



The influence of spatial congruency and movement preparation time on saccade curvature in simultaneous and sequential dual-tasks



Tobias Moehler*, Katja Fiehler

Experimental Psychology, Justus-Liebig-University, Giessen, Germany

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ABSTRACT

Saccade curvature represents a sensitive measure of oculomotor inhibition with saccades curving away from covertly attended locations. Here we investigated whether and how saccade curvature depends on movement preparation time when a perceptual task is performed during or before saccade preparation. Participants performed a dual-task including a visual discrimination task at a cued location and a saccade task to the same location (congruent) or to a different location (incongruent). Additionally, we varied saccade preparation time (time between saccade cue and Go-signal) and the occurrence of the discrimination task (during saccade preparation = simultaneous vs. before saccade preparation = sequential). We found deteriorated perceptual performance in incongruent trials during simultaneous task performance while perceptual performance was unaffected during sequential task performance. Saccade accuracy and precision were deteriorated in incongruent trials during simultaneous and, to a lesser extent, also during sequential task performance. Saccades consistently curved away from covertly attended non-saccade locations. Saccade curvature was unaffected by movement preparation time during simultaneous task performance but decreased and finally vanished with increasing movement preparation time during sequential task performance. Our results indicate that the competing saccade plan to the covertly attended non-saccade location is maintained during simultaneous task performance until the perceptual task is solved while in the sequential condition, in which the discrimination task is solved prior to the saccade task, oculomotor inhibition decays gradually with movement preparation time.

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1. Introduction

Selection-for-perception and selection-for-action are supposed to share a common attentional mechanism (Deubel & Schneider, 1996, 2003; Schneider, 1995). One classical paradigm to investigate these coupled processes is the dual-task paradigm where participants have to discriminate a briefly presented visual target during the preparation of a saccade (Deubel & Schneider, 1996). The locations of the cued discrimination and the saccade target can either coincide at the same location (congruent trials) or appear at spatially separated locations (incongruent trials). Improved perceptual performance has consistently been found at saccade target locations during movement preparation arguing for a pre-saccadic shift of attention to saccade target locations shortly before saccade onset (Born, Ansorge, & Kerzel, 2013; Deubel, 2008; Deubel & Schneider, 1996, 2003; Hoffman &

Subramaniam, 1995; Kowler, Anderson, Doshier, & Blaser, 1995; Tibber, Grant, & Morgan, 2009; Wilder, Kowler, Schnitzer, Gersch, & Doshier, 2009). However, some attentional resources can also be allocated to non-saccade target locations during movement preparation (Castet, Jeanjean, Montagnini, Laugier, & Masson, 2006; Doré-Mazars, Pouget, & Beauvillain, 2004; Kowler et al., 1995; Moehler & Fiehler, 2014; Montagnini & Castet, 2007).

Beyond attentional effects on perception, there is some evidence that movement performance is superior when perceptual and motor tasks are performed at the same location. For example, it has been found that saccades are more precise, more accurate, and initiated faster in spatially congruent compared to incongruent trials (Born et al., 2013; Kowler et al., 1995; Moehler & Fiehler, 2014). Accordingly, when perceptual and motor tasks are performed at spatially distinct locations decrements are observed in perceptual and motor performance indicating the interdependence of attention, perception, and action.

The premotor theory of attention suggests a close coupling of attention and motor planning. Specifically, it states that each shift of covert attention is preceded by a saccade plan to the same location (Rizzolatti, Riggio, Dascola, & Umiltà, 1987; for critical

* Corresponding author at: Experimental Psychology, Justus-Liebig-University, Otto-Behaghel Str. 10F, 35394 Giessen, Germany.

E-mail addresses: tobias.moehler@psychol.uni-giessen.de (T. Moehler), katja.fiehler@psychol.uni-giessen.de (K. Fiehler).

reviews, see: Awh, Armstrong, & Moore, 2006; Smith & Schenk, 2012). Evidence for this theory comes for example from studies investigating saccade curvature. Previous research provides evidence that saccades curve away from the locus of covert endogenous attention (for reviews, see Van der Stigchel, 2010; Van der Stigchel, Meeter, & Theeuwes, 2006). This effect has been commonly explained by the suppression of one of two competing saccade plans, i.e., one to the covertly attended location and another one to the actual saccade target (suppression hypothesis: Sheliga, Riggio, & Rizzolatti, 1994, 1995; population coding: McSorley, Haggard, & Walker, 2004; Tipper, Howard, & Houghton, 2000; for a more recent account, see Kruijne, Van der Stigchel, & Meeter, 2014). However, the direction of saccade curvature seems to depend on saccade latency with short latency saccades (<200 ms) curving towards distractors and long latency saccades (>200 ms) curving away from them. It has been concluded that oculomotor inhibition initially needs time to gradually build up (McSorley, Haggard, & Walker, 2006, 2009; Mulckhuysen, van der Stigchel, & Theeuwes, 2009) and represents a rather short-lived process (Godijn & Theeuwes, 2004; McSorley et al., 2009; Theeuwes & Van der Stigchel, 2009; Theeuwes, Van der Stigchel, & Olivers, 2006).

