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Effects of central and peripheral cueing on perceptual and saccade performance

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ABSTRACT

Previous research on the spatiotemporal dynamics of exogenous and endogenous attentional allocation during saccade preparation yielded conflicting results. We hypothesize that this can be explained by the cueing type used to orient attention in a perceptual task. We investigated the time-course of attentional allocation as a function of cueing type (central vs peripheral), spatial congruency of the cued perceptual and saccade task locations, and cue validity in a dual-task paradigm. Participants performed a visual discrimination task during saccade preparation. We found that central and peripheral cues differentially affected the time-course of attentional allocation depending on spatial congruency and cue validity. Peripheral cues quickly and transiently oriented attention to the cued location. In the congruent condition, attention was maintained by the pre-saccadic attention shift, but declined in the spatially incongruent condition. Central cues slowly oriented attention to the cued location. In the congruent condition, attention was boosted by the pre-saccadic attention shift compared to a slower increase in the spatially incongruent condition. The pre-saccadic attention shift – the automatic and obligatory shift of attention to the saccade target – observed in the invalid spatially incongruent condition was not differentially affected by the cueing type orienting attention away from it. Our results suggest that exogenous and endogenous attention is dynamically and flexibly allocated to cued locations during saccade preparation while pre-saccadic attentional resources are progressively shifted to the saccade target irrespective of the cueing type. We argue that attentional selection for perception represents a partially independent process in contrast to the pre-saccadic attention shift.

1. Introduction

Our natural surroundings are cluttered with a dazzling amount of visual stimuli. This vast load of information makes it necessary to tease apart relevant from irrelevant information for an orderly functioning of our capacity-limited perceptual and motor systems. Attention has been suggested to fulfill such a selection mechanism for perception and action, facilitating the processing of stimuli at and motor actions to selected locations in space (Allport, 1987; Castiello, 1996; Duncan & Humphreys, 1989; Neumann, 1987; Posner, 1980; Schneider, 1995; Treisman & Gelade, 1980). Previous research suggests an intimate – however, still not entirely understood – coupling between attention and eye movements (Awh, Armstrong, & Moore, 2006; Deubel & Schneider, 1996, 2003; Kowler, Anderson, Dosher, & Blaser, 1995; Rizzolatti, Riggio, Dascola, & Umiltá, 1987; Smith & Schenk, 2012). For example, the visual attention model (Schneider, 1995) proposes that selection-for-perception and selection-for-action are closely coupled processes which are mediated by a common visual attention mechanism. Behavioral experiments using dual-task paradigms, in which participants perform a visual discrimination task either at a saccade target or a non-saccade target location, showed that visual processing capabilities at the saccade target location increase during saccade preparation (Born, Ansorge, & Kerzel, 2013; Deubel, 2008; Rolfs, Jonikaitis, Deubel, & Cavanagh, 2011). Importantly, attentional resources can also be allocated to non-saccade target locations during saccade preparation, but less effectively (Castet, Jeanjean, Montagnini, Laugier, & Masson, 2006; Deubel, 2008; Moehler & Fiehler, 2014; Moehler & Fiehler, 2015; Montagnini & Castet, 2007).

Studies investigating the temporal dynamics of attentional allocation to saccade and especially perceptual non-saccade target locations yielded conflicting results. Using a dual-task paradigm, Deubel (2008, exp. 2) used valid and invalid peripheral cues to spatially orient attention in a perceptual task, while the saccade task was centrally cued. He found that attention was quickly allocated to the peripherally cued location and remained at a high level when the saccade was directed to the same location (spatially congruent). When attention was oriented

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away from the saccade goal (spatially incongruent), perceptual performance was initially at a similar high level. However, with approaching saccade onset, perceptual performance decreased suggesting a withdrawal of attentional resources from the non-saccade target location. When the peripheral cue invalidly oriented attention away from the saccade location (invalid spatially incongruent), but the probe appeared at the saccade target location, perceptual performance was at chance long before saccade onset. However, when saccade onset approached, perceptual performance increased suggesting that attention was automatically and obligatorily shifted to the saccade target during saccade preparation. In contrast, when participants were verbally informed, i.e., they had prior knowledge about the perceptual target location which was kept constant across the experimental block, attentional resources were progressively allocated to the spatially congruent location of the perceptual and the saccade target as compared to the fast attentional allocation using peripheral cues (Deubel, 2008, exp. 1). However, when the perceptual and saccade task were spatially incongruent, perceptual performance surprisingly remained stable close to chance throughout saccade preparation (for similar results see Born et al., 2013). Seemingly, participants did not use their prior knowledge of the perceptual target location.

