Exp Brain Res (2010) 201:65–73
DOI 10.1007/s00221-009-2008-x

RESEARCH ARTICLE

Why do humans make antisaccade errors?

Hyung Lee · Mathias Abegg · Amadeo Rodriguez · John Koehn · Jason J. S. Barton

Received: 20 August 2009 / Accepted: 4 September 2009 / Published online: 17 September 2009

Abstract Antisaccade errors are attributed to failure to inhibit the habitual prosaccade. We investigated whether the amount of information about the required response the patient has before the trial begins also contributes to error rate. Participants performed antisaccades in five conditions. The traditional design had two goals on the left and right horizontal meridians. In the second condition, stimulus-goal confusability between trials was eliminated by displacing one goal upward. In the third, hemifield uncertainty was eliminated by placing both goals in the same hemifield. In the fourth, goal uncertainty was eliminated by having only one goal, but interspersed with no-go trials. The fifth condition eliminated all uncertainty by having the same goal on every trial. Antisaccade error rate increased by 2% with each additional source of uncertainty, with the main effect being hemifield information, and a trend for stimulus-goal confusability. A control experiment for the effects of increasing angular separation between targets without changing these types of prior response information showed no effects on latency or error rate. We conclude that other factors besides prosaccade inhibition contribute to antisaccade error rates in traditional designs, possibly by modulating the strength of goal activation.

Keywords Antisaccade · Error · Probability · Decision

H. Lee
Department of Neurology, Keimyung University
School of Medicine, Taegu, South Korea

H. Lee · M. Abegg · A. Rodriguez · J. Koehn · J. J. S. Barton
Departments of Medicine (Neurology) and Ophthalmology and Visual Sciences, University of British Columbia, Vancouver, Canada

J. J. S. Barton (✉)
Neuro-Ophthalmology Section K, VGH Eye Care Center, 2550 Willow Street, Vancouver, BC V5Z 3N9, Canada
e-mail: jasonbarton@shaw.ca

Introduction

In the antisaccade task, participants are asked to make a saccade to a location equal in amplitude but opposite in direction to a stimulus that suddenly appeared in the peripheral field (Hallett 1978; Hallett and Adams 1980). This is a difficult task, unpractised in naïve participants, and is associated with an increase in directional errors and an increase in reaction time compared to prosaccades, the more habitual response of looking at the stimulus (Everling and Fischer 1998; Munoz and Everling 2004; Hutton and Ettinger 2006).

The generation of the antisaccade response is often conceptualized as involving at least two key processes, (1) the suppression of the more habitual prosaccade response and (2) the generation of the novel stimulus–response mapping that results in a gaze shift to the opposite location (Munoz and Everling 2004). Antisaccade errors, in which the subject looks at the stimulus instead of away from it, are often attributed to failure to suppress an unwanted prosaccade, and hence are commonly viewed as a problem of inhibition (Levy et al. 1998). Indeed, excessive antisaccade error rates have been interpreted as evidence of disrupted inhibitory mechanisms in conditions like schizophrenia and attention deficit disorder (Levy et al. 1998; Schulz et al. 2004)—but see (Roberts et al. 1994; Nieuwenhuis et al. 2004) for alternative interpretations involving concepts of goal activation and working memory.

The classic antisaccade experimental paradigm involves two target locations on the horizontal meridian, one right and one left, with a randomized order of appearance of these targets (Hallett 1978). In a recent study, however, we noted that with other target arrangements (e.g., two locations in the middle of the upper and lower quadrants of one hemifield), antisaccade error rates were much lower than those in the traditional paradigm (Gowani et al. 2007). Since these atypical target arrangements have the same requirement for inhibition of the habitual prosaccade toward the stimulus, this suggests that there are additional factors that modulate the antisaccade error rate in the classic paradigm.

We hypothesized that one of the factors affecting antisaccade error rate in that experiment is how much the subject knows about the antisaccade response that will be required before the trial even starts, which we call 'prior response information'. With a cognitively challenging task like an antisaccade, which makes demands on working memory (Roberts et al. 1994) and has weaker neural activation patterns than prosaccades (Everling et al. 1999), the ability to predict some aspects of the response that will be required may be useful for enhancing performance, as previous studies have shown (Barton et al. 2006). In our observation, knowing which hemifield to which to direct the antisaccade in all trials of a given block may offer a distinct advantage over the traditional paradigm, in which one does not know whether the eye movement will be directed to the left or the right. This represents a type of 'partial foreknowledge effect', in which the subject knows something but not everything about the upcoming trial (Barton et al. 2006), and may have similarities to prior probability effects, in which prior knowledge of the increased likelihood of a specific stimulus location enhances saccadic performance (Gold and Shadlen 2001; Trappenberg et al. 2001; Carpenter 2004; Krauzlis et al. 2004; Opris and Bruce 2005), particularly for antisaccades (Gowani et al. 2007).

