RESEARCH ARTICLES

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Sensory biases produce alternation advantage found in sequential saccadic eye movement tasks

Abstract In two-choice reaction time tasks, participants respond faster when the correct decision switches across consecutive trials. This *alternation advantage* has been interpreted as the guessing strategies of participants. Because the participants expect that the correct decision will switch across consecutive trials, they respond faster when this expectation is confirmed and they respond more slowly when it is disconfirmed. In this study, we evaluated the veracity of this *expectancy* interpretation. After replicating a long-lasting alternation advantage in saccadic reaction times (Experiment 1), we show that reducing the participants' ability to guess with a challenging mental rotation task does not change the alternation advantage, which suggests that expectancy is not responsible for the effect (Experiment 2). Next, we used prosaccade and antisaccade responses to dissociate between the sensory and motor contributions of the alternation advantage (Experiment 3) and we found that the alternation advantage originates from sensory processing. The implications of these findings are discussed with regard to guessing strategies, sensory processing, and how these findings may relate to inhibition of return.

Keywords Previous trial effects · Alternation advantage · Reaction time · Saccadic eye movements · Inhibition of return

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Introduction

Responding on one trial has been shown to influence responding on the next trial (see, for example, Bertelson 1961; Kirby 1976; Remington 1969; Soetens 1998; Soetens et al. 1985; for review, see Fecteau and Munoz 2003). This lingering influence from the previous trial has been studied with serial reaction time tasks. In such tasks, participants indicate the location of a visual target on each trial (left or right) and the corresponding reaction time is placed into one of two groups depending on the trial that preceded it; a *repetition* indicates that both trials required the same response (for example, left, left) and an *alternation* indicates that both trials required different responses (for example, left, right). Separating the trials in this way reveals that participants respond faster when the two consecutive trials are different (alternation) than when they are the same (repetition), provided that more than 500 ms has elapsed between the last response and the next target (Kirby 1976; Soetens 1998).

This *alternation advantage* has captured the interest of researchers because it is thought to signify the guessing strategies of participants (Kirby 1976; Soetens 1998; Soetens et al. 1985). According to this *expectancy* view, participants believe that a trial requiring a particular response (for example, left target, saccade left) is more likely to be followed by a trial requiring the opposite response (right target, saccade right) even though the probability of either event is equal. Because the participants expect that the correct response will alternate across consecutive trials, they respond faster when their expectations are confirmed and more slowly when their expectations are disconfirmed (Kirby 1976; Soetens 1998; Soetens et al. 1985).

Although participants do expect that alternations are more "likely" to occur than repetitions in random events (Jarvik 1946), no study has tested this explanation of the alternation advantage directly. The best, albeit indirect, evidence comes from higher-order effects, the changes in reaction times that are obtained across runs of trials. These analyses reveal that long runs of trials exaggerate the

alternation advantage in some instances. For example, after a long string of repeated trials (for example, left, left, left, left), participants respond much faster when the repetition is broken (for example, right) than when the string is continued (left). Similarly, the size of the alternation advantage increases as the string of alternations increases. These changes in behavior have been interpreted as expectancy because, as the participants' expectations of the next event increases, so too does the magnitude of the alteration advantage (see, for example, Kirby 1976; Soetens 1998; Soetens et al. 1985).

In this study, our goal was to establish the source of the alternation advantage. Does it arise from the guessing strategies of participants? If not, then from what does it originate? We begin by describing the simple, but necessary, step of replicating the alternation advantage in saccadic reaction times.

Experiment 1: long-lasting alternation advantage in saccadic reaction times

In most studies, the alternation advantage has been investigated using manual responses (Kirby 1976; Soetens 1998; Soetens et al. 1985). For two reasons, we implemented a saccadic response instead. First, the alternation advantage is best observed in conditions of high stimulus-response compatibility (Soetens 1998). Initiating saccades to visual stimuli that appear abruptly in the periphery is a very compatible stimulus-response relationship (Ingle 1973). Second, the saccadic response permitted us to use a non-competing manual response in Experiment 2 and to dissociate sensory and motor components of the alternation advantage in Experiment 3.

