



Repetitive antisaccade execution does not increase the unidirectional prosaccade switch-cost

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ABSTRACT

An antisaccade is the execution of a saccade to the mirror-symmetrical location (i.e., same amplitude but opposite visual field) of a single and exogenously presented visual target. Such a response requires top-down decoupling of the normally direct spatial relations between stimulus and response and results in increased planning times and directional errors compared to their spatially compatible prosaccade counterparts. Moreover, antisaccades are associated with diffuse changes in cortical and subcortical saccade networks: a finding that has, in part, been attributed to pre-setting the oculomotor system to withhold a stimulus-driven prosaccade. Moreover, recent work has shown that a corollary cost of oculomotor pre-setting is that the planning time for a to-be-completed prosaccade is longer when preceded by an antisaccade (i.e., the unidirectional prosaccade switch-cost). Notably, this result has been attributed to antisaccades imparting a residual inhibition of the oculomotor networks that support the planning of stimulus-driven prosaccades. In the current investigation, we sought to determine if the number of antisaccades preceding a prosaccade increases this residual inhibition and thus influences the magnitude of the unidirectional prosaccade switch-cost. To that end, participants alternated between pro- and antisaccades after every second (i.e., AABB schedule) and every fourth (i.e., AAAABBBB schedule) trial. In addition, participants completed pro- and antisaccades in separate blocks of trials. Results demonstrated that task-switch prosaccades produced longer reaction times than their task-repetition and blocked condition counterparts, whereas antisaccade reaction times did not vary across task-repetition, task-switch and blocked condition trials. Most notably, the magnitude of the unidirectional prosaccade switch-cost was not modulated across the different task-switching schedules. Thus, we propose that the top-down requirements of the antisaccade task do not produce additive inhibition of stimulus-driven saccade networks.

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1. Introduction

A salient feature of human oculomotor control is the rapid and reflexive manner in which a saccade can be generated to an exogenously presented peripheral stimulus (i.e., prosaccade). Notably, the direct retinotopic mappings afforded between stimulus and response (i.e., standard response: e.g., Bruce, Goldberg, Bushnell, & Stanton, 1985; Wurtz & Albano, 1980) during a prosaccade allows for maximally efficient and effective motor output (Fitts & Seeger, 1953; for review see Kornblum, Hasbroucq, & Osman, 1990). It is, however, important to recognize that the direction of an oculomotor response is not ineluctably coupled to the spatial location of a presented stimulus; rather, the oculomotor system can flexibly “look” in a direction other than the stimulus (i.e., non-standard response). The properties of this non-standard response are highlighted in the antisaccade task wherein participants are instructed to look mirror-symmetrical to the location of an exogenously presented target (e.g., Hallett, 1978). Extensive evidence has

shown that antisaccades produce longer reaction times (RT), as well as increased directional errors compared to their prosaccade counterparts (e.g., Fischer & Weber, 1996; Hallett, 1978). Moreover, convergent neuroimaging and electrophysiological studies involving human and non-human primates have linked the behavioral costs of antisaccades to a two-component process requiring: 1. the top-down suppression of a stimulus-driven prosaccade (i.e., response suppression; Everling, Dorris, & Munoz, 1998; Everling, Dorris, Klein, & Munoz, 1999) and 2. the visual remapping of target properties to mirror-symmetrical space (i.e., vector inversion: Funahashi, Chafee, & Goldman-Rakic, 1993; Zhang & Barash, 2000). Furthermore, neuroimaging work has shown that antisaccades are associated with greater activation of classic cortical saccade networks (e.g., frontal eye field, supplementary eye field, and intraparietal sulcus) than their prosaccade counterparts (Brown, Vilis, & Everling, 2007; Curtis & D’Esposito, 2003; DeSouza, Menon, & Everling, 2003; Ford, Goltz, Brown, & Everling, 2005). Thus, evidence indicates that the completion of a successful antisaccade is associated with diffuse changes within the oculomotor system (for review see Munoz & Everling, 2004).

