Unconscious cueing effects in saccadic eye movements – Facilitation and inhibition in temporal and nasal hemifield

Manon Mulckhuyse *, Jan Theeuwes

Vrije Universiteit, Department of Cognitive Psychology, Amsterdam, The Netherlands

ABSTRACT

The current study investigated whether subliminal spatial cues can affect the oculomotor system. In addition, we performed the experiment under monocular viewing conditions. By limiting participants to monocular viewing conditions, we can examine behavioral temporal–nasal hemifield asymmetries. These behavioral asymmetries may arise from an anatomical asymmetry in the retinotectal pathway. The results show that even though our spatial cues were not consciously perceived they did affect the oculomotor system: relative to the neutral condition, saccade latencies to the validly cued location were shorter and saccade latencies to the invalidly cued location were longer. Although we did not observe an overall inhibition of return effect, there was a reliable effect of hemifield on IOR for those observers who showed an overall IOR effect. More specifically, consistent with the notion that processing via the retinotectal pathway is stronger in the temporal hemifield than in the nasal hemifield we found an IOR effect for cues presented in the temporal hemifield but not for cues presented in the nasal hemifield. We conclude that unconsciously processed spatial cues can affect the oculomotor system. In addition, the observed behavioral temporal–nasal hemifield asymmetry is consistent with retinotectal mediation.

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1. Introduction

Attentional processing in the absence of awareness has been shown in studies with hemianopic patients (e.g., Danziger, Fendrich, & Rafal, 1997; Dodds, Machado, Rafal, & Ro, 2002; Kentridge, Heywood, & Weiskrantz, 1999; Rafal, Smith, Krantz, Cohen, & Brennan, 1990) and in studies involving subliminal visual stimuli (e.g., Ivanoff & Klein, 2003; Lambert, Naikar, McLachlan, & Aitken, 1999; McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; Woodman & Luck, 2003). McCormick (1997) was the first to show spatial attentional cueing effects without conscious perception of peripheral cues. Typically, in a spatial cueing task, observers fixate their eyes in the middle of the screen while an uninformative cue is flashed in the periphery (Posner, 1980). Subsequently, a target is presented either at the location where the uninformative flash was presented (validly cued) or at the opposite location where no flash was presented (invalidly cued). When the target immediately follows the cue (short SOA), processing of the target at the validly cued location is facilitated; Reaction Times (RTs) to validly cued targets are faster compared to RTs to invalidly cued targets. In contrast, when the target follows the cue after a relatively long interval (long SOA), processing of the target at the validly cued location is impoverished;

RTs to validly cued targets are slower compared to RTs to invalidly cued targets (Posner & Cohen, 1984). This last phenomenon is called inhibition of return (IOR) and is believed to occur only when attention is captured automatically or when a saccade is endogenously prepared (Rafal, Calabresi, Brennan, & Sciolto, 1989). Note that this latter occurrence indicates the strong relation between the oculomotor system and automatic capture of attention (for review on IOR see Klein, 2000). In McCormick's study, a facilitation effect at the validly cued location was found at the short SOA when observers were unaware of the cue. However, at the long SOA McCormick did not observe IOR. The lack of IOR was attributed to a strategic effect of the observers as a result of the instruction to detect the cue in each trial (see also Ivanoff & Klein, 2003). Presumably, attention lingered longer at the cued location because observers had to search for the cue even though they were unaware of its presence. Nonetheless, subsequent subliminal spatial cueing studies found facilitation at the short SOA as well as inhibition at the long SOA at validly cued locations (e.g., Ivanoff & Klein, 2003; Mulckhuyse et al., 2007). Note that in these studies manual responses were measured. Since attention, IOR and the oculomotor system are strongly related, the current study was designed to determine whether the oculomotor system would be affected by unconscious attentional processing. More specifically we wanted to determine the effect of subliminal cueing on saccade latencies.

One of the interpretations why unconsciously processed visual stimuli can induce attentional orienting involves the retinotectal

* Corresponding author. Address: Cognitive Psychology, Vrije Universiteit, Van der Boechorststraat 1, 1081BT Amsterdam, The Netherlands. Fax: +31 20 598 8971.
E-mail address: M.Mulckhuyse@psy.vu.nl (M. Mulckhuyse).

or extrageniculate pathway of visual information processing. In contrast to the cortical geniculate pathway, which projects from the retina to the lateral geniculate nucleus (LGN) of the thalamus to the striate cortex, the subcortical retinotectal pathway processes visual information from the retina via the superior colliculus (SC) and the pulvinar of the thalamus to the parietal cortex, which are important structures for spatial attention and eye movements (e.g., Bell, Fecteau, & Munoz, 2004; Dorris, Klein, Everling, & Munoz, 2002; Fecteau & Munoz, 2005; Lamme & Roelfsema, 2000; Shipp, 2004). Hemianopic patient studies seem to corroborate the role of the retinotectal pathway in unconscious attentional and oculomotor processes (Danziger et al., 1997; Van der Stigchel, van Zoest, Theeuwes, & Barton, 2008). Hemianopic patients are unaware of visual stimuli in their blind visual field due to a lesion of the retinogeniculostriate pathway or the striate cortex. However, there is evidence of visual processing in the scotoma (the blind area) in for example blindsight (Weiskrantz, 1986). Blindsight refers to the ability of hemianopic patients to correctly report stimuli presented in the scotoma when asked. In a study by Kentridge et al. (1999), unconscious spatial attentional processing was observed in a hemianopic patient with blindsight. 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 and colleagues (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.

