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The Effects of Response Readiness and Error Monitoring on Saccade Countermanding

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Abstract: The stop-signal task (SST) and anti-saccade tasks are both widely used to explore cognitive inhibitory control. Our previous work on a manual SST showed that subjects' readiness to respond to the go signal and the extent to which subjects monitor their errors need to be considered in order to attribute impaired performance to deficits in response inhibition. Here we examine whether these same task-related variables similarly influence oculomotor SST and anti-saccade performance. Thirty-six and sixty healthy, adult subjects participated in an oculomotor SST and anti-saccade task, respectively, in which the fore-period (FP) of imperative stimulus varied randomly from trial to trial. We computed a FP effect to index response readiness to the imperative stimulus and a post-error slowing (PES) effect to index error monitoring. Contrary to what we had anticipated, other than a weak but negative association between the FP effect and anti-saccade errors, these behavioral variables did not correlate with SST or anti-saccade performance.

Key Words: Stop-signal, go/no-go, impulsivity, inhibitory function, frontal, oculomotor.

1. INTRODUCTION

The saccade countermanding tasks – including the oculomotor stop signal task (SST) and anti-saccade task – are widely used to explore executive control functions [1-5]. In an anti-saccade task, there are pro-saccade trials, in which subjects make a visually guided saccadic eye movement toward to a peripheral target, and anti-saccade trials, in which subjects make an eye movement in the opposite direction. In order to execute an anti-saccade, one has to inhibit the reflexive tendency to make a pro-saccade elicited by the peripheral target, and engage the oculomotor machinery to make an eye movement in the desired direction. Occasionally one fails to override the tendency to make a pro-saccade in an anti-saccade trial, resulting in a "directional" error [6]. When one does make an anti-saccade, the RT of the anti-saccade is increased, compared to a pro-saccade, as a result of additional processing during visuomotor transformation in which inhibitory control assumes a critical role. An index of inhibitory control function can thus be derived based on the error rate and RT increase of anti-saccade trials. Because these outcome measures are clearly defined, the anti-saccade task is well suited for exploring the neural mechanism of response inhibition and behavioral impulsivity in patients with neurological or psychiatric conditions. For instance, studies in humans with brain lesions have implicated the prefrontal cortex during impaired anti-saccade performance [7-9].

The SST is another behavioral task widely used to explore inhibitory control [10]. There are two types of trials in the SST. In go trials, subjects respond to a go signal generally as quickly as possible; in stop trials, a stop signal follows the go signal and instructs subjects to withhold the response. There are more go trials than stop trials, so a prepotent response tendency (a "habit") is set up and the processes "countering" this tendency can be examined in the SST. The ease with which one can withhold a response depends on the time interval between the go and stop signals, or the stop-signal delay (SSD): the longer the SSD the more difficult it is for one to stop and vice versa. One way to characterize response inhibition is by way of the stop signal reaction time (SSRT), which describes how long it takes for the stop-signal to be processed so a response can be withheld [11]. For instance, with a staircase procedure, in which the SSD decreases by a specified step to make it easier for the subject to stop at the stop signal if the subject fails at a previous stop trial and increases by the same step if the subject succeeds, one can achieve a success rate of approximately 50% in the stop trials. A "critical" SSD can then be computed that represents the time delay required for the subject to succeed in the stop trials half of the times [12]. The stop signal reaction time (SSRT) is then estimated by subtracting the "critical" SSD from the median reaction time (RT) of the go trials [10,11]. The SST is widely used as a cognitive proxy to describe response inhibition in people with neurological or psychiatric conditions, including patients with substance use disorders [13-24]. These patients invariably were found to have prolonged SSRT, compared to healthy control subjects.

However, cognitive processes other than response inhibition can influence performance in the anti-saccade task or the SST. A major goal of experimental psychology is to dissect these processes so impaired task performance can be attributed to their proper sources. For instance, we previously

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used a manual SST with the afore-described tracking procedure to examine response inhibition both in cocaine dependent and Tourette Disorder patients and in healthy individuals [17, 25-27]. We observed that two task-related variables could influence stop signal performance. We computed a fore-period (FP) effect as a measure of response readiness to the go signal and a post-error slowing (PES) effect as a measure of performance monitoring during the task. The FP effect described how go trials reaction time (RT) decreased with increased duration of preparation during the FP and the PES effect showed how much one slowed down in response to the go trials following a stop error [28-30]. We found that the FP effect correlated positively with SSRT and the PES effect correlated negatively with SSRT in linear regression [25-27]. These results indicate that performance strategy in terms of selectively attending to the go signal (i.e., the FP effect) or the stop signal (i.e., the PES effect) can influence stop signal performance. We suggested that these variables need to be accounted for in order to attribute stop signal performance to response inhibition.