Our plan was to systematically explore factors that might constitute important 'prior response information', using a design that in successive blocks introduced additional sources of information that we hypothesized might influence antisaccade error rate. One might be certainty about saccadic initiation: i.e., whether the trial will require an antisaccade or no response. Second, in the case where an antisaccade is always required, there may be completely reliable prior location information about where the saccade will be made, as when there is only one possible goal location, or there may be some uncertainty, as when there are two stimulus locations. In the case where there are two possible stimulus locations, one could also consider hemifield location as a special spatial factor, as suggested in our prior report (Gowani et al. 2007). In other words, if both goals are in the same hemifield, the right for example, this information may confer an advantage, in being able to know ahead of time that the required antisaccade will be a leftward one, compared to another situation where there are also two possible locations but one on the right and one on the left, as in the usual antisaccade task design. Last, we considered a factor that could also add to task difficulty in the traditional antisaccade design, the overlap between the stimulus on one trial and the goal on the other. This creates a situation of potential confusability between the stimulus and goal across the experimental block. Our hypothesis was that each decrement in prior response information and/or increment in confusability would increase antisaccade error rate and latency, due to a change in the amount of information available before the start of the trial that could be exploited to optimize behavior.

Experiment 1

Methods

Participants

Eighteen participants with a mean age of 29 years (range 18–43) participated, 8 of whom were men. All had normal or corrected-to-normal vision and viewed all the stimuli with both eyes. The protocol was approved by the institutional review boards of Vancouver General Hospital and the University of British Columbia, and all participants gave informed consent in accordance with the declaration of Helsinki.

Apparatus and protocol

Participant sat in standard dim illumination 57 cm away from the screen, with their head position maintained by a chin-rest. Eye movements were recorded by an Eyelink 1000 binocular system (SR Research Ltd, Mississauga, Canada). Stimuli, trials, and experiment blocks were created using SR Research Experiment Builder 1.1.2.

In the antisaccade task, participants were instructed to make a saccade of the same amplitude in the direction opposite to the stimulus as soon as the stimulus appeared. Stimuli were black squares of 0.5 × 0.5°, superimposed upon a white background. Each trial began with a fixation cross at screen center, which was replaced after 750 ms of fixation by the stimulus at an eccentricity of 250 pixels (9.5° of visual angle), which remained until the participant performed a saccade greater than 1.5° in amplitude. The stimulus then disappeared and after 850 ms the fixation spot returned at screen center for the start of the next trial.

There were five experimental conditions, with two blocks for each (so that both rightward and leftward blocks

were available for conditions with asymmetric designs). Each block contained 40 trials in randomized order, for a total of 400 trials in the entire experiment. The ten blocks were given in random order. The five conditions (Fig. 1) were:

1. the *single-target* condition. These blocks had only one type of trial, with only one stimulus location, which was always on the horizontal meridian. In one block this was in the right hemifield and in the second it was in the left hemifield.
2. the *single-target/no-go* condition. These blocks had two types of trials, one an antisaccade trial and one a no-go trial, in which the participant was not to make a saccade of any sort when the stimulus appeared. In both trials, the stimulus was always in the same location on the horizontal meridian (in the right hemifield in one block and in the left hemifield in the other block). No-go trials were cued by a red octagon at screen center appearing at the moment the fixation stimulus disappeared. There were equal numbers of antisaccade trials and no-go trials, in random order.
3. the *two-targets/same-hemifield* condition. These blocks had two types of antisaccade trials. In one trial type, the stimulus was located on the horizontal meridian, while in the other the stimulus was located at 45° above the horizontal meridian. (It should be stressed that only one stimulus appeared on each trial.) The targets for both trial types were located in the same hemifield, though, in the right hemifield in one block and in the left hemifield in the other block.
4. the *two-targets/different-hemifield* condition. This also had two types of antisaccade trials. As with the *two-targets/same-hemifield* condition, one stimulus was located at 45° above the horizontal meridian and the other on the horizontal meridian. However, the difference now was that the stimulus on one trial type was in the hemifield opposite to the stimulus of the other trial type. Thus, in one block the stimulus 45° above the horizontal meridian was in the left hemifield and the stimulus on the horizontal meridian was in the right hemifield, and vice versa in the second block.
5. the *traditional-design* condition. This contained two antisaccade trial types, one with right and one with left targets, both located on the horizontal meridian. In this situation, there is an added factor of 'stimulus-goal confusability', in that the location of the stimulus in one trial is also the location of the goal on the other trial type. While this does not alter the probability of one trial type versus the other compared to the *two-targets/different-hemifield* condition, it is possible that a situation in which the stimuli and goals overlap in location may compound the uncertainty experienced by the observer, beyond that due to changes in probability alone.