A two-choice gap saccade task was used to produce the alternation advantage (see also Carpenter 2001). In this task, participants were instructed to generate a saccade to a visual target that appeared 20° to the left or to the right of fixation. A 200-ms gap was inserted between the disappearance of the fixation marker and the appearance of the target. Although a gap paradigm was not implemented in previous studies that used manual responses (Kirby 1976; Soetens 1998; Soetens et al. 1985), we did not expect that inserting a gap would change the properties of what was being studied. In general, a gap paradigm has been shown to decrease saccadic reaction times of participants (Saslow 1967) because the gap acts as a temporal warning signal that informs participants that the target will appear shortly (see, for example, Kingstone and Klein 1993) and it "disengages active fixation", which is a physiological process that allows the saccade to be initiated faster (Dorris and Munoz 1995, 1998; see also Fischer and Weber 1993). So, beyond letting participants know that a target will be appearing shortly, the gap does not inform them where the upcoming target will appear and, therefore, should not influence their guessing strategies.

In addition, the amount of time that elapsed between consecutive target presentations was manipulated so as to determine the window of time across which the alternation advantage could be produced reliably. This information guided the development of subsequent experiments.

Materials and methods

Participants

Twelve volunteers were recruited from the university community to participate in this study. All participants had normal or corrected-to-normal visual acuity. Before beginning the experiment, they provided informed consent. The experiment was conducted in five sessions across 5 days. All of the experiments in this study were approved by the Queen's University Human Research Ethics Board.

Procedures

The participants were seated comfortably in a dental chair, facing a translucent screen that was positioned 100 cm away. At the beginning of each trial, the participants were instructed to maintain gaze on the central fixation marker and to initiate a saccade to the visual target as soon as it appeared. A 200-ms gap period, during which no visual information was available, was inserted in between the disappearance of the fixation marker and the appearance of the visual target. Red light emitting diodes (LEDs) were used as the central fixation marker and as the visual targets. The central fixation marker (2.0 cd/m^2) was back projected on the center of the translucent screen and the visual targets (5.0 cd/m^2) were mounted 20° to the left and to the right of central fixation. After the visual target disappeared, signaling that the trial was over, the translucent screen was illuminated to prevent dark adaptation because the participants were tested in a dark room. Eye position was not controlled during this intertrial interval.

Five intertarget intervals were tested (1.9, 3.7, 6, 7.7, and 11.2 s) in separate sessions on different days. These intervals were obtained by changing the length of time that the fixation marker was presented (0.3, 1, 2, 2, and 2 s, respectively), the target was presented (0.3, 1, 2, 2, and 2 s, respectively), and the screen was illuminated in between trials (1.17, 1.51, 1.76, 3.46, and 6.96 s, respectively). The order in which the subjects participated in each of these sessions was counterbalanced. Within each session, the field in which the target appeared (left or right) was equally probable and randomly chosen. Each session consisted of 600 trials that were divided into three blocks of 200. Short breaks were provided in between blocks. Every participant was tested individually in a dark, sound-attenuated room.

Data collection and handling

Eye position was measured with direct current electrooculography (EOG). Ag-AgCl electrodes were affixed to the outer canthus of each eye and the grounding electrode was affixed to the center of the forehead. The participants wore the electrodes for about 10 min before the experiment began in order to minimize EOG drift. The EOG signal was amplified and low-pass filtered (50 Hz) with a Grass P18 amplifier. The experimental paradigm and the presentation of the visual targets were controlled and the storage of eye movements was collected with custom software (REX; Hays et al. 1982) running on a PC. Horizontal eye position was digitized at a rate of 500 Hz and was stored on a hard disk. These data were analyzed off-line on a Sun Ultra 60 Spark station.

Saccadic reaction time was defined as the onset of the first saccade that exceeded 30°/s after the target appeared and was included in the analysis when the saccade was initiated to the correct location (±4°) and when the reaction time was greater than 90 ms or less than 1,000 ms in order to eliminate anticipations or atypically

long responses. The mean correct saccadic reaction times were placed into one of two categories depending on the relationship of each trial with the one immediately preceding it. A repetition indicated that the saccades were initiated to the same location (for example, right, right) and an alternation indicated that the saccades were initiated to different locations (for example, left, right).

In this experiment, 2.7% of all trials were eliminated because a saccade was generated at an inappropriate time during the trial, because a direction error was made, or because the participant blinked near the time that a saccade was to be generated.