In this study we hypothesized that these same considerations apply to oculomotor SST and anti-saccade task, both of which involve motor preparation and error monitoring [2, 31-33]. We made two specific predictions. First, in the oculomotor SST, the SSRT correlates positively with the FP effect and inversely with the PES effect. Second, in the anti-saccade task, the error rate and RT increase of the anti-saccade trials correlate positively with the FP effect and inversely with the PES effect. More broadly, confirmation of these hypotheses would provide further evidence that motor preparation and error monitoring are important cognitive variables that may influence performance in a wide range of neuropsychological tasks.

2. METHODS

Subjects and General Experimental Condition

A total of 101 college students (18 to 27 years of age) were paid to participate in the study. Forty of them (18 women and 22 men) took part in the saccade countermanding task and the other 61 (35 women and 26 men) in the anti-saccade task. All of them had normal or corrected-to-normal vision. No formal psychiatric interview or medical exams were performed but they all denied ever having a neurological or psychiatric condition or using an illicit substance. All subjects consented after given a detailed description of the study, in accordance to institute guidelines. Studies were conducted in an office dimly lit, mostly in the evening or over the weekend where it was quiet and free of interruptions. Subjects sat in front of a PC monitor approximately 57 cm away with their chin supported by a chin rest. Eye position was monitored by an infra-red system (EyeLink®II, SR Research Ltd., Mississauga, Ontario, Canada) at a spatial resolution of 0.1º (of visual angle) and 500 Hz, and corrected for head movement. The set up was calibrated for each individual subject before the study. Saccadic eye movements were defined to have a minimum velocity of 30°/s and minimum acceleration of 9,500°/s^2. The onset of a saccade was defined as the time when the eye movement velocity exceeded 30°/s. Our previous work showed that these criteria were useful in capturing the dynamics of saccadic eye movements under the same setup [34].

Oculomotor SST

Fig. (**1a**) illustrates the task. The oculomotor SST consisted of 270 “go” and 90 “stop” trials, randomly intermixed in an experiment. In a go trial, a fixation point (1º across) appeared at the center of the screen to engage attention and eye fixation. The subjects were instructed to press a control button to initiate each trial whenever they felt they have acquired the center fixation. The trial would start only if the subject had maintained fixation within the center square. The fixation point extinguished following a randomized fore-period (FP) between 0.5 and 1.5 sec (selected from a uniform distribution), and a target (the “go” signal) appeared at a peripheral location, 6º to the left or right. The subjects were to make a saccadic eye movement to the target. The trial terminated after the target was acquired or after 750 ms elapsed, whichever came first. A premature saccade also terminated the trial and counted as a fixation error. In a stop trial, the center fixation (the “stop” signal) re-appeared after the onset of the peripheral target, instructing the subjects to maintain fixation at the center square. They had to maintain fixation for at least 750 ms for the trial to be considered as a success. The time delay between the go and the stop signal or the stop-signal delay (SSD) varied from trial to trial (irrespective of target location) following a staircase procedure; if the subjects failed in a previous stop trial, the SSD decreased by 40 ms and, conversely, if the subjects succeeded in a previous stop trial, the SSD increased by 40 ms. With the staircase procedure, we anticipated that most subjects would succeed in maintaining their eye fixation at the center location in approximately 50% of the stop trials. Subjects who made an excessive number of fixation failures during the FP or achieved a success rate less than 95% in the go trials or more than 55% or less than 45% of stop trials were considered as not following the instructions and excluded from further analysis. Most subjects completed the task within 40 minutes.