Importantly, such block-wise verbal cueing tasks fundamentally differ from peripheral cueing tasks. First, keeping the saccade target or the perceptual target constant across the experimental block might undermine the flexibility in attentional allocation and saccade planning by reducing attentional demands and facilitating automatic and stereotyped movements and attentional responses. Thus, covert attentional orienting as well as motor planning in such conditions lack flexible selection processes compared to randomly varying target settings, and are hardly comparable to conditions in which the peripheral cue re-orients attention on each single trial. Second, the cueing procedures differ in timing. In the verbal cueing tasks, the cue is given before the block whereas in the peripheral cueing condition, the cue appears at a fixed time point on each trial. Therefore, attentional processes triggered by verbal instructions or by peripheral cues may operate at different scales, with a rather poor temporal control of endogenous orienting due to prior knowledge. Third, verbal cueing is associated with endogenous attentional orienting to the instructed location while peripheral cueing is associated with exogenous attentional orienting and both processes have been shown to exhibit different time courses (Berger, Henik, & Rafal, 2005; Cheal & Lyon, 1991; Jonides, 1981; Mueller & Findlay, 1988; Mueller & Rabbitt, 1989).

We hypothesize that the cueing type strongly contributes to the spatiotemporal modulations of perceptual performance during movement preparation. As outlined before, previous studies examining exogenous and endogenous attention during saccade preparation applied cueing tasks which were hardly comparable. The use of visually presented central cues would provide an answer as they are associated with endogenous attentional orienting at a predefined point in time and from trial to trial, comparable to visually presented peripheral cues associated with exogenous attentional orienting. For the first time, we directly compare the effects of endogenous and exogenous orienting of attention to a perceptual target location during saccade preparation. In a dual-task paradigm, we investigated cueing effects on the time-course of attentional allocation in different trial types (congruent, incongruent, invalid incongruent). To this end, we varied whether a central or a peripheral cue oriented attention to the perceptual target location (cueing condition). To investigate the coupling of visual attention for perception and action, we manipulated the spatial congruency of the cueing directions of a perceptual and a saccade task. Therefore, the cued saccade target location could either coincide with the cued perceptual target location or not (spatial congruency). In order to examine the pre-saccadic attention shift, we used a validity manipulation in the spatially incongruent condition. The perceptual target cue could orient attention away from the saccade target, although the perceptual target would appear at the saccade target location (validity). For the *peripheral cueing condition*, we expect to replicate the findings by Deubel (2008) showing high and stable perceptual performance during saccade preparation in congruent trials, initially high but decreasing performance with saccade onset approaching in incongruent trials, and initially low but increasing performance in invalid incongruent trials due to the pre-saccadic shift of attention. In contrast to stable perceptual performance throughout saccade preparation due to prior knowledge, we expect that perceptual performance increases in the *central cueing condition* due to the associated slow nature of endogenous attentional orienting. In congruent trials, performance should increase more strongly compared to incongruent trials as additional attentional resources come from saccade preparation. In the invalid spatially incongruent condition, we expect a similar pre-saccadic attention shift as in the peripheral cueing condition as the saccade task is always centrally cued.

Previous studies suggested that saccade parameters – especially saccade accuracy, precision, and curvature – are sensitive to the orientation of covert attention away from the saccade target during movement preparation (Born et al., 2013; Kowler et al., 1995; Moehler & Fiehler, 2014; Moehler & Fiehler, 2015; Sheliga, Riggio, & Rizzolatti, 1994, 1995), i.e., movement performance is decreased when attention is oriented away from the movement goal. Here, we asked whether the cueing type (central vs peripheral) differentially affects movement performance in congruent compared to incongruent trials.

2. Methods

2.1. Participants

Ten naive participants (right-handed, six female, age range: 20–27 years, $M = 22.8$, $SD = 2.53$) with normal or corrected-to-normal vision took part in the study and received course credit or payment for their time of participation. The experimental procedures were approved by the local ethics committee and were in line with the requirements of the Declaration of Helsinki (2008).

2.2. Apparatus

Participants were seated in a lit room in front of a table. A chin and forehead rest restrained their head. We used a VIEWPiXX monitor (22.5 in. LCD monitor, VIEWPixx, VPixx Technologies, Saint-Bruno, Québec, Canada, refresh rate 100 Hz, screen resolution 1920 × 1200 pixels) on which we presented visual stimuli. Participants viewed these stimuli on the monitor at a distance of 50 cm. Presentation® (Version 19.0, www.neurobs.com) controlled stimulus presentation. We used a tower-mounted EyeLink 1000 to record movements of the participants' right eye (SR Research, Mississauga, ON, Canada; sampling rate 1000 Hz) which was calibrated before each experimental block (13 point calibration). A keyboard with defined start and response buttons was fixed on the table in front of the participant.

2.3. Stimuli

Visual stimuli were presented on a medium grey background (50%). The fixation cross (0.6° × 0.6°) and the colored arrows (width = 0.6°, height = 0.6°) were presented centrally on the screen. Four boxes (width = 1°, height = 1°) framing a random dot pattern (0.9° × 0.9°, randomly arranged black and grey squares; width = .03°, height = .03°) defined the target locations for the perceptual and the saccade task which were presented at an eccentricity of 5° around the fixation cross (at 10:30, 1:30, 4:30, and 7:30 o'clock). The distractors (vertically oriented Gabor patches; width = 0.9°, height = 0.9°; 50% contrast; 3 cycles per picture, Gaussian envelope) and the probes (counterclockwise or clockwise oriented Gabor patches; 1–45°) had the same size as the random dot patterns. For the response, the question "Counterclockwise or clockwise?" was presented in the center of the screen.