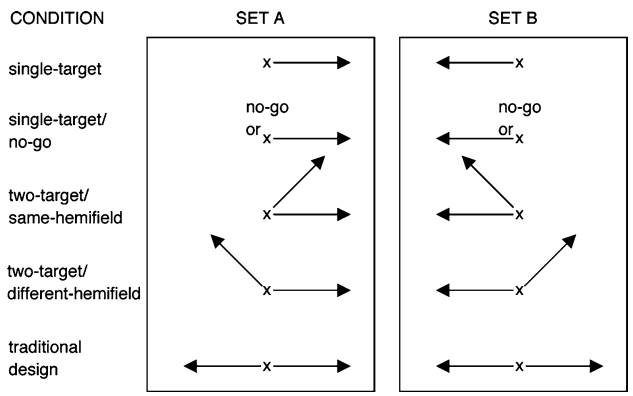

Fig. 1 Experimental blocks. There are ten blocks for five different conditions. '*X*' marks fixation, with *arrows* indicating the desired antisaccade(s) for that block. In the *single-target* condition, there is only one antisaccade goal on the horizontal meridian, to the *left* in one block, to the *right* in the other. In the *single-target/no-go* condition this is interspersed with no-go trials. In the *two-targets/same-hemifield* condition, there is a second antisaccade goal in the same hemifield, located at a similar eccentricity but along the 45° diagonal. In the *two-targets/different-hemifield* condition, the second antisaccade goal is also along the 45° diagonal, but now in the opposite hemifield. In the *traditional-design* condition, there are two targets on the horizontal meridian, one in the *right* and one in the *left* hemifield

Analysis

Eye movements were analyzed with SR Eyelink Data Viewer 1.7.5. Saccades were detected when eye velocity 31°/s, acceleration exceeded 9,100°/s^2, and position change by more than 0.15°. The first saccade of at least 1.5° after stimulus onset was considered the saccadic response. Reaction time was calculated as the time from stimulus onset to saccadic onset. Those saccades with reaction time less than 80 ms (considered as anticipatory eye movements or blink) and more than 800 ms (considered delayed movements) were excluded from further analysis. If the first saccade (>1.5°) in a given trial started from a point greater than 50 pixels from the fixation cross it was also discarded. Altogether, we excluded 9.8% (704/7,200) of the trials.

In the remaining 6,496 trials, an error was scored when an initial saccade toward the peripheral stimulus was executed. Saccades were classified as directionally correct if their vector was within 22.5° of the goal vector, and as a reflexive prosaccade-like error if directed toward the stimulus rather than the saccade goal, i.e., if the saccade vector was within ±22.5° of the stimulus vector. Antisaccade error rate was calculated for each participant as the number of reflexive (prosaccade-like) antisaccade errors

