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Effects of preparation time and trial type probability on performance of anti- and pro-saccades

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ABSTRACT

Cognitive control optimizes responses to relevant task conditions by balancing bottom-up stimulus processing with top-down goal pursuit. It can be investigated using the ocular motor system by contrasting basic prosaccades (look toward a stimulus) with complex antisaccades (look away from a stimulus). Furthermore, the amount of time allotted between trials, the need to switch task sets, and the time allowed to prepare for an upcoming saccade all impact performance. In this study the relative probabilities of anti- and pro-saccades were manipulated across five blocks of interleaved trials, while the inter-trial interval and trial type cue duration were varied across subjects. Results indicated that inter-trial interval had no significant effect on error rates or reaction times (RTs), while a shorter trial type cue led to more antisaccade errors and faster overall RTs. Responses following a shorter cue duration also showed a stronger effect of trial type probability, with more antisaccade errors in blocks with a low antisaccade probability and slower RTs for each saccade task when its trial type was unlikely. A longer cue duration yielded fewer errors and slower RTs, with a larger switch cost for errors compared to a short cue duration. Findings demonstrated that when the trial type cue duration was shorter, visual motor responsiveness was faster and subjects relied upon the implicit trial probability context to improve performance. When the cue duration was longer, increased fixation-related activity may have delayed saccade motor preparation and slowed responses, guiding subjects to respond in a controlled manner regardless of trial type probability.

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1. Introduction

The context in which a cognitive task is performed affects subjects' ability to prepare an appropriate response and, thus, the behavioral characteristics elicited. Cognitive control is a set of top-down processes that supervise the execution of such tasks and manage neural resources in order to achieve current task goals. Saccades (rapid eye movements made to foveate a location of interest) provide a readily-quantifiable model through which cognitive control is studied. A basic, visually-guided prosaccade consists of a saccade toward a newly appearing peripheral stimulus, while a more complex, volitionally-driven antisaccade requires a saccade to the mirror image location (opposite direction, same amplitude) of a stimulus (Hallett, 1978). Antisaccade performance, especially, evokes cognitive control processes to suppress the tendency of looking toward the stimulus, to transform stimulus spatial information into the opposite visual hemifield, and to generate voluntarily a saccade to an unmarked location based on arbitrary task instructions. The increased cognitive demand of an antisaccade task typically results in higher error rates and slower reaction times (RTs) than for a prosaccade task (Evdokimidis et al., 2002; Hutton, 2008).

Saccade paradigm design can affect the cognitive demands for each saccade type (e.g., by changing the difficulty of stimulus or response selection, taxing attentional and working memory processes or rewarding quick responses), and impact behavioral response measures accordingly. For example, blocks of a single saccade type yield better performance (fewer errors, faster RTs) than blocks of interleaved prosaccades and antisaccades in which multiple task instructions must be maintained and coordinated (Ethridge, Brahmbhatt, Gao, McDowell, & Clementz, 2009). Within mixed blocks, repetitions of the same trial type result in fewer errors than when a change of task is required between trials (task switching costs; Barton, Greenzang, Hefter, Edelman, & Manoach, 2006; Cherkasova, Manoach, Intriligator, & Barton, 2002; Ethridge et al., 2009). Another method of manipulating the context of saccade trials is to change the probability that a stimulus will appear at a given location (Carpenter & Williams, 1995; Koval, Ford, & Everling, 2004; Liu et al., 2010; Noorani & Carpenter, 2013) or that a particular trial type will occur within a mixed block of saccades (Chiau et al., 2011; Massen, 2004; Pierce, McCardel, & McDowell, 2015). In this case, the expectancy of generating a specific motor command (e.g., "look 10° left") or utilizing a given task set (e.g., "perform an

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antisaccade") is modulated according to the previous saccade trials in the block.

In a previous study on saccade trial type probability, Massen (2004, Exp. 1) presented subjects with blocks of 25, 50, and 75% anti- versus pro-saccades and found that when the probability of an antisaccade trial was lower, antisaccade error rates and RTs were higher. This result supported a competition model of saccade generation, with anti- and pro-saccade programs both being initiated by the stimulus and racing toward a threshold for motor performance (cf. (Cutsuridis, Smyrnis, Evdokimidis, & Perantonis, 2007; Kristjansson, 2007; Noorani & Carpenter, 2013)); a lower antisaccade probability slowed the antisaccade program and allowed the error prosaccade to be completed more often than in high probability blocks. An earlier study from our laboratory (Pierce et al., 2015), however, found that antisaccade error rates were unaffected by trial type probability, while prosaccade error rates were higher when the probability of a prosaccade was lower. This finding showed a similar benefit of a higher probability of a saccade trial type, but only for the stimulus-directed prosaccade (for which errors were not reported in Massen (2004)).

