



Effects of spatial congruency on saccade and visual discrimination performance in a dual-task paradigm



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ABSTRACT

The present study investigated the coupling of selection-for-perception and selection-for-action during saccadic eye movement planning in three dual-task experiments. We focused on the effects of spatial congruency of saccade target (ST) location and discrimination target (DT) location and the time between ST-cue and Go-signal (SOA) on saccadic eye movement performance. In two experiments, participants performed a visual discrimination task at a cued location while programming a saccadic eye movement to a cued location. In the third experiment, the discrimination task was not cued and appeared at a random location. Spatial congruency of ST-location and DT-location resulted in enhanced perceptual performance irrespective of SOA. Perceptual performance in spatially incongruent trials was above chance, but only when the DT-location was cued. Saccade accuracy and precision were also affected by spatial congruency showing superior performance when the ST- and DT-location coincided. Saccade latency was only affected by spatial congruency when the DT-cue was predictive of the ST-location. Moreover, saccades consistently curved away from the incongruent DT-locations. Importantly, the effects of spatial congruency on saccade parameters only occurred when the DT-location was cued; therefore, results from experiments 1 and 2 are due to the endogenous allocation of attention to the DT-location and not caused by the salience of the probe. The SOA affected saccade latency showing decreasing latencies with increasing SOA. In conclusion, our results demonstrate that visuospatial attention can be voluntarily distributed upon spatially distinct perceptual and motor goals in dual-task situations, resulting in a decline of visual discrimination and saccade performance.

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1. Introduction

We live in a complex environment with a vast amount of different stimuli competing for our attention. Attentional mechanisms must select relevant stimuli and deselect irrelevant stimuli within the visual field (selection-for-perception) in order for our visual system to function efficiently. In addition, attention is required for movement programming and execution, in particular for the selection of movement-relevant visuospatial information which has to be integrated into a movement plan (selection-for-action; Allport, 1987; Neumann, 1987).

Schneider (1995) proposed the visual attention model (VAM) which assumes that visual attention fulfills two main functions: selection-for-action and selection-for-perception. One commonly used paradigm to examine the relationship between these two

functions is the dual-task paradigm by Deubel and Schneider (1996). Participants perform a tachistoscopically presented visual discrimination task at one location while they program a movement towards the same (congruent condition) or a distinct (incongruent condition) location. A wealth of studies demonstrated that prior to saccade onset perceptual processing is obligatorily enhanced at the saccade target location whereas it is poor at non-saccade locations (Deubel, 2008; Deubel & Schneider, 1996, 2003; Hoffman & Subramaniam, 1995; Kowler et al., 1995; Tibber, Grant, & Morgan, 2009; Wilder et al., 2009). Even when the time to program the saccade is extended up to 1200 ms, attention remains locked at the saccade target and cannot be withdrawn from it (Deubel & Schneider, 2003). However, studies on sequential saccades demonstrated that pre-saccadic perceptual facilitation can also occur at multiple saccade targets (Baldauf & Deubel, 2008; Godijn & Theeuwes, 2003). Attention seems to be allocated prior to saccade onset to all locations of the saccade sequence in a parallel, non-contiguous, and gradual manner (Baldauf & Deubel, 2008).

There is converging evidence that during saccade programming at least some attentional resources can be allocated to non-saccade

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locations improving perceptual processing at these locations (Castet et al., 2006; Deubel, 2008; Doré-Mazars, Pouget, & Beauvillain, 2004; Kowler et al., 1995; Montagnini & Castet, 2007). In support, studies on predictive remapping show that visual attention is not only allocated to the saccade target location, but also at predictively remapped locations (Harrison et al., 2013; Jonikaitis et al., 2013; Rolfs et al., 2011). However, the dynamics of attentional allocation during the preparation of eye movements seem to differ between saccade and non-saccade locations. Studies varying the time between the discrimination task and the saccade target cue (=Go-signal) suggest that attentional resources progressively shift to the saccade location with decreasing time to saccade onset, whereas they remain constant at non-saccade locations (Born, Ansorge, & Kerzel, 2013; Deubel, 2008, Exp. 1).

Dual-task studies have primarily focused on the effect of pre-saccadic visual attention on perceptual performance. Following the view that selection-for-perception and selection-for-action share common and capacity-limited attentional resources (Schneider, 1995), one would also expect that movement performance is affected when attention is drawn away from the movement goal. In other words, when one is required to perform a movement to a specific location in space which is not the single locus of attention, movement performance should be poor compared to situations where the movement target location is fully attended. Accordingly, some studies found slower and less accurate saccades in addition to decreased perceptual performance when attention was directed away from the saccade target (Born, Ansorge, & Kerzel, 2013; Deubel, 2008; Hoffman & Subramaniam, 1995; Kowler et al., 1995). In contrast, other studies which also reported effects of visual attention on perceptual performance were unable to find attention-dependent changes in saccade parameters (Deubel & Schneider, 1996, 2003). These inconsistent findings might be explained by the fact that the oculomotor system is hardly affected when drawing little attention away from the saccade target which can already lead to some increase in perceptual performance at non-saccade locations. However, if most of the attentional resources are allocated to the perceptual task during movement programming, costs emerge for the oculomotor system resulting in longer saccade latency and decreased saccade accuracy (Kowler et al., 1995).