Anti-Saccade Task

Fig. **(1b)** illustrates the task. The anti-saccade task consisted of 270 pro-saccade and 90 anti-saccade trials, randomly intermixed in an experiment. A light point subtending 1º in diameter appeared at the center of the screen to begin a trial. The subject was instructed to fixate the center light stimulus and press a control button to initiate a trial whenever they have acquired the target. The trial started only if the subject had maintained fixation within the center square. After the FP or a randomized time interval between 0.5 and 2.0 sec following successful fixation, a target appeared in one of the two square boxes (approximately 2º x 2º) located at 6º to the right and left of the center fixation. In a pro-saccade trial, the target was a disk (2º across), signaling the subject to make a visually guided eye movement to the target. The subject had to initiate a saccade within 750 ms or the trial was aborted. In an anti-saccade trial, the target was an “X”, signaling the subject to make an eye movement toward the box across. The subjects had to initiate the anti-saccade within 1,500 ms. If subjects made a fixation error or an error in the pro-saccade or anti-saccade trials, a new trial would be inserted at the end of the “stack.” Most subjects completed the task within 45 minutes.

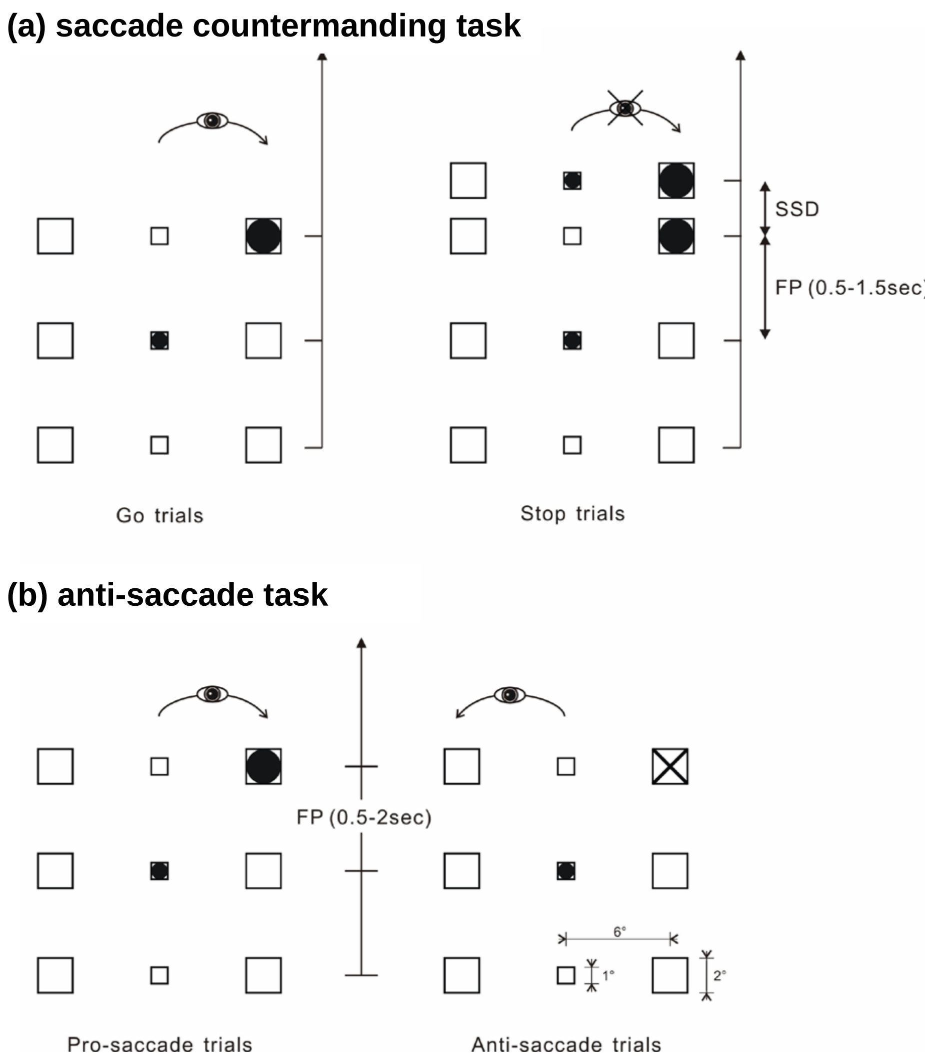

Fig. (1). Behavioral tasks. All stimuli were presented in white against a dark background; arrow indicates the direction of time (**a**) saccade countermanding task; a fixation point appeared at the center square at the beginning of a trial. In a go trial, a peripheral target appeared at the right or the left square after a fore-period (FP) that varied randomly between 0.5 and 1.5 seconds at the same time when the center fixation disappeared, and the subject was to make a saccade to acquire the target within 750 ms. In a stop trial, the fixation point re-appeared in the center square after a stop signal delay (SSD) following the appearance of the peripheral target, instructing the subjects to hold their fixation at the center square. The SSD was updated from one stop trial to another following a staircase procedure (see text). (**b**) anti-saccade task; a fixation point appeared at the center square at the beginning of a trial. In a pro-saccade trial, a peripheral target appeared after a fore-period (FP) that varied randomly between 0.5 and 2 seconds at the same time when the center fixation disappeared, and the subject was to make a saccade to acquire the target within 750 ms. In an anti-saccade trial, an "X" appeared at the periphery, instructing the subjects to make a saccade in the opposite direction (time window =1,500 ms).

Data Analysis

Oculomotor SST

