Neuroscience Letters 530 (2012) 150–154

Contents lists available at SciVerse ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Task-switching in oculomotor control: Unidirectional switch-cost when alternating between pro- and antisaccades

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HIGHLIGHTS

- Antisaccades have been shown to alter the activity of oculomotor networks.
- We had participants alternate between pro- and antisaccades.
- We demonstrate a reaction time switch-cost for prosaccades but not antisaccades.
- We propose that antisaccades produce residual inhibition in prosaccade networks.

ARTICLE INFO

Article history:
Received 6 August 2012
Accepted 3 October 2012

Keywords:
Antisaccade
Inhibition
Oculomotor
Prosaccade
Reaction time
Task-switching

ABSTRACT

The antisaccade task requires the suppression of a reflexive prosaccade (i.e., response suppression) and the remapping of a target location to mirror-symmetrical space (i.e., vector inversion). Moreover, antisaccades are associated with increased activation of cortical oculomotor networks: a finding attributed to the top-down requirements of response suppression and vector inversion. The goal of the present study was to determine if the increased cortical activity associated with antisaccades elicits a residual inhibition of oculomotor planning networks. To that end, each trial in this investigation entailed the onset of a single and exogenously presented target (i.e., archetypical antisaccade task) and participants were instructed to alternate between pro- and antisaccades in blocked and random task-switching schedules. In the blocked schedule, the saccade tasks (i.e., pro- and antisaccades) alternated on every second trial (AABB paradigm) whereas in the random schedule the saccade tasks were pseudo-randomly interleaved on a trial-by-trial basis. Reaction times for task-switch prosaccades were longer and more variable than their task-repetition counterparts, whereas antisaccades did not vary as a function of task-switch and task-repetition trials: a finding that was consistent across blocked and random presentation schedules. In other words, results demonstrate a unidirectional switch-cost for prosaccades. As such, we propose that the top-down processes required to complete an antisaccade results in residual inhibition of oculomotor networks supporting a subsequent prosaccade.

Introduction

Prosaccades are rapid eye movements that entail spatial overlap between stimulus and response (i.e., a standard task). Such actions exhibit maximally efficient and effective motor output due to their mediation via dedicated oculomotor networks that operate independent of high-level cognitive properties (for review see [32]). It is, however, important to recognize that individuals are able to decouple the normally direct spatial relations between a stimulus and a response and look in a direction other than a cued target (i.e., non-standard task). Indeed, non-standard tasks represent an important area of inquiry because they provide a basis for determining how high-level cognitive demands influence oculomotor control. One non-standard task that has been extensively studied is the antisaccade. In the archetypal antisaccade task (e.g., [24]), a single target is exogenously presented relative to a fixation cross and participants are instructed to look mirror-symmetrical (i.e., 180° spatial transformation) to the target's location. Results from this task have shown that antisaccades exhibit longer reaction times and more directional errors than prosaccades [21,24]. Moreover, convergent behavioural, electrophysiological and neuroimaging evidence from humans and non-human primates has attributed the longer reactions times and increased errors to a two component process requiring the suppression of a stimulus-driven prosaccade (i.e., response suppression) and the visual remapping of

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http://dx.doi.org/10.1016/j.neulet.2012.10.007

target parameters to a mirror-symmetrical position in space (i.e., vector inversion) [e.g., 16,43; for review see 34].

An interesting question arising from the above-mentioned work is the consequence of alternating between pro- and antisaccades. In other words, does the nature of a preceding trial (i.e., pro- vs. antisaccade) differentially influence the planning times for a to-be-completed response? The basis for this question stems, in part, from human neuroimaging studies demonstrating that antisaccades exhibit more activation within overlapping fronto-parietal networks than prosaccades (e.g., [12,14,22,40]), and also exhibit activation in non-overlapping regions such as the middle inferior parietal area ([11] for antipointing see [25]). Presumably the increased and more diffuse activation is tied to the computational demands of response suppression and vector inversion. Moreover, Ford et al. [22] has suggested that a top-down "pre-setting" of the oculomotor system precedes the implementation of a directionally correct antisaccade. As such, a corollary to Ford et al. is that the completion of an antisaccade may engender a task-specific or non-specific cost to the planning of an ensuant pro- or antisaccade.