In the current study we aim to investigate the temporal characteristics of the short-lived oculomotor inhibitory process when covert attention is endogenously directed to a perceptual and a saccade target location in a dual-task paradigm. To this end, we follow up on a recent study which hypothesized that saccade curvature as a measure of oculomotor inhibition should decline with movement preparation time in sequential dual-tasks but remain stable in simultaneous dual-tasks (Moehler & Fiehler, 2014). Evidence for the latter was reported by Moehler and Fiehler (2014) who found that saccades curved away from an attended non-saccade location where a perceptual task had to be performed during saccade preparation relative to a condition when the non-saccade location was unattended and the perceptual task had to be performed at the saccade target location (simultaneous dual-task). Saccade curvature was unaffected by the time to prepare the saccade, i.e., irrespective of the time between saccade target cue and Go-signal, saccades curved away from the attended non-saccade target location. These results indicate that the competition between two saccade plans (i.e., one to the covertly attended non-saccade target location where the perceptual task is performed and one to the actual saccade target location) is still active as covert attention needs to be maintained at the discrimination target location throughout movement preparation time until the perceptual task is solved. Therefore, in the simultaneous dual-task the strength of oculomotor inhibition as indicated by the strength of saccade curvature should be independent of movement preparation time. Moehler and Fiehler (2014) suggested that the result pattern found in the simultaneous dual-task should differ from the one in sequential dual-tasks where the perceptual task is performed *before* the saccade task. In sequential dual-tasks, the incongruent saccade plan to the discrimination target location can be inhibited before saccade preparation starts and therefore, the competition between the two saccade plans should decrease with increasing time between the perceptual and the saccade task (Godijn & Theeuwes, 2004; McSorley et al., 2009; Theeuwes & Van der Stigchel, 2009; Theeuwes et al., 2006). Specifically, oculomotor inhibition measured by saccade curvature should decline with increasing movement preparation time.

We tested these hypotheses by varying spatial congruency of the saccade and the perceptual target location as well as movement preparation time in a simultaneous and a sequential dual-task. In the classical simultaneous condition, participants perform the perceptual task shortly after the Go-signal to execute the saccade, i.e., during saccade preparation. In line with our previous

findings (Moehler & Fiehler, 2014), we expect saccades to curve away more strongly from the non-saccade location in incongruent (attended non-saccade location) relative to congruent trials (unattended non-saccade location) independent of movement preparation time. In contrast, in the sequential condition participants perform the perceptual task before the saccade task. We also expect saccades to curve away more strongly from the non-saccade location in incongruent relative to congruent trials, but this time saccade curvature should decline as a function of movement preparation time. This decline in saccade curvature is assumed to be specific to incongruent trials, as oculomotor inhibition should exclusively affect the saccade plan to the covertly attended non-saccade location when the perceptual and the saccade task do not spatially coincide.

Additionally, we want to replicate the effects of spatial congruency on perceptual and saccade performance in the simultaneous condition from our previous study (Moehler & Fiehler, 2014). We expect discrimination performance to be superior in congruent than in incongruent trials due to the pre-saccadic perceptual facilitation effect. Furthermore, discrimination performance in incongruent trials should be above chance, as some attentional resources can be diverted from the saccade target and deployed to the incongruent non-saccade location. Regarding saccade parameters, we expect latencies to decline with increasing movement preparation time. Saccade accuracy and precision should be better in congruent than in incongruent trials due to interference effects of the two competing saccade plans. With respect to the sequential condition, we expect discrimination performance to be independent of spatial congruency and movement preparation time as the perceptual task is performed before the saccade task. Although we do not have explicit hypotheses about how spatial saccade parameters should be affected in the sequential condition, we performed exploratory analyses.

2. Experiment 1

2.1. Methods

2.1.1. Subjects

Fourteen right-handed participants with normal or corrected-to-normal vision participated in the experiment. For their participation, they either received course credit or monetary compensation. Subjects (6 female) were between 21 and 31 years old ($M = 24.1$, $SD = 2.8$). 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 lit room with their head restrained by a chin rest. We presented visual stimuli on a 22 inch CRT monitor (refresh rate 85 Hz; screen resolution 1280 × 960 pixels) which was placed 50 cm in front of the participant. Stimulus presentation was controlled by Presentation® (Version 16.3, www.neurobs.com). We recorded monocular movements of participants' right eye with a head mounted video-based EyeLink® II (SR Research, Mississauga, ON, Canada) at a sampling rate of 500 Hz. The eye tracker was calibrated using a 9 point calibration procedure before each block. An optoelectronic motion tracking system (Optotrak® Certus, Northern Digital Inc., Waterloo, ON, Canada) which registered a position marker placed on the right index finger recorded manual choice responses to the discrimination task with a sampling rate of 150 Hz.

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