The modulation of oculomotor networks during an antisaccade task is thought to result, in part, from a task-specific response mode

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that pre-sets the network to withhold a reflexive prosaccade (DeSouza et al., 2003; Ford et al., 2005). As such, a corollary to the *pre-setting* theory is that antisaccades engender a persistent response-set that delays the planning of a subsequent pro- or antisaccade. To address this issue, our previous work investigated the planning costs associated with alternating from a prosaccade to an antisaccade and vice versa (i.e., task-switching paradigm). In particular, participants alternated between pro- and antisaccades using a block of trials involving the classic task-switching paradigm (i.e., ABBB paradigm; Weiler & Heath, 2012a,b) and a block wherein pro- and antisaccades were presented in pseudo-randomized task-switching order (Weiler & Heath, 2012b). Our results have consistently shown that a prosaccade completed after an antisaccade (i.e., task-switch prosaccade) elicits longer RTs in comparison to the second of two consecutively completed prosaccades (i.e., task-repetition prosaccade). In contrast, RTs for antisaccades were refractory to the nature of the previously completed response (i.e., task-switch and task-repetition antisaccades). In other words, our results demonstrate a unidirectional prosaccade switch-cost and our results have recently been replicated by an independent group (Chan & DeSouza, 2013). Notably, such findings are in-line with the cognitive task-switching literature reporting a unidirectional switch-cost when alternating from a non-standard to a standard task. For example, Allport, Styles, and Hsieh (1994) showed that alternating from the unfamiliar color-naming (i.e., non-standard task) to the familiar word-naming (i.e., standard task) Stroop task resulted in a reliable switch-cost, whereas the converse switch did not.

It is, however, important to bear in mind that most cognitive task-switching studies require a simple button press or oral response (for review see Kiesel et al., 2010), whereas task-switching in oculomotor control requires the evocation of a spatially constrained action. As such, task-switching in oculomotor control adds importantly to the literature inasmuch as it demonstrates that such an effect manifests in the context of an action constrained by speed/accuracy relations. Indeed, due to the symmetry between oculomotor (Chan & DeSouza, 2013; Weiler & Heath, 2012a,b) and cognitive task-switching results (Allport et al., 1994) as well as oculomotor neuroimaging (Brown et al., 2007; Curtis & D'Esposito, 2003; DeSouza et al., 2003; Ford et al., 2005) and electrophysiology (Everling & DeSouza, 2005; Everling et al., 1998, 1999) evidence, we have proposed that the top-down processes required to implement an antisaccade results in a residual inhibition of the dedicated oculomotor networks that support the planning of subsequent prosaccades.

An interesting question arising from our previous work is whether the residual inhibition of oculomotor networks accumulates over successive antisaccade trials. This question stems from evidence demonstrating that a switch-cost can increase as a function of the number of non-standard trials preceding a standard switch-trial. For example, Wylie and Allport (2000) demonstrated that increasing the ratio of the non-standard trials preceding a standard trial reliably increased the magnitude of the switch-cost (see Fig. 8 of Wylie & Allport, 2000). Thus, it is possible that the unidirectional prosaccade switch-cost noted in our previous work may be influenced by the number of previously completed antisaccade trials. Such a finding would suggest that antisaccades not only delay the planning of subsequent prosaccades, but also engenders residual inhibition that accumulates (or strengthens) over successive trials.

The first goal of the present investigation was to determine if the number of antisaccades preceding a to-be-completed prosaccade influences the documented unidirectional prosaccade switch-cost (Weiler & Heath, 2012a,b). To accomplish that objective, switch-costs were compared in separate blocks wherein tasks (i.e., pro-, antisaccades) alternated after every second (i.e., double block) and fourth (i.e., quadruple block) trial. In terms of research predictions, if antisaccades provide additive inhibition to oculomotor networks then the magnitude of the unidirectional prosaccade switch-cost is predicted to increase as a function of the number of previously completed antisaccades. In contrast, if

the inhibition of oculomotor networks does not engender an additive level of oculomotor inhibition, then it is predicted that the magnitude of the unidirectional prosaccade switch-cost will be refractory to the number of previously completed antisaccades.