Barton and Manoach and their co-workers addressed the consequence of switching responses between cued and un-cued target locations using various task-switching paradigms (e.g., AABB trial order) (e.g., [2–4,8,23,29,30] see also [9]). In their work, participants were presented with a preview of identical targets located to the left and right of a central fixation. Subsequently, one of the targets was cued (via a surrounding annuli) and participants were provided advanced information to saccade to the cued (i.e., their prosaccade task) or un-cued (i.e., their antisaccade task) target. Notably, both targets remained visible throughout the response. Results showed a reliable "switch-cost" for prosaccades; that is, a prosaccade completed after an antisaccade (i.e., task-switch prosaccade) elicited longer reaction times than the second of two consecutively completed prosaccades (i.e., task-repetition prosaccade). In turn, a "paradoxical switch-benefit" was associated with antisaccades. Specifically, task-switch antisaccades (antisaccade completed after a prosaccade) yielded shorter reaction times than their task-repetition (the second of two consecutively completed antisaccades) counterparts. Based on these findings, Barton and Manoach proposed that the task-switch cost and paradoxical task-switch benefit respectively tied to pro- and antisaccades reflects residual inhibition of oculomotor networks (so-called '*prior-antisaccade effect*'). Put another way, a recently completed antisaccade results in a lingering inhibition of oculomotor networks that delays the planning of a task-switch prosaccades. In turn, task-repetition antisaccades are subject to the general inhibition associated with planning the current response as well as the residual inhibition from the previously completed antisaccade.

The results of Barton and Manoach's group are notable for at least two reasons. First, their results diverge from general findings from the task-switching literature showing a unidirectional switch-cost when alternating between standard and non-standard tasks. For example, Allport et al.'s [1] seminal examination of the colour naming and word reading Stroop task showed that switching from the unfamiliar colour-naming task (i.e., non-standard) to the familiar word-naming task (i.e., standard) elicited a reliable cost, whereas the converse switch did not. Allport et al.'s findings, as well as those of others [13,31,41,42] have been interpreted as evidence of unidirectional residual inhibition when switching from a non-standard to a standard task (for review see [28]). Second, it is important to recognize that Barton and Manoach's antisaccade task did not require vector inversion. Indeed, in an archetypical antisaccade task a single target is exogenously presented and participants are required to evoke a two-component process of response suppression and vector inversion. Recall, however, that Barton and Manoach (e.g., [2–4,8,23,29,30]) employed a paradigm wherein a cued and an un-cued target were concurrently presented during saccade planning and execution. As such, Barton and Manoach's task entailed an environment wherein the un-cued target ultimately served as the veridical location of a to-be-completed antisaccade response. Such a paradigm does not require vector inversion; rather, the task requires disengagement of attentional resources from the cued to the un-cued target location [35]. Moreover, once attentional capture of the un-cued target has been completed, the stimulus (i.e., the un-cued target) and response are spatially compatible: a situation allowing for the evocation of a standard prosaccade response.

The goal of the present investigation was to determine the effects of task-switching using an archetypal antisaccade task. In particular, we were interested in determining whether the paradoxical switch-benefit described by Barton and Manoach's group manifests in a task requiring response suppression and vector inversion. To that end, participants completed pro- and antisaccades to briefly presented target stimuli in separate trial schedules (blocked and random). In the blocked schedule, pro- and antisaccades were alternated every other trial (i.e., AABB), whereas in the random schedule pro- and antisaccades were pseudo-randomly interleaved on a trial-by-trial basis. Notably, the random schedule included the same number of task-repetition and task-switch trials as the blocked schedule. The basis for the two schedules was to determine whether inter-trial knowledge related to task goals influences putative task-switching costs. In terms of our primary research question, if the prior-antisaccade effect elicits a residual inhibition of oculomotor networks, then task-switch prosaccades and task-repetition antisaccades should exhibit a movement planning cost (i.e., the prior antisaccade effect: e.g., [2]). In other words, any trial that follows an antisaccade should demonstrate an increase in reaction time. In contrast, if task-switch prosaccades selectively demonstrate increased reaction times, then results would evince a unidirectional cost of switching from a non-standard to a standard response [1]. Moreover, support for the latter hypothesis would demonstrate that antisaccades produce a unidirectional residual inhibition to the oculomotor networks mediating prosaccades.

Methods

Participants

Twenty participants (12 female and 8 male: age range 18–27 years) from the student population at The University of Western Ontario volunteered for the current investigation. All participants had normal or corrected-to-normal vision and were self-declared right-hand dominant. All participants signed consent forms approved by the Office of Research Ethics, The University of Western Ontario, and this research was conducted according to the Declaration of Helsinki.

Apparatus and procedure

Participants sat at a table with their head placed in a head-chin rest for the duration of data collection. Visual stimuli were presented on a 30 in. LCD monitor (60 Hz, 8 ms response rate, 1280 × 960 pixels, Dell 3007WFP, Round Rock, TX, USA) centred on participants midline and located at a viewing distance of 550 mm. The gaze location of participants left eye was obtained via a video-based chin-mounted eye tracking system (Eye-Trac 6: Applied Sciences Laboratories, Bedford, MA, USA) sampling at 360 Hz. Prior to data collection, a nine-point calibration of participants viewing space was performed and the accuracy of this calibration was confirmed via an immediate follow-up recalibration. Two additional