To test retinotectal processing in healthy human observers, Ro, Shelton, Lee, and Chang (2004) used transcranial magnetic stimulation (TMS) to mimic a lesion of the retinogeniculostriate pathway. The delivered TMS at striate cortex (V1) interfered with cortical processing and induced a scotoma near fixation. Observers had to make a saccade to a target in the periphery while a distractor was presented in the scotoma. Normally, the presence of a visible remote distractor increases saccade latencies to a target (e.g., Walker, Deubel, Schneider, & Findlay, 1997). In Ro's study, the distractor was presented in the TMS induced scotoma and therefore observers were unaware of the distractor. However, saccade latencies to the target were still increased. Nonetheless, the delay in responding was only observed for saccadic responses. When observers had to make a manual response to the target, the distractor had no effect on reaction time. Ro et al. concluded that the selective disruptive effect of a distractor on saccade latencies and not on manual responses indicated that this process was mediated by the retinotectal pathway. In particular, they reasoned that this selective disruptive effect signified the important role of the SC in this pathway (see also Boyer, Harrison, & Ro, 2005). This selective disruptive effect on saccade latencies is consistent with studies that used a particular type of color contrast (S-cone stimuli), which are not processed via the retinotectal pathway (Sumner, 2006; Sumner, Nachev, Vora, Husain, & Kennard, 2004). In several studies, Sumner et al. (2004) and Sumner (2006) showed that cueing with S-cone stimuli resulted in IOR when a manual response was required but not when a saccadic response was required. They concluded that oculomotor IOR relies more on processes in the retinotectal pathway with an essential role for the SC while 'manual' IOR relies more processes in other collicular pathways. As already mentioned the SC receives direct input from the retina via the retinotectal pathway (Munoz, 2002) and is essential for IOR (Dorris et al., 2002; Rafal, Posner, Friedman, Inhoff, & Bernstein, 1988).

A secondary line of evidence for an important role of the retinotectal pathway and the SC in unconscious processing comes from the temporal–nasal asymmetry effect in attentional orienting: visual stimuli in the temporal hemifield have stronger attentional effects than visual stimuli in the nasal hemifield (e.g., Ansorge, 2003;

Dodds et al., 2002; Posner & Cohen, 1980; Rafal, Henik, & Smith, 1991; Rafal et al., 1990; Simion, Valenza, Umilta, & Dallabarba, 1995). It has been suggested that these behavioral asymmetry effects arise from an anatomical asymmetry in the retinotectal pathway. The retinotectal pathway is essentially monocular and has more connections from the nasal hemiretina (corresponding to the temporal hemifield) to the contralateral superior colliculus than from the temporal hemiretina (corresponding to the nasal hemifield) to the contralateral superior colliculus. This anatomical asymmetry has been found in cats (Sherman, 1974; Sprague, 1966) and in monkeys (Perry & Cowey, 1984) but is however less clear in humans (Williams, Azzopardi, & Cowey, 1995). Nonetheless, an fMRI study with humans showed that stimulus processing in the SC differed between stimuli presented in the temporal and in the nasal hemifield while this effect was not evident in the LGN or visual cortex (Sylvester, Josephs, Driver, & Rees, 2007). Consistent with the behavioral asymmetry, Sylvester et al. found enhanced activity in the SC for stimuli presented in the temporal hemifield compared to stimuli in the nasal hemifield. However, note that behavior was not measured in this study.

Behavioral studies with hemianopic patients under monocular viewing conditions indicate that unconscious processing is stronger in the temporal hemifield than in the nasal hemifield. In a study by Dodds et al. (2002), a hemianopic patient was tested in a forced choice localization task with targets presented either in the temporal blind hemifield or in the nasal blind hemifield. The results showed that performance was highly accurate in the temporal hemifield and at chance level in the nasal hemifield. Furthermore, in a study by Rafal et al. (1990) hemianopic patients showed an asymmetry effect of a remote distractor in a saccade task: when the distractor was presented in the temporal (blind) hemifield saccade latency increased relative to a no distractor condition, whereas a distractor in the nasal (blind) hemifield did not increase saccade latency.

However, the results from Rafal et al. (1990) were not replicated in a different study with hemianopic patients (Walker, Mannan, Maurer, Pambakian, & Kennard, 2000). Although this study reported a small temporal–nasal asymmetry distractor effect in healthy humans the effect was not present in hemianopic patients. Walker et al. suggested that other cortical processes rather than the retinotectal pathway are responsible for the behavioral asymmetry effect. This conclusion was corroborated in a recent study by Bompas, Sterling, Rafal, and Sumner (2008). In this study they used 'normal luminance' stimuli, which are processed via the retinotectal pathway and S-cone stimuli, which are not processed via the retinotectal pathway. The task they used was the same saccade choice task employed by Posner and Cohen (1980). In this task, observers choose to make a saccade either to a stimulus presented in the temporal hemifield or to a stimulus presented in the nasal hemifield. Observers showed a preference to saccade to the stimulus in the temporal hemifield irrespective of stimulus type, i.e., whether the stimuli were processed by the retinotectal pathway (normal luminance stimuli) or not (S-cone stimuli). The authors concluded that the temporal–nasal asymmetry cannot be the result of processing via the retinotectal pathway but rather is the result of higher cognitive processes. Note that in the Bompas et al. study, participants were aware of the presentation of the cues. Therefore, it is difficult to compare this study with studies in which participants do not consciously process visual stimuli, either because of a lesion or because of the way of stimulus presentation. In addition, although an anatomical asymmetry for cortical visual processing in the temporal and nasal hemifield has been shown in striate cortex in monkeys (LeVay, Connolly, Houde, & Van Essen, 1985), the behavioral asymmetry effect only manifests itself for stimuli beyond the blind spot (>20°; Fahle & Schmid, 1987; Paradiso & Carney, 1988).