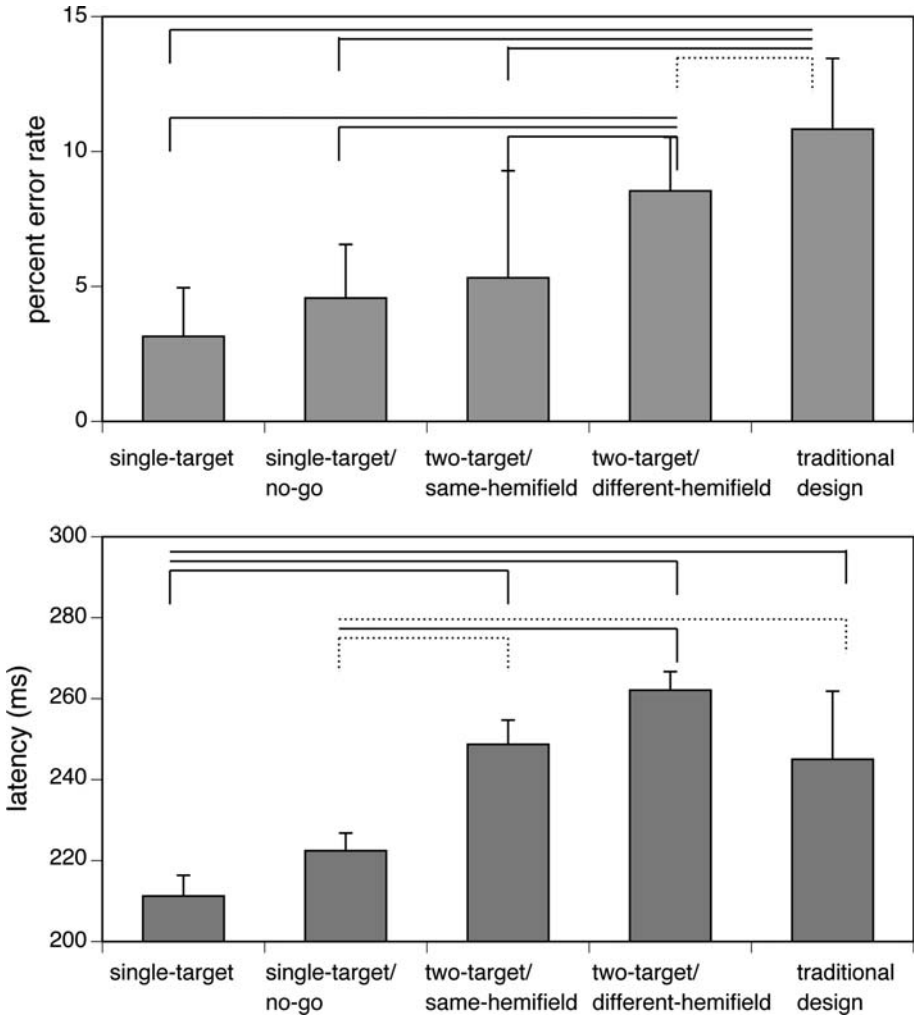

Fig. 2 Error rates and latency data, "Experiment 1". Top graph shows mean antisaccade percent error rate for the five different conditions. *Brackets* in the *top* of the graph show linear contrasts that were significant (*solid brackets*) or showed a trend to significance (*dotted brackets*). *Bottom graph* shows mean latency of correct antisaccades for the five different conditions, and similar brackets denoting significant linear contrasts. *Error bars* in both graphs show standard errors based on within-subject confidence interval methods (Masson and Loftus 2003; Cousineau 2005)

divided by the total number of valid trials. (Thus responses that were not within ±22.5° of either the goal or the stimulus were excluded from the analysis.) Mean antisaccade latency was calculated for directionally correct antisaccades as well. Antisaccade error rates and latency were analyzed in a general linear model using JMP IN 5.1 (http://www.jmp.com), with main factor of condition, and participants as a random factor.

Last, because the four conditions that presented a stimulus on every trial (i.e., excluding the *single-target/no-go* condition) were designed to add increments of uncertainty from one condition to the next in the series, we were interested in whether the error rates also showed a progressive increase across the series. In other words, would the *single-target condition* show the lowest error rate, the *two-targets/same-hemifield* the next lowest, the *two-targets/different-hemifield* the third lowest, and the *traditional-design* the highest? To do this, we determined the rank of error rate for the four conditions in each participant, and used the Friedman test (Friedman 1937) to determine if there was a consistent progression of error rate across the series.

Results

All participants had valid trials of at least 67% in each block: across the entire experiment valid trials ranged from 269 to 398 out of a possible total of 400 trials, with similar values for leftward and rightward trials. The mean antisaccade error rate across the entire experiment was 6.25% (SD 0.24), without a significant difference by direction (5.89 ± 0.24% for leftward antisaccades and 6.61 ± 0.25% for rightward antisaccades).

For antisaccade error rate, there was a highly significant effect of condition ($F(4,153) = 10.99$, $p < 0.0001$) (Fig. 2, top). Linear contrasts showed that the error rate in the *traditional-design* condition (two targets, right and left on the horizontal meridian) was significantly greater than that in the *single-target* condition ($t = 5.74$, $p < 0.0001$), the *single-target/no-go* condition ($t = 4.68$, $p < 0.0001$), and the *two-targets/same-hemifield* condition ($t = 4.12$, $p < 0.0001$), with a trend to significance from the *two-targets/different-hemifield* condition ($t = 1.71$, $p = 0.088$). Likewise, error rates in the *two-targets/different-hemifield*

condition were significantly greater than those in the *two-targets/same-hemifield* condition ($t = 2.41$, $p < 0.017$), the *single-target* condition ($t = 4.03$, $p < 0.0001$), and the *single-target/no-go* condition ($t = 2.97$, $p < 0.003$). In contrast, there was no significant difference between the *single-target* and the *single-target/no-go* conditions ($t = 1.06$, $p = 0.29$), the *single-target* and the *two-targets/same-hemifield* conditions ($t = 1.62$, $p = 0.11$), and the *single-target/no-go* and *two-targets/same-hemifield* conditions ($t = 0.55$, $p = 0.58$).

For the series of four conditions that presented a target on every trial, we used the Friedman test to determine if there was a progressive increase in error rate across the series, from a low rate in the *single-target* condition to a high rate in the *traditional-design* condition. For each participant the error rates across the four conditions were ranked, with 1 for the condition with the lowest error rate and 4 for that with the highest (Table 1). The Friedman test confirmed a significant difference in ratings across the four conditions ($Q = 15.8$, $p\,(X^2_{(3)} \geq Q) = 0.0012$).

A review of the frequency of excluded trials in each block showed that increases in error rate were not due to a reduction in the denominator (total valid trials) because of a greater number of excluded trials (Table 2). If that were the case, we would expect that the number of excluded trials would be least in the *single-target* and *single-target/no-go* conditions and greatest in the *traditional-design* and *two-target/different hemifield* conditions. In fact, the *single-target* condition had slightly more excluded trials than the other conditions, rather than the least. The *traditional-design* and *two-target/different hemifield* conditions had low exclusion rates, which were not significantly different from that of the *single-target/no-go* condition.