We computed for each individual subject a critical stop-signal delay (SSD) which represents the time delay between the go and the stop signal in order for the subjects to succeed in half of the stop trials [12]. The stop-signal reaction time (SSRT) was then computed by subtracting the critical SSD from the median go trial RT [10]. We computed the fore-period (FP) effect: FP effect = median saccade RT of go trials with FP < 1 sec – median saccade RT of go trials with FP ≥ 1 sec; and the post-error slowing (PES) effect: PES effect = median saccade RT of go trials following a failed stop trial – median saccade RT of go trials that did not follow a stop trial (irrespective of target location). Note that in our previous study we computed the post-signal slowing (PSS) effect to index the extent to which subjects were engaged in performance monitoring (PSS effect = median saccade RT of go trials that followed a stop trial – median saccade RT of go trials that did not follow a stop trial). Since the PES and PSS effects were highly correlated (Pearson r= 0.875, P<0.001 for the oculomotor SST; Pearson r=0.668, P<0.001 for the anti-saccade task, see next section), we focused here only on the PES effect (see, however, [35] for an exception). We examined for a correlation each between the FP effect and SSRT and between the PES effect and the SSRT across all subjects with linear regression.

Anti-Saccade Task

Two outcome measures were derived: error rate of anti-saccades and the increase in the RT of anti-saccades, compared to pro-saccades. The increase in anti-saccade RT or "anti-saccade RT gain" may be considered as the cost in information processing as resulting from a partial error [36,37]. Failure to execute a saccade or saccades that failed to land within the target box in the anti-saccade trials were counted as a directional error. The anti-saccade RT gain was computed by subtracting the mean RT of pro-saccades from the mean RT of anti-saccades, separately for rightward and leftward saccades. An average RT gain was then computed by weighting the proportion of leftward and rightward saccades (Appendix). The same weighting was also employed in the computation of FP and PES effects. We likewise examined for a correlation between the FP effect and anti-saccade error rate, between the FP effect and anti-saccade RT gain, between the PES effect and anti-saccade error rate, and between the PES effect and anti-saccade RT gain, by performing a linear regression in each case. Given these multiple tests, the results were evaluated at an α of 0.0125.

3. RESULTS

Oculomotor SST

Four subjects succeeded in less than 45% of the stop trials and were excluded from further analysis. The remaining data set consisted of 36 subjects. Table **1a** shows their general performance. Subjects succeeded in an average of 98% of go trials and in 51% of the stop trials, suggesting the adequacy of the staircase procedure in tracking their performance. The stop signal reaction time (SSRT) was computed on the basis of the race model [10]. The mean SSRT was 114 ms, in the range of those values reported in previous studies using oculomotor countermanding tasks [32, 38-42]. All but four subjects demonstrated a positive FP effect and all subjects demonstrated a positive PES effect. We assessed for an association across subjects each between SSRT and the FP effect and between SSRT and the PES effect. Linear regression showed that neither the correlation between the SSRT and the FP effect (p=0.152, Pearson r=-0.244, Fig. **2a**) nor the correlation the SSRT and the PES effect (p=0.617, Pearson r=0.086, Fig. **2b**) was significant.