The second goal of the current investigation was to evaluate the specific locus of the unidirectional prosaccade switch-cost. Indeed, Wylie and Allport (2000) have cautioned against the fundamental task-switching assumption that task-repetition trials represent a proxy for a baseline measure of standard or non-standard trials because "...the comparison of Repeat trial RTs and RTs in a baseline condition is [usually] not possible" (pp. 213). In other words, task-repetition trial-types may differ from their counterparts performed in a separate block of trials (Goffaux, Phillips, Sinai, & Pushkar, 2006). Given this consideration, a critique of our past work is that we did not demonstrate that the relative increase in RTs for task-switch compared to task-repetition prosaccades was selectively related to a previously completed antisaccade (Weiler & Heath, 2012a,b); rather, it is possible that the difference between prosaccade task-switch and task-repetition trials may be linked to a shortening of RTs in the latter condition. To illustrate this issue, Fig. 1 presents theoretical data for prosaccade task-switch and task-repetition trials as well as prosaccades performed in separate blocks of trials. The top panel of the figure shows that prosaccade task-switch trials produce longer RTs than their task-repetition and blocked trial counterparts (which do not differ): a pattern of results that would support our contention of a unidirectional prosaccade switch-cost. In turn, the bottom panel shows that prosaccade task-repetition trials produce shorter RTs than task-switch and blocked trial counterparts. In this scenario, the relative difference between the RTs for task-switch and task-repetition prosaccades is not the result of a previously completed antisaccade; rather, the hypothetical difference is the result of a "speeding-up" of the second of two consecutively completed prosaccades. To directly address this issue,

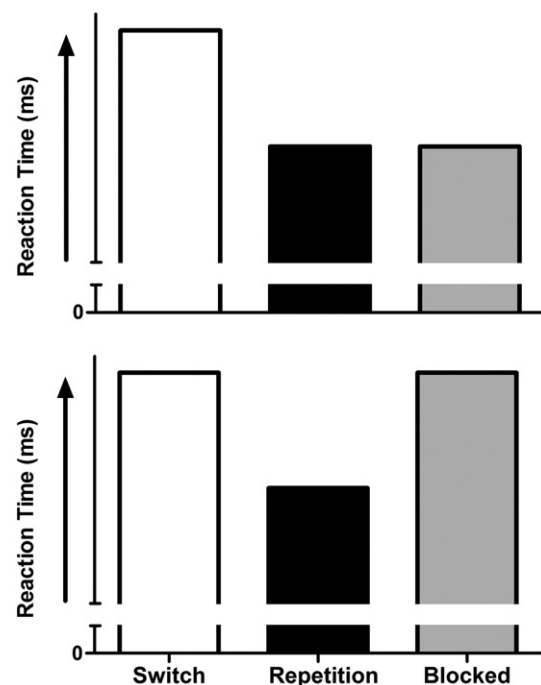


Fig. 1. Switch-cost, or repetition-benefit?: Hypothetical data highlighting potential differences between blocked, task-switch and task-repetition prosaccades. The top panel shows longer RTs for task-switch prosaccades compared to their task-repetition and blocked counterparts (which do not differ): a result consistent with our assertion of a unidirectional prosaccade switch-cost. In contrast, the bottom panel depicts shorter RTs for task-repetition prosaccades than their task-switch or blocked conditions counterparts (which do not differ). Indeed, results conforming to the lower panel would suggest that differences between task-switch and task-repetition prosaccades relates to a "speeding up" of oculomotor planning mechanisms.

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