For latency, there was a significant effect of condition ($F(4,68) = 4.67$, $p < 0.003$) (Fig. 2, bottom). Linear contrasts showed that antisaccades in the *single-target* condition were significantly faster than those in all conditions with two possible targets (*two-targets/same-hemifield* $t = 2.77$, $p < 0.008$; *two-targets/different-hemifield*s $t = 3.77$, $p < 0.003$; *traditional-design* $t = 2.50$ $p < 0.015$). Similarly, antisaccades in the *single-target/no-go* condition were significantly faster than those in the *two-targets/different-hemifield* condition ($t = 2.93$, $p < 0.005$), with a trend to being faster than those in the *two-targets/same-hemifield* ($t = 1.94$, $p = 0.056$) and *traditional-design* ($t = 1.67$, $p = 0.099$) conditions. Latencies between the two conditions with single targets did not differ, nor was there any difference between any of the conditions with two targets. Thus the main variable affecting latency was whether there was one or two possible targets.

Table 1 Rank order effects

Condition	Mean rank	Standard error
Single-target	1.64	0.14
Two-target/same-hemifield	2.44	0.22
Two-target/different-hemifield	2.72	0.21
Traditional-design	3.19	0.26

Table 2 Excluded trials per block of 40

Condition	Mean	Standard deviation
Single-target	6.59	6.79
Single-target/no-go	1.71	2.84
Two-target/same-hemifield	4.71	8.27
Two-target/different-hemifield	3.03	4.60
Traditional-design	2.65	5.06

Comment

These results confirm a progressive pattern of increments of error frequency across the series of blocks we constructed, from a single goal, to two goals in a single hemifield, to goals in two hemifields, and finally to the traditional design of two goals mirror-symmetric across the meridian, in which there is not only uncertainty about goal and hemifield location, but also spatial overlap between the goals and stimuli of the different trials. Our guiding hypothesis was that these increments would reflect the degree of prior response information (or conversely, the degree of partial foreknowledge) at trial onset. However, it is also possible that the increment in error rate might originate from a different factor, the degree of angular separation between the targets. Thus, for example, the difference between the *two-targets/same-hemifield* and the *two-targets/different-hemifield* conditions by necessity also contained an increase of 90° in the angular separation between the two goals. To examine whether the degree of angular separation between the two goals influences antisaccade error rate independent of prior response information, we created a second experiment, in which all blocks contained two goals that were confined to a single hemifield, but varying in angular separation.

Experiment 2

Methods

Participants

Eleven participants with a mean age of 34 years (range 25–43) participated, 5 of whom were men. All of them had

normal or corrected-to-normal vision and viewed the stimuli with both eyes.

Apparatus and protocol

The apparatus was the same as in "Experiment 1". Target stimuli were filled white disks with a diameter of 25 pixels, superimposed upon a black background. Each trial began with a fixation cross at screen center, which was replaced after 750 ms of fixation by the target at 9.5° eccentricity, which remained until the participant performed a saccade greater than 3.0° in amplitude. The target then disappeared and after 850 ms the fixation spot returned at screen center for the start of the next trial.

There were ten experimental blocks, given in random order. Each block contained 40 trials in randomized order, for a total of 400 trials in the entire experiment. There were 8 blocks for antisaccades and two blocks for prosaccades. Each block of trials had only two target locations. One was always located on the horizontal meridian in the right hemifield, while the second was located either above or below the meridian in the same hemifield. In the eight antisaccade blocks, there were four conditions, with two blocks per condition. In the first condition, the angular separation between the targets was 20°, with one block having the second target in the inferior field and the other block having the target in the upper field. In the second condition the angular separation was 40°, in the third it was 60°, and in the fourth it was 80°.

Analysis

Our analysis focused on the antisaccade data. The same definitions of correct antisaccade and reflexive (prosaccade-like) antisaccade errors were used. Antisaccade error rate was again calculated for each participant as the number of reflexive (prosaccade-like) antisaccade errors divided by the total number of valid trials. Mean antisaccade latency was calculated for directionally correct antisaccades. Antisaccade error rates and latency were analyzed in a general linear model using JMP IN 5 1 (SAS Institute Inc), with main factor of condition (20,40, 60, 80 angular separations), and participants as a random factor.

Results

For the rate of reflexive (prosaccade-like) antisaccade errors, the GLM shows no significant effect of condition ($F(3,10) = 0.31$, n.s.). For the latency of correct antisaccades, the GLM likewise showed no main effect of condition ($F(3, 3357) = 0.98$, n.s.). Thus, increasing the angle of separation between two possible antisaccade targets from 20° to 80° did not show any effect on latency or error rate indices of performance (Fig. 3). Thus, both the data on error rate and that for latency show a lack of effect of angular separation when this does not affect the degree of prior response information regarding the hemifield location of the antisaccade goal.