Mean correct saccadic reaction times and direction errors (defined as a saccade being generated within ±4° of the wrong response location) were analyzed with repeated measures analysis of variance (ANOVA) that included the variables *intertarget interval* (1.9, 3.7, 6, 7.7, versus 11.2 s), *relationship of consecutive saccades* (repetition versus alternation), and *target location* (left target versus right target). An alpha of 0.05 was adopted as an acceptable type I error. Simple effects were analyzed with means comparisons that also used the *F* distribution. Bonferroni corrections were made when more than three comparisons were required. Because *target location* did not interact with any other variable (all *P*s>0.05) in this experiment or any of the experiments in this study, it will not be described further.

Results and discussion

The mean correct saccadic reaction times for repeated and alternating trials at each intertarget interval tested are illustrated in Fig. 1A. Two noteworthy findings are evident when inspecting this figure. First, an alternation advantage was obtained in saccadic reaction times. Second, its magnitude decreased as the amount of time that elapsed between trials increased (Fig. 1B). Consistent with these observations, the main effect of *relationship of consecutive saccades* ($F_{(1,11)}$=45.482, P<0.05), indicating that an alternation advantage was obtained overall, was modified by *intertarget interval* ($F_{(1,11)}$=5.273, P<0.05). Separate analyses of each intertarget interval revealed that a significant alternation advantage was obtained at every interval tested except for the longest (1.9 s, $F_{(1,11)}$=66.175, P<0.01; 3.7 s, $F_{(1,11)}$=36.940, P<0.01; 6 s, $F_{(1,11)}$=28.366, P<0.01; 7.7 s, $F_{(1,11)}$=17.350, P<0.01; and 11.2 s, $F_{(1,11)}$=3.749, P>0.01). However, the proportion of variance for which the alternation advantage was responsible decreased as the intertarget interval increased (partial η^2=0.60, 0.46, 0.39, 0.28, and 0.08, respectively) in a seemingly linear fashion (r=−0.99; slope=−1.03, intercept=14.68).

Consistent with the reaction time data, an analysis of direction errors revealed that more errors were made when the target appeared at the same location (1.7%) than at the opposite location (0.9%) across consecutive trials, resulting in a main effect of *Target Position*, $F_{(1,11)}$=37.7, P<0.05. Nothing else in this analysis was significant: all *F*s<1.4, all *P*s>0.1.

In summary then, an alternation advantage was obtained in saccadic reaction times (see also Carpenter 2001) and it was present for a long time, even when 7.5 s separated consecutive target presentations. However, the magnitude of the alternation advantage was not consistent across all of the intertrial intervals that were tested; instead, it decreased linearly as the intertrial interval increased. There
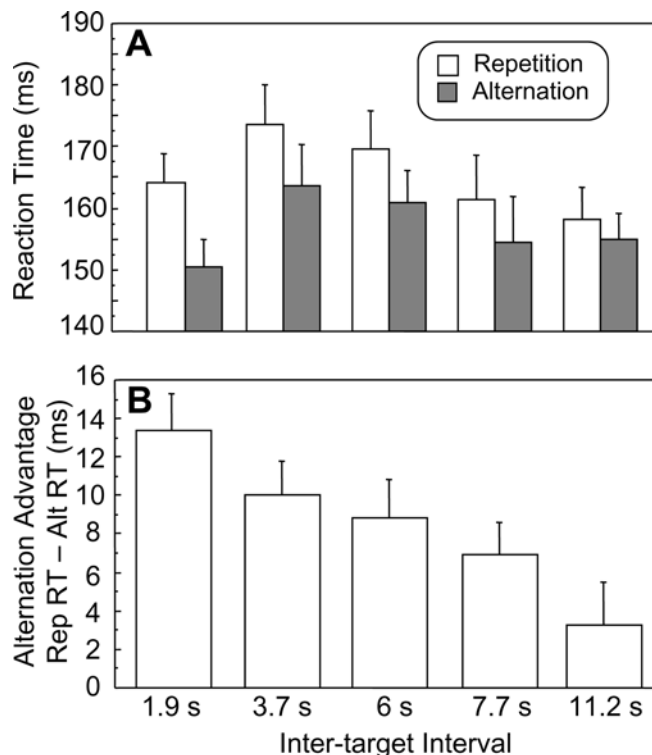