Anti-Saccade Task

One subject did not finish the task, so the data set consisted of 60 subjects (Table **1b**). The subjects showed an average 2.0 ± 15.0% of fixation failures during the fore-period, indicating excellent compliance of the subjects to task instructions. They made a directional error in an average of 38% of the anti-saccade trials, and these directional errors were almost always followed by a corrective eye movement (data not shown). All but 8 subjects showed a positive FP effect, and all but 3 subjects showed a positive PES effect. Anti-saccade performance was assessed with directional error rate and the anti-saccade RT gain (see Methods). Simi-

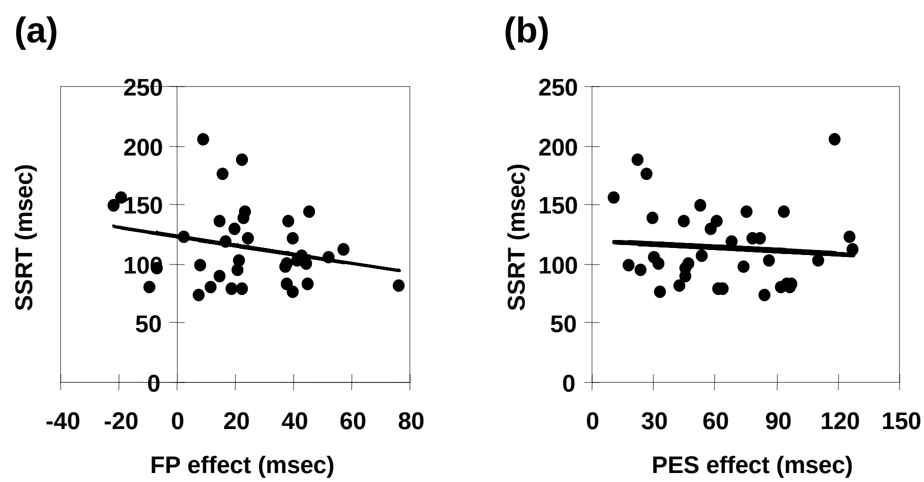

Fig. (2). Countermanding performance. The stop signal reaction time (SSRT) did not correlate with the fore-period (FP) effect (**a**) or with the PES effect (**b**). See text for statistics

Table 1. Performance in the Saccade Countermanding (a) and Anti-Saccade (b) Task

(a) Countermanding task							
Go Trial (succ %)	**Stop Trial (succ %)**	**Fixation Error #)**	**Mean Go RT (ms)**	**Median Go RT (ms)**	**SSRT (ms)**	**FP Effect (ms)**	**PES Effect (ms)**
98.0 ± 1.2	51.2 ± 3.0	2 ± 3	341 ± 78	330 ± 93	114 ± 33	24 ± 21	64 ± 32

(b) anti-saccade task					
Pro-Saccade RT (ms)	**Anti-Saccade RT (ms)**	**RT Increase (ms)**	**Anti-Saccade error (%)**	**FP Effect (ms)**	**PES Effect (ms)**
245 ± 46	333 ± 80	88 ± 61	38 ± 21	12 ± 13	24 ± 19

Note: mean ± s.d. across subjects; RT = reaction time; SSRT = stop signal reaction time; FP = fore-period; PES = post-error slowing; succ=success.

larly, we examined for an association between these performance indices and the FP and PES effects across subjects. The results of linear regression showed a marginally significant inverse correlation between the anti-saccade RT gain and the FP effect (p=0.012, Pearson r=-0.32, Fig. **3b**). Anti-saccade error did not correlate with FP effect (p=0.158, Fig. **3a**). Neither anti-saccade error rate nor RT gain correlated with the PES effect (p=0.396 and p=0.066, respectively; Fig. **3c** and **3d**).

Apart from linear correlation, we employed another approach to examine whether response readiness was indeed inversely associated with anti-saccade RT gain in the anti-saccade task. Thus, we compared across all 60 subjects the error rate and RT gain between anti-saccade trials when the FP was short (FP<1.25s; FP1) and when the FP was long (FP≥1.25s; FP2). The result showed no difference in the error rate between trials with FP1 (37 ± 21%) and those with FP2 (38 ± 21%). However, the RT gain was indeed significantly greater when the FP was short (RT gain = 95 ± 63 ms) than when the FP was long (RT gain = 82 ± 63 ms, t_{59}=3.113, p=0.003; paired t test).

