, as already mentioned, inhibition is not always found for stimuli presented in the periphery (Schlaghecken & Eimer, 2000, but see Lingnau & Vorberg, 2005). In addition, the explanation for the negative congruency effect as a motor-inhibition account has been subject to debate (for review, see Sumner, 2007).

9. Neurophysiology of orienting induced by subliminal gaze cues

In their study with subliminally presented gaze cues, Sato et al. (2007) speculated that a possible neural mechanism for gaze induced unconscious attentional orienting may involve a subcortical route involving the amygdala, pulvinar and superior colliculus. It is clear that the SC and the pulvinar play an essential role in exogenous attention (e.g., Shipp, 2004), but the role of the amygdala in exogenous attention is yet not so clearly understood. The amygdala is associated with face and gaze perception (De Gelder, Frissen, Barton, & Hadjikhani, 2003) but also with fear and emotion processing (e.g., LeDoux, 2000). For face processing, a temporal-nasal asymmetry difference has been found. In a study by De Gelder and Stekelenburg

(2005) in which ERPs were measured, it was shown that observers had a higher sensitivity to faces presented in the temporal hemifield. The authors suggested that the temporal-nasal asymmetry effect was due to processing via the subcortical route involving a network that includes the SC, pulvinar, amygdala and cortical areas involved in face processing. The subcortical pathway involving the amygdala, which has reciprocal connections with the pulvinar, is able to process low spatial frequency information of a face (Johnson, 2005). Recently, De Gelder et al. (2003) proposed a model in which a dual route is responsible for face processing. The cortical pathway is involved in face identification whereas the subcortical pathway is involved in face expression and eye gaze perception. Eye gaze information is transmitted to temporal brain areas via the direct subcortical route. Although speculative, it is possible that the reflexive nature of orienting based on eye gaze results from processing via the same direct subcortical pathway that is involved in exogenous orienting to abrupt onsets. The difference between these two modes of orienting would lie in subsequent processing. Because eye-gaze is further processed by temporal regions and not by parietal regions, there is no 'inhibitory tag' feeding back into the SC as is the case in exogenous orienting to abrupt onsets. Therefore, no IOR is found in gaze induced exogenous orienting. Another explanation is that face processing in the cortical pathway overrules information processing in the subcortical pathway after the initial shift of attention. It has been suggested that the dominant cortical route takes over processing of the subcortical route with age (De Gelder & Stekelenburg, 2005). Therefore, it would be interesting to examine whether IOR does occur when masked gaze cues are used. In other words, if the subcortical route would dominate in processing eye-gaze information, cortical activity could less influence these subcortical processes (see also Jolij & Lamme, 2005). Future research on the neural correlates of gaze perception could elucidate the paradoxical finding of exogenous orienting induced by eye gaze without the occurrence of IOR.

10. Discussion and conclusion

Although it seems contradictory that abrupt onset cues that are not perceived can capture attention, the studies discussed clearly indicate that exogenous spatial attention can be dissociated from consciousness. Presumably, attentional engagement to subliminal spatial cues dissolves more rapidly than attentional engagement to supraliminal spatial cues. Therefore, short SOAs are required to measure attentional facilitation at subliminally cued locations. If spatial cues do not fulfill the criteria of exogenous cueing, for example, because the cue is informative of the upcoming target location or has to be detected after each trial, the temporal dynamics of exogenous orienting are modulated. Often this is observed by the absence of IOR following early facilitation.

Feedforward processing via the subcortical pathway could be the mechanism for the rapid automatic attentional orienting response to unconsciously processed exogenous cues. The subcortical retinotectal pathway is associated not merely with unconscious attentional processes and face processing but also with unconscious processing of fear related and biologically relevant stimuli (e.g Jiang, Costello, Fang, Huang, & He, 2006; Lin, Murray, & Boynton, 2009; Morris, Ohman, & Dolan, 1999). It is plausible that the subcortical route in unconscious exogenous attentional processes always involves amygdala activation since subliminally presented cues in the periphery could imply a potential threat. Fig. 1 shows a simplified network for this attentional system.

Previous research has demonstrated a link between spatial attention and emotion processing (Pourtois, Thut, de Peralta, Michel, & Vuilleumier, 2005; Vuilleumier, 2005). Some results suggest the link between unconscious spatial attention and unconscious emotion processing is even stronger. For instance, in an fMRI study by Liddell et al. (2005) a network consisting of attentional areas, such as SC, pulvinar and fear-related areas, such as the amygdala was activated by masked fear-related stimuli. In this study, either fear faces or neutral faces were presented at fixation that were all backward masked with neutral faces. Their results indicated that observers were not able to perceive the affect of the faces but the fear faces activated this attentional emotional network. They concluded that the network served as an alarm system for rapid orienting to sources of threat.

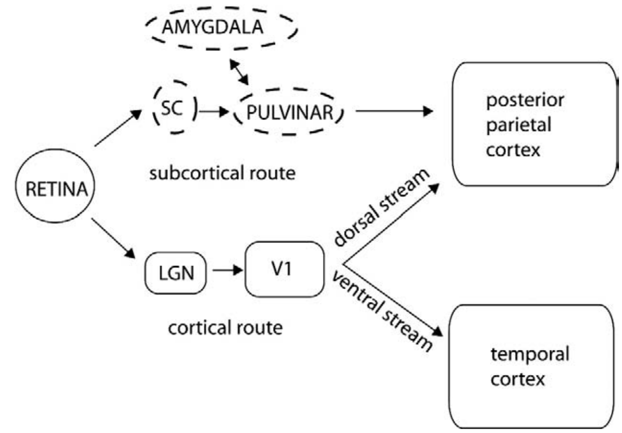

Fig. 1. A possible fast subcortical pathway for unconscious attentional orienting to subliminally presented stimuli, including mechanisms important for attention, such as the superior colliculus and the pulvinar as well as mechanism important for fear processing, such as the amygdala.

To conclude, if visual information could imply a possible threat, such as abrupt onsets in the periphery or diverted eye-gaze, a fast subcortical network involving SC, pulvinar and amygdala rapidly processes this information via the feedforward sweep and triggers an exogenous orienting response. In addition, if no conscious information about the source of the threat becomes available, the exogenous attention system would only rely on this feedforward sweep of information. In this sense unconscious exogenous orienting can be viewed as an alarm mechanism to detect danger in the absence of awareness.

It is important to note that in visual masking studies, such as described in Liddell et al. (2005) the stimulus does not reach consciousness because processing in the cortical pathway is disrupted by the subsequent onset of the mask. Most likely, the cue will not enter awareness because recurrent processing is interrupted (Fahrenfort, Scholte, & Lamme, 2007). This halting of reentrant processing does not necessarily disrupt feedforward processing in the cortical pathway. These cortical feedforward connections rapidly reach areas important for attention and eye movements such as MT and FEF (Lamme, 2003; Lamme & Roelfsema, 2000) and could result in attentional orienting. This is in contrast to visual processing in hemianopic patients with a lesion in the cortical pathway. Therefore, one has to be careful in comparing unconscious attentional orienting processes due to masking in healthy human observers, where processing in cortical and subcortical pathways is still intact and unconscious attentional orienting processes in hemianopic patients where processing in the cortical pathway is completely abolished.

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