Fig. 1 A Mean correct saccadic reaction time for each intertarget interval in experiment 1. **B** Magnitude of alternation advantage for each intertarget interval. *Error bars* are 1 SE

are three, not mutually exclusive, reasons why this may have occurred. Albeit long lasting, the mechanisms responsible for the alternation advantage may decay across time. Alternatively, eye position was not controlled during the intertrial interval. If intervening saccades modify the alternation advantage, then more eye movements could have been made as the time that elapsed between the targets increased. Finally, the participants' thoughts may have strayed from the task as time increased, making them forget where the previous saccade was initiated or making them less motivated to guess. As will soon be shown, this last possibility does not seem to be an important factor.

Experiment 2: alternation advantage unaffected when cognitive resources are divided

In Experiment 1, we demonstrated that the alternation advantage is a long-lasting effect. Our next goal was to establish whether or not guessing strategies are responsible. As mentioned in the Introduction, it is assumed that the alternation advantage originates from the guessing strategies of participants because they believe that consecutive trials demand opposite responses (see, for example, Kirby 1976; Soetens 1998; Soetens et al. 1985). This assumption has never been tested directly.

We assessed the veracity of this view with a dual task procedure. The logic of this procedure is simple. Performance on one task is compared when it is performed by itself and when it is performed alongside a second task.

If the second task interferes with the first (i.e., performance decreases when the two tasks are performed together compared to when the one task is performed alone), then these tasks are presumed to tap into the same (or interdependent) networks in the brain. In contrast, if the second task does not interfere with the first task (i.e., performance on the task remains the same across the two conditions), then it presumed that the two tasks depend on independent networks. In this experiment, the participants performed the basic saccade task by itself and alongside a mental rotation task. We chose a mental rotation task because identifying the location of a target interferes with performing mental rotation tasks (see, for example, Bruyer and Scailquin 1998). Thus, if the alternation advantage depends upon anticipating the upcoming location of the target, then the mental rotation should reduce or eliminate its magnitude. Alternatively, if it does not, then no interference should be observed.

Materials and methods

Participants

Twelve volunteers were recruited from the university community to participate in this study. All participants had normal or corrected-to-normal visual acuity. Before beginning the experiment, they provided informed consent. The experiment was conducted in two separate sessions tested across two different days.

Procedures

The participants were seated comfortably in a chair that faced a computer screen positioned 60 cm away. Head position was stabilized with an adjustable chinrest. Each trial began with the participants maintaining their gaze at a central fixation marker. After self-initiating the trial with a key press, the fixation marker was replaced with the letter R (subtending 2.8° in the vertical direction and 2.2° in the horizontal direction) that appeared for 200 ms in its normal orientation, R, or in its mirror orientation, Я, and was rotated 45°, 135°, 225°, or 315° from its upright position. After the letter was erased from the screen, the fixation marker appeared for 400 ms and was followed by a 200-ms gap before the first saccadic target (a green square, subtending 0.65° on each side) appeared 10° to the left or to the right of fixation. The participants were instructed to generate a saccade to the visual target. After completing the saccade, the participants were given 500 ms to return gaze to center. Then the second letter R appeared for 200 ms in its normal or its mirror orientation. The remaining events were the same as before, the second saccadic target appeared after a 200 ms gap period and the participants initiated a saccade to its position. When the participants returned their gaze to central fixation this time, however, they were required to indicate whether the two letters appeared in the same orientation (for example, normal, normal) or in different orientations (normal, mirror) by pressing the space bar when they were in the same orientation and to refrain from responding when they were in different orientations. Participants were given 700 ms to enter a response. All of the factors in this *dual task* version of this experiment, the orientation of the stimuli and the location of the saccadic targets, were equally probable and randomly selected.

In addition, the participants performed the *single task* version, in which all of the experimental parameters were the same, with two notable exceptions. Both letters appeared in the upright position and normal orientation (in order to reduce the possibility that participants may make spontaneous judgments about them) and the participants did not respond to the letters. These different versions were tested in separate sessions on different days. The order of participation was counterbalanced across participants.

The participants contributed 256 trials to both versions of the task, which were tested on different days. All of the trials were presented in one large block. The participants self-initiated each trial with a key press and they were encouraged to take a break whenever they wished.