Two key differences between Massen (2004) and Pierce et al. (2015) were 1) the amount of time provided between trials and 2) the duration of the cue that informed subjects of the appropriate saccade task to perform on the upcoming trial. In Massen (2004) subjects were given 200 milliseconds (ms) to prepare the specific saccade task set before the target appeared and had an interval of 2000 ms between trials. In contrast, Pierce et al. (2015) presented the trial type cue for 1000 ms before the target with an average inter-trial interval of 3500 ms. These timing differences likely affected subjects' ability to prepare a given trial type and the degree of influence of the prior trial context. Previous research on antisaccades performed in single blocks found that on trials with shorter fixation intervals (near 1000 ms) participants generated slower RTs and more errors than trials with longer fixation intervals (near 2000 ms; Smyrnis et al., 2002). Additionally, a study on saccade trials performed in mixed blocks (Barton et al., 2006) demonstrated that shorter cue-to-target intervals (200 ms) increased RTs and error rates, and led to differential task switching effects on anti- and pro-saccades compared to conditions with longer cue-to-target intervals (2000 ms). This is consistent with general findings in the task switching literature, suggesting that passive dissipation of the previous task set and active task set reconfiguration processes for the current trial are time-consuming. Longer preparation time therefore allows these processes to be completed successfully, while inadequate preparation time hinders performance (Allport, Styles, & Hsieh, 1994; Meiran, 1996; Meiran, Chorev, & Sapir, 2000; Monsell, 2003; Wylie & Allport, 2000).

In saccade tasks, switching effects differ from other cognitive tasks (Hunt & Klein, 2002) because the responses are triggered by the same visual stimuli requiring opposite motor commands with highly asymmetric dominance. Prosaccades are habitual, stimulus-driven responses whereas antisaccades require cognitive control mechanisms to facilitate the appropriate action. Hence, activating the antisaccade stimulus–response mapping following the trial type cue is particularly difficult for this type of arbitrary rule (look to mirror image location). Furthermore, antisaccade execution has a stronger influence on a subsequent prosaccade because this novel task set must be strongly activated to be correctly executed (Barton et al., 2006; Cherkasova et al., 2002) and the task itself requires suppression of the prosaccade tendency to look toward the stimulus. As such, persistent suppression and interference from an antisaccade trial can last long into a following prosaccade trial, while competition from a previous prosaccade task set minimally impacts the always-demanding antisaccade trial (Weiler & Heath, 2012).

In the current study, the implicit probability of an antisaccade (AS) trial occurring was varied within-subjects across five blocks (10, 25, 50, 75, and 90% AS). The trial type cue duration and inter-trial interval (ITI) were varied between-subjects to examine the impact of trial preparation time. For each trial, the direction and latency of the initial response were recorded to acquire a measure of error rate and RTs for correct trials for each subject. It was hypothesized that performance would be worse (more errors, slower RTs) in blocks with a low probability of a given trial type (e.g., antisaccades would yield the most errors in the 10% AS run) and that this effect would be accentuated in conditions with shorter ITIs and shorter trial type cues. With less preparation time, subjects may be more dependent on the trial context and therefore benefit more strongly from an increased trial type probability. Task switching costs were predicted to be stronger in the shorter ITI and shorter cue groups as well, when the effects of the previous trial were more proximate.

2. Methods

2.1. Subjects

Subjects were recruited from the University of Georgia Department of Psychology's online undergraduate student research pool ($n = 145$) and given course credit for participation. Analyses were conducted on 111 subjects with complete data (34 subjects' data were excluded as a result of stringent requirements for eye tracking data quality across all five blocks to warrant inclusion in the analyses). Subjects were on average 19.4 years old ($SD = 1.2$), 72% female, 69% white/13% black, and 95% right-handed, with normal or corrected-to-normal vision (sub-groups did not differ in age, gender, or education level, all $t < 2$, $p =$ n.s.). All activities were approved by the Institutional Review Board of the University of Georgia.

2.2. Procedure

Subjects provided written informed consent, completed a demographic survey and were given task instructions for anti- and pro-saccade trials. Subjects were not explicitly informed of the different trial type probabilities in each block during the study. For antisaccade trials, subjects were instructed to look as quickly and accurately as possible to the mirror image location (opposite side, same distance from the center) of the peripheral circle when it appeared; for prosaccade trials, they were instructed to look toward the circle itself. They were then seated with their head in a chin rest in front of the display monitor (Samsung 40-in. LCD, frame rate 60 Hz) and the eye-tracking apparatus (EyeLink II, SR Research, Ontario, Canada) was placed on their heads and adjusted. Subjects' eye position relative to the monitor was calibrated with both EyeLink's built-in 9-point calibration and an in-house horizontal 7-point calibration for offline confirmation of eye position amplitude. Subjects completed a practice run with twenty interleaved anti- and pro-saccade trials (10 trials each), followed by five task blocks with rest periods in between runs as necessary. Stimuli were displayed in a darkened room (<0.05 cd/m^2) using Presentation Software (Neurobehavioral Systems, Inc., Albany, CA), which synchronized trial presentation triggers with EyeLink's recording of the relative pupil positions of both eyes (sampled and digitized at 500 Hz).

2.3. Saccade task design

Each subject performed five blocks of saccade trials that differed in the relative probability of anti- to pro-saccades: 1) 10% anti- and 90% pro-saccades (10% AS), 2) 25% anti- and 75% pro-saccades (25% AS), 3) 50% anti- and 50% pro-saccades (50% AS), 4) 75% anti- and 25% pro-saccades (75% AS), and 5) 90% anti- and 10% pro-saccades (90% AS). The order in which the blocks were presented was pseudorandomized between subjects. Hereafter, blocks will be referred to by only the antisaccade probability.

For all blocks, fixation consisted of a light gray (70 cd/m^2) cross subtending 1 degree of visual angle in the center of a black (0.15 cd/m^2) background (Fig. 1). Following the fixation interval, antisaccade trials were cued by a gray diamond illuminated around the central cross and

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