4. DISCUSSION

Fore-Period (FP) Effect and Response Inhibition

The current results come in striking contrast to what we have hypothesized. In the oculomotor SST, the SSRT did not correlate with the FP effect, and in the anti-saccade task, anti-saccade RT gain correlated inversely with the FP effect, though only with marginal significance. The latter result suggests greater response readiness during FP2, as compared to FP1, is associated with less processing cost during execution of an anti-saccade. Therefore, whereas greater response readiness as indexed by the FP effect is associated with decreased inhibitory control in the manual SST, it is associated with greater inhibitory control in the anti-saccade task. What might account for this discrepancy?

One possibility is that, in the manual SST employed in our previous study, the visual stimuli always appeared at the center of fixation [17, 25-27]. Therefore, a greater FP effect may reflect processing advantage conferred to the go signal, which takes temporal precedence to the stop signal. On the other hand, in the current, oculomotor SST, the imperative stimulus or the "go" signal appears at either side of the fixation while the "stop" signal appeared exactly at the center fixation. Therefore, stop signal processing may have been expedited *via* a foveal attention effect, with greater advantage conferred later during the fore-period when attention is better engaged at the fixation. Thus, although subjects are better prepared to make an eye movement during the second half of the fore-period, this advantage does not compromise the processing of the stop signal, as is the case in the manual SST. In fact, the spotlight theory of visual attention would predict spatial averaging of attention allocation and enhanced processing of visual stimuli at the center fixation [43,44]. The fixation cells of the superior colliculus may also play a

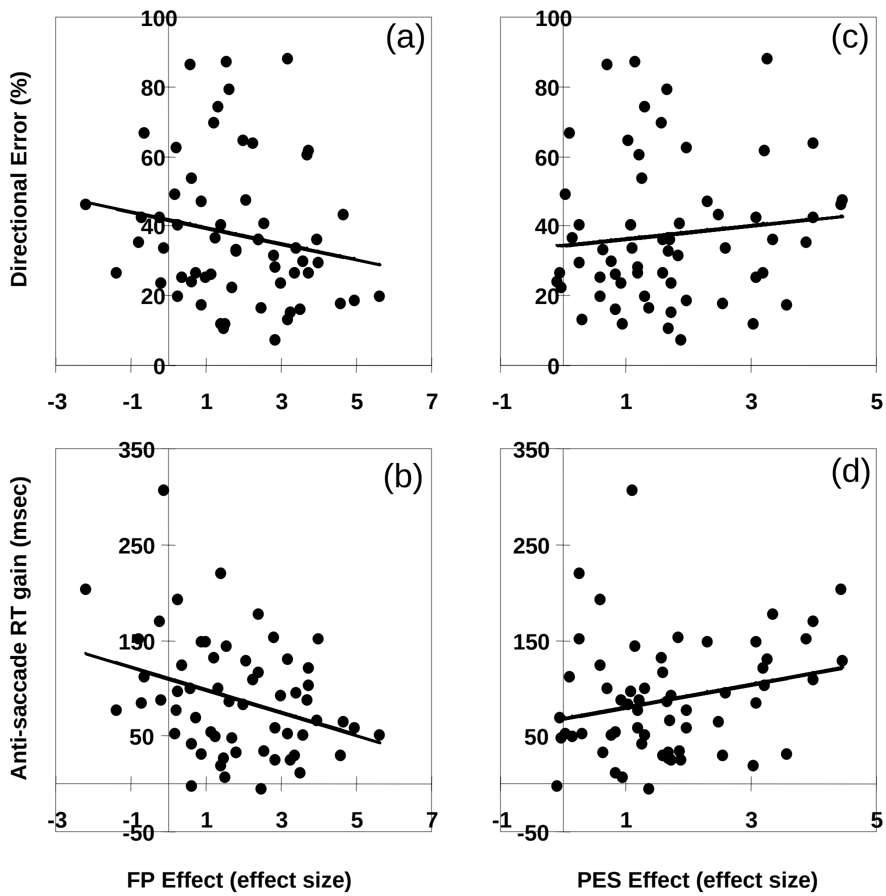

Fig. (3). Anti-saccade performance. (**a**) The directional error did not significantly correlate with the fore-period (FP) effect. (**b**) The reaction time (RT) gain of anti-saccades trials showed a marginally significant, weak, inverse correlation with the FP effect. Neither directional error (**c**) nor RT gain (**d**) correlated significantly with the PES effect. See text for statistics.

role in facilitating the effects of the stop signal in "arresting" saccades [4].