Eye position was monitored with a video-based eyetracking system (Eyelink; SR Research, Toronto, Canada). This system monitors the horizontal and vertical position of the pupils with two infrared cameras that are mounted on the participant's head with an adjustable headband. Only the position of the left eye was monitored in this study. In addition, head position was monitored with a camera positioned at the center of the forehead that registered four beacons that were positioned in the four corners of the computer monitor.

The visual stimuli were presented on a 17-inch computer monitor with a 60-Hz refresh rate. Eye position was sampled at a rate of 250 Hz. The experimental paradigm and the presentation of the visual targets were controlled, and the storage of eye movements was collected with Eyelink's custom software (SR Research) running on a PC.

Data handling

Saccadic reaction times and direction errors were calculated in the same way and they were separated into the same two categories as in Experiment 1.

In this experiment, 22% of all trials were rejected from the reaction time analysis because a saccade was generated at an inappropriate time during the trial, because the eye did not fall within 4° of the target, or because the participant blinked near the time that a saccade was to be generated. More trials were eliminated from the cognitive load version (28%) than from the no load version (16%) ($F_{(1,11)}=7.971$, $P<0.05$). However, no differences were obtained for the *relationship of consecutive response* variable, indicating that a similar number of repetition and alternation trials were eliminated from the analysis ($Fs<1.6$, $Ps>0.1$).

Saccadic reaction times and direction errors were analyzed with mixed-design ANOVA that included the between-subject variable *order* (single task first versus dual task first) and the within-subject variables *relationship of consecutive responses* (repetition versus alternation) and *version of task* (no cognitive load versus cognitive load). *Order* was dropped from the analysis because it resulted in no main effects or interactions ($Fs<2.4$, $Ps>0.1$).

Results and discussion

Figure 2 illustrates the mean correct saccadic reaction times for repeating and alternating responses in both versions of the task. This figure shows that performing the mental rotation task alongside the saccade task did not eliminate the alternation advantage. Consistent with these observations, the main effect of *relationship of consecutive saccades* was significant ($F_{(1,11)}=29.917$, $P<0.05$), indicating that an alternation advantage was obtained overall. Neither the main effect of *version* ($F_{(1,11)}<1$) nor the interaction between these variables ($F_{(1,11)}<2.7$, $P>0.1$) achieved significance. Note that the mental rotation task was challenging to the participants, as the average performance was quite low (about 37% of the responses were in error).

The analysis of direction errors revealed that very few direction errors (<1%) were made in this experiment overall, with more errors made in the no load (1.6% of
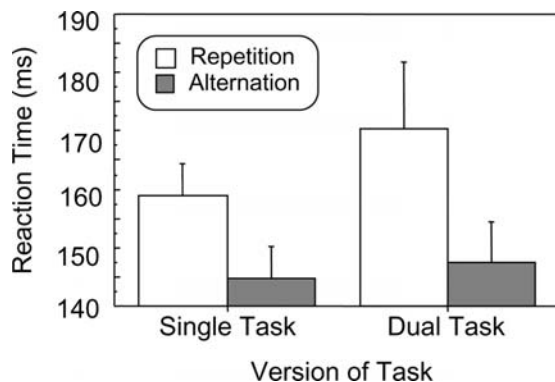
Fig. 2 Mean correct saccadic reaction time for no load and load conditions in experiment 2. *Error bars* are 1 SE

trials) than in the load (0.6%) version of this task ($F_{(1,11)}$=6.2, P<0.05). Nothing else was significant in this analysis (Fs<1, P>0.1).

The results from this experiment do not support the view that the alternation advantage originates from participants anticipating the upcoming location of the target. Had guessing the target's location been responsible, the magnitude of the alternation advantage should have been reduced in size when the mental rotation task was performed simultaneously. This was not the case.

However, this explanation assumes that the mental rotation task interfered with the participants' strategy to guess the upcoming location of the target. This may not have been true, even though interference would be expected on the basis of the previous literature (Bruyer and Scailquin 1998).

