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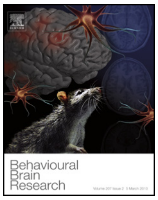

Research report

The unidirectional prosaccade switch-cost: Electroencephalographic evidence of task-set inertia in oculomotor control

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HIGHLIGHTS

- The completion of an antisaccade delays the RT of a subsequent prosaccade.
- It is proposed that this finding reflects task-set inertia in oculomotor control.
- Here we assessed the P3 ERP in an oculomotor task-switch experiment.
- P3 amplitude of task-switch prosaccades were comparable to antisaccade trial-types.
- The EEG finding support the proposal of task-set inertia in oculomotor control.

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ABSTRACT

The execution of an antisaccade selectively increases the reaction time (RT) of a subsequent prosaccade (the *unidirectional prosaccade switch-cost*). To explain this finding, the task-set inertia hypothesis asserts that an antisaccade requires a cognitively mediated non-standard task-set that persists inertially and delays the planning of a subsequent prosaccade. The present study sought to directly test the theoretical tenets of the task-set inertia hypothesis by examining the concurrent behavioural and the event-related brain potential (ERP) data associated with the unidirectional prosaccade switch-cost. Participants pseudo-randomly alternated between pro- and antisaccades while electroencephalography (EEG) data were recorded. As expected, the completion of an antisaccade selectively increased the RT of a subsequent prosaccade, whereas the converse switch did not influence RTs. Thus, the behavioural results demonstrated the unidirectional prosaccade switch-cost. In terms of the ERP findings, we observed a reliable change in the amplitude of the P3 – time-locked to task-instructions – when trials were switched from a prosaccade to an antisaccade; however, no reliable change was observed when switching from an antisaccade to a prosaccade. This is a salient finding because extensive work has shown that the P3 provides a neural index of the task-set required to execute a to-be-completed response. As such, results showing that prosaccades completed after antisaccades exhibited increased RTs in combination with a P3 amplitude comparable to antisaccades provides convergent evidence that the unidirectional prosaccade switch-cost is attributed to the persistent activation of a non-standard antisaccade task-set.

1. Introduction

The rapid reorientation of gaze towards a salient visual target (i.e., prosaccade) represents the most frequent motor response that humans perform on a day-to-day basis [29]. Notably, prosaccades require minimal top-down control due to their mediation via retinotopically organized motor maps within the superior colliculus ([46]; see also [39]). It is, however, possible to decouple direct stimulus and response (SR) relations and 'look' to any desired region of the visual field (i.e., non-standard task: see [17,32]). Indeed, non-standard tasks represent an important area of inquiry because they provide a framework for understanding how top-down cognitive control influences oculomotor networks. The antisaccade is an exemplar non-standard task and requires decoupling SR relations and the evocation of a saccade to a target's mirror-symmetrical location [24,25]. Extensive behavioural evidence has demonstrated that antisaccades have longer reaction times (RT) [24], increased directional errors [16,24], and less

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accurate and more variable endpoints [9,22,26] than prosaccades. These behavioural 'costs' have been attributed to the top-down suppression of a stimulus-driven prosaccade (i.e., response suppression) and the visual remapping (i.e., 180° spatial transformation) of the target's spatial location (i.e., vector inversion) ([20,47]; for review of the antisaccade task see [37]). Moreover, antisaccades have been linked to increased activity in an extensive fronto-parietal network (frontal eye field, supplementary eye field, dorsolateral prefrontal cortex, anterior cingulate cortex, and lateral intraparietal cortex) [5,8,11,18] and show a respective increase and decrease of collicular fixation and buildup neurons prior to target presentation [14,15]. The aforementioned changes to the oculomotor system are thought to reflect a preparatory response-set that withholds a reflexive prosaccade and permits sufficient time to complete the sensorimotor transformation necessary for an antisaccade [5].

In addition to the above-mentioned behavioural and neural changes linked to the antisaccade task, a series of recent studies have shown that the execution of an antisaccade lengthens the RT of a *subsequent* prosaccade ([6,7,10,41,42–45]). More specifically, results from our group have shown that the RT of a prosaccade completed after an antisaccade (i.e., task-switch prosaccade) are between 10 and 20 ms longer than a prosaccade completed after a prosaccade (i.e., task-repetition prosaccades). In contrast, RTs for task-switch and task-repetition antisaccades do not differ. As such, we have termed the selective increase in the RTs of task-switch prosaccades as the *unidirectional prosaccade switch-cost* and have shown that such an effect is not accounted for by the independent or interdependent effects of response suppression [44] and vector inversion ([45]; see also [10]). In accounting for the unidirectional prosaccade switch-cost our group extended [1] task-set inertia hypothesis to the oculomotor domain and proposed that responses entailing non-dominant SR mapping (e.g., an antisaccade) require the implementation of cognitively meditated task-rules (i.e., a task-set) for their successful execution. Moreover, the hypothesis asserts that the cognitively mediated task-set persists inertially and delays the planning of a subsequent response with standard and dominant SR mapping (e.g., a prosaccade). In turn, the hypothesis contends that the completion of a response with dominant SR relations does not require the activation of a cognitively based task-set and therefore does not influence the planning of a subsequent response with non-dominant SR mapping. Thus, task-set inertia asserts a null cost when switching from a prosaccade to an antisaccade.