A previous study examined the effect of partial information (by varying the probability of go versus no-go signal) on lateralized readiness potential (LRP) during a choice reaction time go/no-go task, with the visual stimuli presented at visual fixation [45]. Greater LRP was found to be associated with blocks of trials with higher go probability. Moreover, more commission errors were made in these blocks with higher go probability. Therefore, greater readiness to respond to an imperative stimulus appears to be associated with poor response inhibition, a finding consistent with our earlier results in the manual task but at odds with our current finding [26]. On the other hand, a recent study manipulated response readiness by cueing subjects of an imminent onset of a no-go signal during a choice RT go/no-go task [46]. The visual stimuli were presented at center fixation. They found that no-go signal processing was delayed, instead of expedited, during episodes of decreased response readiness. This result is thus consistent with our present findings but at odds with those we reported in the manual SST [26]. The authors suggested that reduced response readiness might give rise to more forceful responses that were more difficult to inhibit. Alternatively, we have suggested that in van den Wildenberg *et al.*, 2002 subjects might have adopted a conservative response strategy during episodes preceded by a no-go signal cue such that their general motivation level or vigilant attention imparted disadvantage not only upon go but also no-go signal processing, resulting in prolonged RT and SSRT [26]. Overall, these disparate results indicate that multiple psychological processes may have been subsumed under the rubric of "response readiness" and that the effect of response readiness on stop signal and anti-saccade performance can vary depending on specific stimulus conditions and task requirements.

Several other factors may also complicate how FP effect influences task performance. Response readiness during the fore-period does not necessarily increase linearly with the preparation time; namely, the FP effect may not be linear with respect to the duration of the fore-period [47,48]. For instance, in an fMRI study where we varied the fore-period between 1 and 5 seconds in a manual SST, we did not observe an association between the FP effect (similarly defined by dividing the fore-period into 2 time periods of equal duration) with stop signal performance [25]. Thus, although the majority of our subjects demonstrated a positive FP effect, the FP effect as computed may not have captured the same psychological state as we have intended. Indeed, in the current study, 16 of the 36 subjects showed a linear FP effect ($p<0.05$, RT linearly and inversely correlated with FP duration across all go trials within an individual subject) during the oculomotor SST. Importantly, there was a trend that the SSRT is inversely correlated with the FP effect across these 16 subjects ($p<0.07$). That is, linear response readiness within the FP between 0.5 and 1.5 s is associated with decreased SSRT during saccade countermanding. Thus, a linear trend in motor preparation seems to confer certain advantage upon stop signal processing, a result in accord with the current findings from the anti-saccade task. Finally, we have observed a robust FP effect in a recent study examining response inhibition in children with Tourette's Disorder (mean age = 12 years, [17]). However, neither children with Tourette's Disorder nor their age-matched healthy controls demonstrated a significant association between the FP effect and their countermanding performance (SSRT). Taken together, we feel that the FP effect remains an important task-related variable to compute in order to account for the effect of motor preparation on countermanding performance. However, studies are required to systematically explore the temporal dynamics of this readiness effect, to separate the readiness effect specific to the imperative stimulus from one that perhaps is more general and depends to a greater extent on a subject's vigilant attention or motivation, and to investigate how this effect is modulated by age.

Post-Error Slowing (PES) Effect and Response Inhibition

We obtained a positive PES effect in both the oculomotor SST and anti-saccade task, providing further evidence for performance monitoring in these cognitive-motor paradigms. However, in neither task does the PES effect correlate significantly with outcome measures, consistent with a earlier report on error monitoring deficits in children with attention deficit hyperactivity disorder [49]. This result stands in contrast with our previous studies where we observed an inverse correlation between the PES effect and the SSRT across different samples of subjects, an association suggesting that greater performance monitoring improves countermanding performance [25,27]. It is worth noting that both the mean (pro-) saccade RT in the anti-saccade (ca. 250 ms) and the countermanding (ca. 340 ms) task are substantially shorter than the manual RT (ca. 500 ms) obtained in the previous studies. Moreover, the SSRT (ca.114 ms) obtained in the current oculomotor SST is also shorter than the SSRT (ca. 200 ms) obtained from the simple manual reaction time task in our previous studies [17, 25-27]. Thus, both the "agonistic" and "antagonistic" processes are completed within a significantly shorter duration in the oculomotor than manual task [39]. The speeded sensorimotor transformation that occurs during the execution of a saccadic eye movement is probably less "penetrable" by higher-level cognitive processes, as compared to the execution of the manual response.