Experiment 3: alternation advantage arises from sensory processing

The results from Experiment 2 suggest that the alternation advantage may not originate from participants anticipating the upcoming location of the target. This leaves us without an explanation of the alternation advantage in saccadic reaction times. In this experiment, we used a powerful technique to determine whether a sensory or a motor bias drives this effect. In most eye movement studies, including the experiments that have been described here, the participants' task is to generate a saccade to a visual target. In this case, the sensory stimulus is presented in and the motor response is initiated to the same location, making it difficult to dissociate between the sensory and motor components of the response. In contrast, the sensory stimulus and the motor response can be dissociated by requesting the participants to initiate the saccade in the direction opposite the sensory stimulus (Hallett 1978). These different response demands have been called prosaccade and antisaccade, respectively.

In this experiment, we assessed whether the alternation advantage originates from sensory or motor processes by having participants initiate prosaccades or antisaccades in response to visual targets. Both responses were interleaved randomly in the same block of trials, with the color of the fixation marker indicating the response that was required on each trial. If the alternation advantage arises from motor processing, then it should follow the direction of the previous saccade and not the location of the previous target. In contrast, if the alternation advantage arises from sensory processing, then it should follow the location of the previous target and not the direction of the previous saccade.

Materials and methods

Participants

Twelve volunteers were recruited from the university community to participate in this experiment. All participants had normal or corrected-to-normal visual acuity. Before beginning the experiment, they provided informed consent. The experiment was conducted in one session.

Procedure

The procedural details of this experiment were similar to those described in Experiment 1, so we will mention only the differences between the two. In this experiment, the participants were instructed to initiate a saccade to the target (prosaccade) when the central fixation light was red and to initiate a saccade to the position directly opposite the target (antisaccade) when the central fixation light was green. Red and green LEDs that were back-projected onto the screen were used as the central fixation markers. Only the 3.7-s intertarget interval was given. Prosaccade and antisaccade trials were equally probable and randomly selected. All participants performed 600 trials that were divided into three blocks of 200 trials.

Data handling

In this experiment, 9.9% of all trials were rejected from the reaction time analysis because a saccade was generated at an inappropriate time during the trial, because the eye did not fall within 4° of the target, or because the participant blinked near the time that a saccade was to be generated. More trials were eliminated from the antisaccade condition (15%) than from the prosaccade version (4.7%) ($F_{(1,11)}$=23.9, P<0.05). Nothing else was significant in this analysis (all Ps>0.1).

Mean correct saccadic reaction times and direction errors were analyzed with repeated measures analysis of variance that included the variables *current response* (prosaccade versus antisaccade), *previous response* (prosaccade versus antisaccade), and *target position* across consecutive trials (same versus different).

Results and discussion

Figure 3 illustrates the relationship between consecutive target positions and previous responses in mean correct saccadic reaction times for prosaccades (*upper panel*) and antisaccades (*lower panel*). This figure shows that the alternation advantage followed the position of the previous target and not the direction of the previous saccade. Consider first the prosaccade response shown in the upper panel of Fig. 3. In this case, the participants were faster to respond when the target appeared in different positions
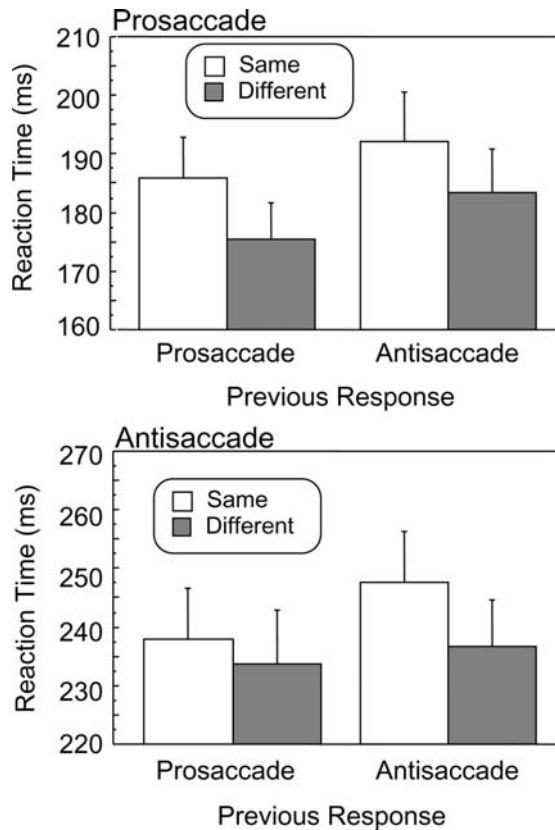
Fig. 3 Mean correct saccadic reaction time for prosaccade responses (*upper panel*) and antisaccade responses (*lower panel*) in experiment 3. *Error bars* are 1 SE