An important issue to revolve is *how* a persistently active antisaccade task-set delays the planning of a subsequent prosaccade. In other words, identifying the component element of prosaccade planning that is influenced by the antisaccade task-set would provide a direct explanation of how the task-set inertia hypothesis accounts for the unidirectional prosaccade switch-cost. One possible explanation is shown in Fig. 1. In particular, the figure shows that advanced information specifying antisaccade task-cuing (time A) results in the adoption of a cognitively mediated antisaccade task-set in advance of the exogenous stimulus cuing the response (i.e., response-cuing; see time B). Importantly, the figure further shows that the antisaccade task-set persists inertially and is present throughout a subsequent prosaccade task- (time C) and response-cuing (time D) interval. Indeed, it is predicted that an appropriate prosaccade task-set is adopted only after response-cuing (time E) and it is only after this time that the ensuing response can be planned with standard SR rules. Put more simply, we propose that the basis for the prosaccade switch-cost is that the antisaccade task-set persists inertially and delays *when* the prosaccade task-set can be adopted. Furthermore, and as outlined in the preceding paragraph, Fig. 1 (time G) shows that the prosaccade task-set does not persist inertially and therefore does not delay the adoption of a non-standard antisaccade task-set.

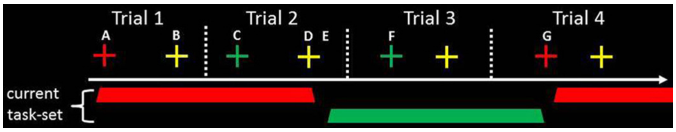

Fig. 1. Theoretical predictions for how task-set inertia elicits a unidirectional prosaccade switch-cost. Trials 1 through 4 represent task-repetition antisaccades (trial 1), task-switch prosaccades (trial 2), task-repetition prosaccades (trial 3) and task-switch antisaccades (trial 4). Red and green crosses denote anti- and prosaccade task-cues, respectively. Yellow crosses denote response-cuing (i.e., target presentation). Red and green rectangles at the bottom of the figure represent anti- and prosaccade task-sets, respectively. Notably, the figure shows that the task-cue for task-switch prosaccades (time C) is associated with an antisaccade task-set, whereas the task-cue for task-repetition prosaccades (time F) is associated with a task-set distinct from all other trial-types. That is, time F in the panel demonstrates a task-set with direct SR relations.

Our explanation of the unidirectional prosaccade switch-costs is predicated on the assertion that the antisaccade task-set persists inertially and delays the adoption of the prosaccade task-set until after response-cuing. In other words, we propose that the preparatory interval (i.e., time between task-cuing and response-cuing) associated with task-switch prosaccades is associated with an antisaccade task-set, whereas the preparatory interval for task-repetition prosaccades is associated with its own distinct standard task-set (see Fig. 1). In order to test this hypothesis, the present investigation directly compared the concurrent behavioural and a human event-related brain potential (ERP) evoked by pro- and antisaccade task-switching. Notably, we identified the P3 ERP component as a means to measure the task-set inertia hypothesis because an extensive literature has shown that changes (i.e., modulation) in the amplitude of this waveform reflects the task-set required for a newly adopted response. For example, previous work in the motor control literature has shown that the amplitude of the P3–time-locked to task-cuing–differs between pro- and antipointing (i.e., the respective manual response analogues of pro- and antisaccades; [27]) and that the amplitude of the P3 is modulated when propointing must engage in an online trajectory correction to account for an unexpected target 'jump' [34]. More directly, the different P3 amplitudes for pro- and antipointing and for target jump and no-jump trials have been interpreted to reflect the task-set commensurate with current task-goals. Similarly, results from the perceptual literature have shown that task-switch and task-repetition trial-types are associated with distinct P3 amplitudes. For example, [21] demonstrated an increase in the amplitude of the P3 when participants switched from identifying the magnitude to the parity – or vice versa – of a to-be-presented numerical digit. According to the authors, the increase in P3 amplitude for task-switch trials reflected the adoption of the 'new' task-set required to successfully complete the response (see also [2,3,38]). Thus, convergent evidence indicates that modulation of the P3 reflect the adoption of a task-set required to meet the demands of the upcoming response.

In the current experiment participants initially viewed a task-irrelevant fixation cross and were then provided task instructions – via a fixation cross colour-change – which indicated whether to execute a pro- or antisaccade in response to an upcoming visual stimulus (i.e., task-cuing). The presentation of the target stimulus (i.e., response-cuing) occurred between 1000 and 2000 ms following the task-instruction cue. Importantly, we examined changes in P3 amplitude time-locked to, and evoked by, the task-instruction cue (i.e., the fixation cross colour-change) as this was the time-point when participants were informed whether to maintain or adopt a new task-set for the upcoming response. As such, the P3 time-locked to fixation cross colour-change provides an analogue of participants' premovement task-set. In terms of research predictions, if the unidirectional prosaccade switch-cost is explained