Saccade curvature has been identified as one important parameter which is tightly associated with the spatial deployment of attention (Van der Stigchel, 2010; Van der Stigchel, Meeter, & Theeuwes, 2006). Previous studies demonstrated that target-directed saccades curve away from covertly attended locations (Sheliga, Riggio, & Rizzolatti, 1994, 1995; Van der Stigchel & Theeuwes, 2005, 2007). Saccade curvature has often been explained by inhibitory accounts assuming that curvature away is caused by the inhibition of a saccade plan towards the covertly attended location (suppression hypothesis; Sheliga, Riggio, & Rizzolatti, 1994), or on a neuronal level by inhibitory mechanisms acting on neuronal population codes representing competing saccade programs to target and distractor (population coding account; McSorley, Haggard, & Walker, 2004; Tipper, Howard, & Houghton, 2000; for an alternative account see Kruijine, Van der Stigchel, & Meeter, 2014). Explanations of saccade curvature have often been related to the premotor theory of attention which proposes that shifts of covert attention are a by-product of saccade preparation, suggesting that attention and eye movements are tightly linked (Rizzolatti et al., 1987). According to this theory, each shift of covert attention is preceded by an eye movement program to the locus of covert attention. Attention and eye movements usually play in concert, but they are not inextricably interwoven (Awh, Armstrong, & Moore, 2006). Recent studies even claim that “endogenous attentional orienting is entirely independent of motor control” (Smith & Schenk, 2012, p. 1112; see also, Smith, Ball, & Ellison, 2014; Smith, Schenk, & Rorden, 2012).

So far, effects of covert attention on saccade curvature have been revealed in tasks requiring the detection of an imperative signal triggering a saccade (Sheliga, Riggio, & Rizzolatti, 1994, 1995). Previous evidence from a study which applied a dual-task-like paradigm in which participants performed a letter discrimination task before a saccade task found that target-directed saccades curved away from attended non-saccade locations when multiple locations were attended before the saccade was initiated (Van der Stigchel & Theeuwes, 2005). Our study aims to extend their findings on saccade curvature to the classical dual-task paradigm by Deubel and Schneider (1996) where a saccade and a highly demanding discrimination task must be performed simultaneously, facilitating competition between attentional resources.

The present study aims to investigate how spatial congruency and movement preparation time influence different saccade parameters in a modified version of the dual-task paradigm by Deubel and Schneider (2003). We varied the spatial congruency of a primary saccade task and a secondary visual discrimination task. We measured perceptual performance in the visual discrimination task and evaluated different saccade parameters with respect to spatial congruency and movement preparation time. The visual discrimination task was embedded into the saccade task so that it had to be performed during saccade preparation. In order to examine discrimination performance in more detail, we applied a 4 alternative forced choice (4-AFC) task (see also Khan, Song, & McPeck, 2011). Discrimination performance and saccade parameters (latency, accuracy, and precision) were taken as measure of visual attention for perception and action, respectively. Additionally, saccade curvature was used as an oculomotor measure of attentional allocation in space. We hypothesize that discrimination performance in the congruent condition should exceed performance in the incongruent condition and performance in the incongruent condition should be better than chance, as attention can be diverted from the saccade target when subjects are informed about the future DT-location. Based upon the assumption that selection-for-action and selection-for-perception share at least some attentional resources, saccade parameters should deteriorate similarly as perceptual performance deteriorates in spatially incongruent trials. In view of saccade curvature, we expect target-directed saccades to curve away from attended non-saccade locations, i.e. in situations where the DT-location has been specified.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

Ten right-handed human subjects with normal or corrected-to-normal vision participated in the first experiment. They either received course credit or monetary compensation. The participants (4 female) were between 20 and 28 years old ($M = 23.9$, $SD = 2.6$). Written informed consent approved by the local ethics committee was provided by each subject prior to participation. The experiment was performed in accordance with the Declaration of Helsinki (2008).

2.1.2. Apparatus

Participants sat at a table in a dimly-lit room with their head restrained by a chin rest. Stimuli were presented on a 22 in. CRT monitor (Iiyama, MA203DT; refresh rate 85 Hz; screen resolution 1280 × 960 pixels) placed 50 cm in front of the subject. Stimulus delivery was controlled by Presentation[®] (Version 16.3, www.neuro-robots.com). Monocular movements of participants' right eye were recorded via a head mounted video-based EyeLink[®] II (SR Research, Mississauga, ON, Canada) at a sampling rate of 500 Hz. Before each

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