General discussion

Our results show that the antisaccade error rate in the usual design of a block with two target locations 180° apart from each other reflects not just difficulty in inhibiting the habitual prosaccadic response, but also a number of other task factors related to prior response information and/or stimulus/goal confusability. Chief among these appears to be uncertainty about the hemifield in which the response is to be made. Error rates were significantly lower in all three of our conditions where the hemifield into which the

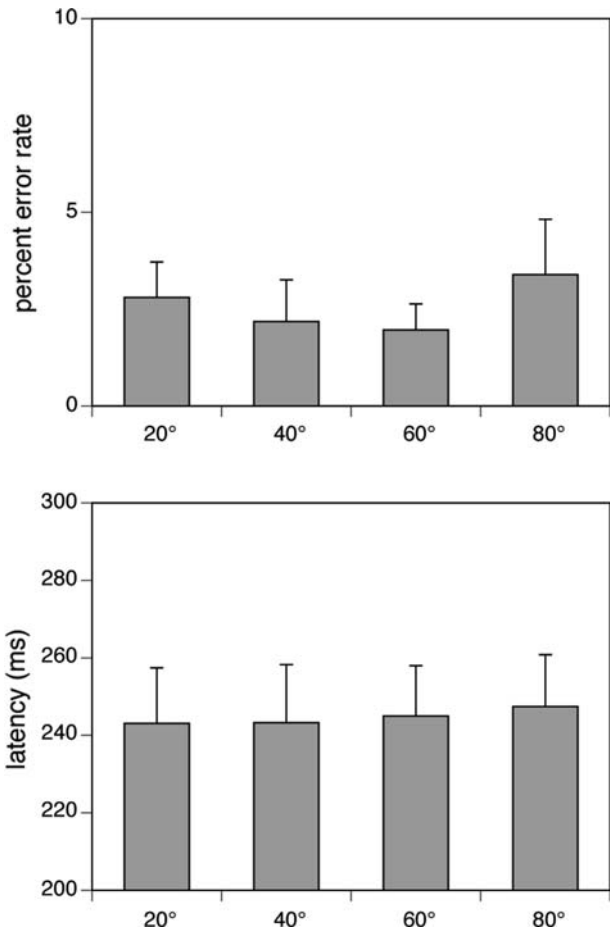

Fig. 3 Error rates and latency data, "Experiment 2". *Top graph* shows mean antisaccade percent error rate for the four different conditions, namely angular separations of targets of 20°, 40°, 60° or 80°. *Bottom graph* shows mean latency of correct antisaccades for the four different conditions. *Error bars* in both graphs showing one standard error

antisaccade response was to be made was the same in all trials, compared to the two conditions where the participant had to make responses into the right or left hemifield in random order in the same block.

We also considered whether 'stimulus-goal confusability' in the traditional design (i.e., the fact that the stimulus on one trial was the antisaccade goal on the other trial) could have contributed to antisaccade error rates. The *two-targets/different-hemifield* condition was designed to address this possibility. This condition used one target in each hemifield, as in the *traditional-design* condition, but one target was displaced away from the horizontal meridian so that the stimuli and goals of the two types of trial did not overlap in space. We found that there was a trend to reduced error rates in this condition, but the effect was not as great as that of eliminating hemifield uncertainty.

As expected, the lowest antisaccade error rate belonged to the *single-target* condition, where there is complete certainty about the need to make an antisaccade, the location of the goal, and the hemifield into which the saccade would be made. Adding saccade decision uncertainty by introducing no-go trials did not significantly increase error rate. Adding uncertainty about the goal location but not the hemifield also did not result in a statistically significant increase in error rate.

These results might suggest that prior information about the saccade-decision or goal-location do not modulate antisaccade error rate, while prior information about the hemifield and probably stimulus-goal confusability do. However, it may be premature to conclude that there is no effect of uncertainty regarding the saccade-decision and the goal-location: Fig. 2 suggests small effects that may prove significant in a larger sample. Also, our experiment was designed so that (apart from the *single-target/no-go* condition) each subsequent condition removed an additional piece of prior response information that had been present in the preceding condition. Thus, compared to the *single-target* condition, the *two-targets/same-hemifield* condition removed certainty about goal location. Next, the *two-targets/different-hemifield* condition added hemifield uncertainty to goal-location uncertainty, and finally the *traditional-design* added stimulus-goal confusability to both of these. The Friedman tests suggested that there was a significant step-wise increment in antisaccade error rate as participants progressed through these conditions, suggesting that all elements of prior response information may modulate antisaccade error rate, with each additional element of information generating approximately a beneficial 2% decrease in errors.

The latency effects were different from the effects on error rate. Hemifield uncertainty and stimulus-goal confusability, the most significant elements in modulating error rate, had no apparent influence on the latency of correct antisaccades. Rather, latency was modulated only by whether there were one or two target locations.