across consecutive trials than when it appeared in the same position. This effect was not modulated by the previous motor response because, if it were, then the opposite pattern would have been obtained (i.e., a same side advantage) when the previous trial required an antisaccade. Now consider the antisaccade response shown in the lower panel of Fig. 3. Similar to the prosaccade response, faster saccadic reaction times were obtained when the target appeared in different positions (alternation) than when they appeared in the same position (repetition).

Consistent with these observations, the main effects of *current response* ($F_{(1,11)}=129.806$, $P<0.05$), indicating that prosaccades were generated faster than antisaccades, the main effect of *previous response* ($F_{(1,11)}=13.431$, $P<0.05$), indicating that responding was faster when the previous response was a prosaccade, and the main effect of *target position* ($F_{(1,11)}=12.780$, $P<0.05$), indicating that responding was faster when the previous target appeared in the opposite position, did not interact with any other variable (all Fs<1).

The analysis of direction errors revealed that fewer errors were produced on prosaccade (1.1%) than on antisaccade trials (3.4%), resulting in a main effect of *current trial* ($F_{(1,11)}=24.7$, $P<0.05$), and fewer errors were made when the target appeared at the same location (2%) than at the opposite location (2.6%) across consecutive trials, resulting in a main effect of *target position*

($F_{(1,11)}=6.8$, $P<0.05$). Finally, the interaction between *current trial* and *previous trial* approached significance ($F_{(1,11)}=3.9$, $P<0.1$), indicating that prosaccade trials were more greatly affected by task switching (previous trial prosaccade 0.7% errors versus antisaccade 1.5% errors) than were antisaccade trials (previous trial antisaccade 3.3%, previous trial prosaccade 3.5%). Nothing else in this analysis was significant: all Fs<2.8, all Ps>0.1.

Because the direction error analysis revealed that fewer errors were made when the previous target appeared at the same location (a <1% difference between conditions), which suggests that a speed-accuracy trade-off may be occurring, we computed inefficiency scores (reaction time/ proportion of accurate responses that correct for speed-accuracy tradeoffs; Townsend and Ashby 1983), and conducted the same analyses as before. This analysis produced the same pattern of significant outcomes as the reaction time analysis.

The results from this experiment are straightforward. Using prosaccade and antisaccade responses to delineate between the sensory and motor contributions to the alternation advantage reveals that the alternation advantage originates from sensory processing.

General discussion

When performing a two-choice reaction time task, participants respond faster when the previous trial required a different response than when it required the same response. This alternation advantage is thought to signify the guessing strategies of participants. That is, because the participants believe that the correct response will alternate across trials, they respond faster when their expectations are confirmed (alternation) and more slowly when their expectations are disconfirmed (repetition). Yet, despite the widespread acceptance of this proposal (Kirby 1976; Soetens 1998; Soetens et al. 1985), no study had assessed its veracity until now.

After verifying the presence of a long-lasting alternation advantage in saccadic reaction times in Experiment 1, we explored whether the alternation advantage arose from the guessing strategies of participants in Experiment 2 by implementing a dual-task procedure. In this task, the participants performed a difficult mental rotation task alongside the two-choice saccade task that elicits the alternation advantage. Had the alternation advantage arisen from participants guessing the upcoming location of the target, it should have been eliminated with this manipulation because the mental rotation task would interfere with the participants' ability to guess the location of the upcoming saccadic target. Instead, an alteration advantage of similar size was obtained, indicating that guessing is not responsible.

Providing evidence against the expectancy view led us to our next question: if not guessing strategies, then what? In Experiment 3, we assessed whether sensory or motor processes contributed to the alternation advantage with prosaccade and antisaccade responses. We found the

alternation advantage followed the target's location, indicating that the alternation advantage arises from sensory processing, a finding that cannot be explained with the expectancy view.