In an anti-saccade task, participants are often not aware of their directional error when they are inquired immediately after a trial, although these errors are almost always followed by a corrective eye movement [50,51]. Electrophysiological studies have generally identified two components of event-related brain potentials (ERP) associated with a response error [51,52]. The error-related negativity (Ne/ERN) peaks around 80 ms after an incorrect response and has a fronto-central distribution, whereas the error-related positivity (Pe) is a slower ERP which often follows the Ne/ERN and has a centroparietal distribution. The Ne/ERN and Pe are thought to reflect the operation of an internal/sub-conscious and a peripherally driven/conscious error monitoring mechanism. Nieuwenhuis *et al*., 2001 found a greater Pe during perceived than unperceived errors, while the Ne/ERN remained indistinguishable, providing evidence for two distinct error monitoring mechanisms. Importantly, they observed that the perceived but not unperceived errors were associated with post-error slowing [51]. Since all but 3 of our 60 subjects showed a positive PES effect in the current study, our subjects seemed to be aware of their error during the anti-

Appendix

First, we grouped all pro-saccade trials with respect to their saccade direction (rightward or R and leftward or L) and fore-period (FP1: < 1.25 sec and FP2: ≥ 1.25 sec). Assume there were $N_{FP1,R}$ saccades with a mean RT of $RT_{FP1,R}$, $N_{FP1,L}$ saccades with a mean RT of $RT_{FP1,L}$, $N_{FP2,R}$ saccades with a mean RT of $RT_{FP2,R}$, $N_{FP2,L}$ saccades with a mean RT of $RT_{FP2,L}$. Let $N_{pro\text{-}sacc} = N_{FP1,R} + N_{FP2,R} + N_{FP1,L} + N_{FP2,L}$. The FP effect was computed as $(RT_{FP1,R} - RT_{FP2,R})*(N_{FP1,R} + N_{FP2,R})/N_{pro\text{-}sacc} + (RT_{FP1,L} - RT_{FP2,L})*(N_{FP1,L} + N_{FP2,L})/N_{pro\text{-}sacc}$. Second, we grouped all pro-saccade trials according to their direction and whether they followed a pro-saccade or failed anti-saccade. Let $RT_{Pro,R}$, $RT_{Pro,L}$, $RT_{Anti,R}$, $RT_{Anti,L}$ be the mean RT of rightward pro-saccades preceded by a pro-saccade, of leftward pro-saccades preceded by a pro-saccade, of rightward pro-saccade preceded by a failed anti-saccade, and of leftward pro-saccade preceded by an failed anti-saccade, respectively. Moreover, let $N_{Pro,R}$, $N_{Pro,L}$, $N_{Anti,R}$, $N_{Anti,L}$ be the number of trials for each of these pro-saccades and $N_{Pro,R} + N_{Pro,L} + N_{Anti,} + N_{Anti,L} = N'_{pro\text{-}sacc}$. The post-signal slowing or PES effect was then computed as $(RT_{Anti,R} - RT_{Pro,R})*(N_{Pro,R} + N_{Anti,R})/N'_{pro\text{-}sacc} + (RT_{Anti,L} - RT_{Pro,L})*(N_{Pro,L} + N_{Anti,L})/N'_{pro\text{-}sacc}$.

saccade task. The latter rules out the possibility that our subjects simply did not attempt to better their countermanding performance because they were not aware of their errors.

An alternative possibility concerns the stimulus configuration we have employed in the current study. Our subjects were "slowing down" after committing an error and to slow down, they would have to attend less to where the imperative stimulus appeared. Since the target stimuli directing a pro-saccade and anti-saccade appeared with similar timing and at the same spatial locations, subjects would have paid less attention to the anti-saccade target, too. These attentional processes could have complicated the relationship between PES effect and anti-saccade performance.

In summary, along with our earlier work we have demonstrated that the effects of motor preparation and error monitoring on response inhibition can vary between manual and oculomotor tasks and with spatial and temporal stimulus configurations. Future studies can perhaps take advantage of these differences in order to understand how motor acts are initiated and suppressed. In particular, a formal model incorporating response readiness and error monitoring could provide a didactic tool for making predictions about countermanding performance in a broader, cognitive context [5, 53-55].

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