We also considered an alternative explanation of our results. Since prior response information about aspects of the antisaccade goal (location, hemifield) were generated by spatial manipulations that also increased the angular separation of our targets, it is possible that our findings reflected an influence upon error rate and latency of the proximity of the targets to each other. However, our second experiment showed that changes in angular separation ranging from 20° to 80° did not influence error rate or latency. While this result makes it less plausible that effects of angular separation are responsible for the results of "Experiment 1", it cannot entirely exclude this as an explanation, since the difference in angle of 90° between the *two-targets/same-hemifield* and *two-targets/different-hemifield* conditions is larger than the difference in angles that could be explored in "Experiment 2" without affecting hemifield certainty.

Regardless of explanation, though, our results underline the fact that antisaccade error rate reflects additional factors beyond the failure of inhibition of habitual prosaccades (Levy et al. 1998). Such inhibition was required in all our conditions, yet there was up to a three-fold variation in error rate. Clearly there are other important modulating factors in our experiment that contribute to antisaccade performance. We tentatively attribute these to prior response information factors, which can be framed in terms of the contribution to antisaccade execution of functions such as goal activation (Nieuwenhuis et al. 2004; Reuter et al. 2005; Reuter et al. 2006) or working memory (Roberts et al. 1994). Goal activation is likely simpler and demands on working memory less when there are no competing activations from a second goal location, and our data suggest that these processes may be more effective when activated goal representations are confined to a single hemifield, and more difficult when stimuli and goals overlap in space.

These effects can also be discussed in the context of current models of antisaccade generation. Antisaccades involve both a suppression of the reflexive prosaccade (Everling et al. 1998) and a vector inversion to generate the novel antisaccade response (Zhang and Barash 2004; Moon et al. 2007). The need to suppress the reflex prosaccade is predicated upon the assumption that the appearance of the stimulus leads to automatic programming of such a reflexive 'exogenous' response (Massen 2004), and indeed, neurophysiological studies have confirmed the existence during antisaccade trials of prosaccade-like activity in structures like the superior colliculus (Everling et al. 1998). Whether or not a subject executes a correct antisaccade or an erroneous reflexive prosaccade then depends upon the outcome of a competition between the parallel

programming of these two responses (Massen 2004). Accumulator models depict these as the build-up of pre-saccadic neural activity toward a threshold for triggering a saccade (Munoz and Everling 2004). If the neural activity for a reflexive prosaccade reaches threshold before that for the correct antisaccade, an error occurs.

Pre-target activity can significantly influence error rate in an accumulator model: a lower pre-target baseline of activity increases the time required and reduces the probability of a response reaching the triggering threshold. Studies confirm that compared to errors, correct antisaccade responses are associated with lower pre-target baseline activity in the direction of the reflexive prosaccade (Everling et al. 1998). Prior knowledge effects may modulate this pre-target baseline activity. Studies of the effects of prior probability on prosaccades show that an increased likelihood of a goal location is associated with an increase of baseline preparatory activity of buildup neurons, which in turn is correlated with reduced saccadic reaction times (Basso and Wurtz 1997; Basso and Wurtz 1998; Dorris and Munoz 1998). We hypothesize that decisional certainty and partial foreknowledge for antisaccades may have similar effects to prior probability for prosaccades, in that these enhance the pre-target baseline activity for the correct antisaccade, facilitating its competition against the reflexive prosaccade in an accumulator model (Munoz and Everling 2004).

Our data also have implications for the interpretation of elevated antisaccade error rates in patient populations (Hutton and Kennard 1998; Reuter and Kathmann 2004; Hutton and Ettinger 2006), a behavioral deficit which has sometimes been attributed simply to inhibitory failure (Levy et al. 1998). Given that most of these reports use the traditional design, however, elevated error rates could also have reflected difficulty with modulating factors such as stimulus-goal confusion, competing representations in different hemifields, and multiple target locations in the programming of highly volitional responses like antisaccades. Indeed, theories that place the origin of antisaccade errors in impaired goal activation (Nieuwenhuis et al. 2004) would predict that these participants would have incrementally greater difficulty in coping with the removal of more and more pieces of prior response information in an experimental paradigm. Currently a number of groups have been examining paradigms or correlations that may clarify whether deficits in inhibition or goal activation best characterize the antisaccade deficit in schizophrenia (Donohoe et al. 2006; Reuter et al. 2006; Barton et al. 2008). Further application in patient populations of experimental designs similar to our study would add interesting data to this debate.

Acknowledgments This work was supported by CIHR operating grant MOP-81270. JB was supported by a Canada Research Chair and a Senior Scholar Award from the Michael Smith Foundation for Health Research. MA was supported by a grant from the Swiss Foundation for Grants in Biology and Medicine and the Swiss National Science Foundation.