How then should the alternation advantage be interpreted? In our view, the alternation advantage may be linked to inhibition of return (the tendency of participants to be slower to reorient to a previously attended location; Posner and Cohen 1984; Posner et al. 1985). Consider the similarities between these phenomena. First, the tasks used to study the alternation advantage and inhibition of return are very similar (and in some instances, the same). Both tasks measure the influence of a previous stimulus (the preceding peripheral target or the cue) on responding to the next stimulus. The difference between these tasks is that the participants respond to both stimuli in the serial reaction time task and to the second stimulus in the cue-target paradigm. It is important to mention that this distinction is true only in some circumstances, as inhibition of return has also been studied using target-target paradigms, in which the participants respond to the cue and to the target. Target-target paradigms produce similar patterns of data as do cue-target paradigms (Maylor and Hockey 1985; Rafal et al. 1989, 1994; Taylor and Klein 2000; also see Taylor and Donnelly 2000 for noteworthy differences). Second, the data produced by these tasks are qualitatively similar. Both the alternation advantage and inhibition of return have measurable influences lasting for more than 2 s (see, for example, Danziger et al. 1998; Kirby 1976). Both effects are obtained only when the time that elapses between consecutive stimuli is longer. When this time is shorter, both tasks produce a same side advantage instead (see, for example, Kirby 1976; Maylor 1985; Posner and Cohen 1984; Soetens 1998). In both instances, the timing of this crossover can be shifted forward or backward depending on the complexity of the response (see, for example, Lupianez et al. 1997; Soetens 1998). Finally, both effects are eliminated, or even reversed, when a probability manipulation favors a repetition (see, for example, Soetens et al. 1985; Wright and Richard 2000).

One problem with linking the alternation advantage to inhibition of return is that our findings indicate that the alternation advantage originates from sensory processing, whereas inhibition of return is believed to originate from the oculomotor system (i.e., the reflexive planning of a saccade in response to the abrupt appearance of a visual object; see, for example, Klein 2000; Posner et al. 1985; Rafal et al. 1989; Taylor and Klein 1998, 2000; Wright and Ward 1998). Compelling evidence supports this view. Inhibition of return can be obtained when the participant plans, but does not execute, a saccade to a location when no peripheral cue appears (Rafal et al. 1989) and damage to the superior colliculus, a brain structure that is involved in the generation of saccadic eye movements, eliminates inhibition of return (Posner et al. 1985; Sapir et al. 1999). Therefore, if the alternation advantage is simply a manifestation of inhibition of return, then the alternation advantage should have followed the motor action in experiment 3.

Does this mean that the alternation advantage and inhibition of return are separate phenomena after all? Not necessarily. If anything, our results have replicated previously reported, and rarely cited, findings in the inhibition of return literature. Rafal et al. (1994), using prosaccade and antisaccade responses in a cue-target task, reported that inhibition of return followed the position of the target and not the motor response, findings entirely consistent with those obtained in experiment 3 (see also Fischer et al. 2003). Based on this evidence, the alternation advantage and inhibition of return operate in similar ways in similar circumstances: both follow the sensory stimulus when an antisaccade response is used.

Recent neurophysiological evidence has provided converging support that inhibition of return arises from sensory processing (see Bell et al. 2004; Dorris et al. 2002; Fecteau et al. 2004). When monkeys perform a cue-target task, they also are slower to respond to a target when a preceding cue appeared in the same location (Bell et al. 2004; Dorris et al. 1999; Fecteau et al. 2004). Simultaneous recordings of visual and visuomotor neurons in the superior colliculus reveal that the location of the cue changes the burst of activity in response to the target. When the cue appears in the opposite location to the target, the target elicits a strong burst of activity. When the cue appears in the same field as the target, the target-related response is attenuated (Bell et al. 2004; Dorris et al. 2002; Fecteau et al. 2004). In short, IOR in behavior correlates with attenuated sensory responses in the superior colliculus when the cue and target appear at the same location. We speculate that the alternation advantage may arise from a similar mechanism in human participants.

In summary, these results contradict the claim that the alternation advantage originates from the guessing strategies of participants (Kirby 1976; Soetens 1998; Soetens et al. 1985). Instead, we propose that a sensory-based mechanism is at work, causing the participant to be slower at processing information in a region of space that was recently stimulated. This effect may originate from attenuated responsiveness to the second stimulus. How these findings may or may not relate to all facets of inhibition of return remains to be seen (see, for example, Abrams and Dobkin 1994; Taylor and Klein 2000).

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