References

Barton J, Kuzin A, Polli F, Manoach D (2006) The use of working memory for task prediction: what benefits accrue from different types of foreknowledge? Neuroscience 139:385–392

Barton JJ, Pandita M, Thakkar K, Goff DC, Manoach DS (2008) The relation between antisaccade errors, fixation stability and prosaccade errors in schizophrenia. Exp Brain Res 186:273–282

Basso M, Wurtz R (1997) Modulation of neuronal activity by target uncertainty. Nature 389:66–69

Basso M, Wurtz R (1998) Modulation of neuronal activity in superior colliculus by changes in target probability. J Neurosci 18:7519–7534

Carpenter R (2004) Contrast, probability, and saccadic latency: evidence for independence of detection and decision. Curr Biol 14:1576–1580

Cousineau D (2005) Confidence intervals in within-subject designs: a simpler solution to Loftus and Masson's method. Tutor Quant Methods Psychol 1:42–45

Donohoe G, Reilly R, Clarke S, Meredith S, Green B, Morris D, Gill M, Corvin A, Garavan H, Robertson I (2006) Do antisaccade deficits in schizophrenia provide evidence of a specific inhibitory function? J Int Neuropsychol Soc 12:901–906

Dorris M, Munoz D (1998) Saccadic probability influences motor preparation signals and time to saccadic inhibition. J Neurosci 18:7015–7026

Everling S, Fischer B (1998) The antisaccade: a review of basic research and clinical studies. Neuropsychologia 36:885–899

Everling S, Dorris MC, Munoz DP (1998) Reflex suppression in the anti-saccade is dependent on prestimulus neural processes. J Neurophysiol 80:1584–1589

Everling S, Dorris MC, Klein RM, Munoz DP (1999) Role of primate superior colliculus in preparation and execution of anti-saccades and pro-saccades. J Neurosci 19:2740–2754

Friedman M (1937) The use of ranks to avoid the assumption of normality implicit in the analysis of variance. J Am Stat Assoc 32:675–701

Gold J, Shadlen M (2001) Neural computations that underlie decisions about sensory stimuli. Trends Cogn Sci 5:10–16

Gowani SA, Barton JJS, Levin M, Fox CJ (2007) Prior probability effects and their inter-hemispheric interactions in human prosaccades and antisaccades. Vision Sciences Society, Sarasota. J Vis 7(9):141

Hallett P (1978) Primary and secondary saccades to goals defined by instructions. Vis Res 18:1279–1296

Hallett P, Adams B (1980) The predictability of saccadic latency in a novel voluntary oculomotor task. Vis Res 20:329–339

Hutton S, Ettinger U (2006) The antisaccade task as a research tool in psychopathology: a critical review. Psychophysiology 43:302–313

Hutton S, Kennard C (1998) Oculomotor abnormalities in schizophrenia. A critical review. Neurology 50:604–609

Krauzlis R, Liston D, Carello C (2004) Target selection and the superior colliculus: goals, choices and hypotheses. Vis Res 44:1445–1451

Levy D, Mendell N, LaVancher C (1998) Disinhibition in antisaccade performance in schizophrenia. In: Lenzenweger M, Dworkin R

et al (eds) Origins and development of schizophrenia. American Psychological Association, Washington, DC, pp 185–210
Massen C (2004) Parallel programming of exogenous and endogenous components in the antisaccade task. Q J Exp Psychol A 57:475–498
Masson M, Loftus G (2003) Using confidence intervals for graphically based data interpretation. Can J Exp Psychol 57:203–220
Moon SY, Barton JJ, Mikulski S, Polli FE, Cain MS, Vangel M, Hamalainen MS, Manoach DS (2007) Where left becomes right: a magnetoencephalographic study of sensorimotor transformation for antisaccades. Neuroimage 36:1313–1323
Munoz D, Everling S (2004) Look away: the anti-saccade task and the voluntary control of eye movement. Nat Rev Neurosci 5:218–228
Nieuwenhuis S, Broerse A, Nielen M, de Jong R (2004) A goal activation approach to the study of executive function: an application to antisaccade tasks. Brain Cogn 56:198–214
Opris I, Bruce C (2005) Neural circuitry of judgment and decision mechanisms. Brain Res Rev 48:509–526
Reuter B, Kathmann N (2004) Using saccade tasks as a tool to analyze executive dysfunctions in schizophrenia. Acta Psychol (Amst) 115:255–269
Reuter B, Rakusan L, Kathmann N (2005) Poor antisaccade performance in schizophrenia: an inhibition deficit? Psychiatry Res 135:1–10
Reuter B, Herzog E, Kathmann N (2006) Antisaccade performance of schizophrenia patients: evidence of reduced task-set activation and impaired error detection. J Psychiatr Res 40:122–130
Roberts R, Hager L, Heron C (1994) Prefrontal cognitive processes: working memory and inhibition in the antisaccade task. J Exp Psychol Gen 123:374–393
Schulz K, Fan J, Tang C, Newcorn J, Buchsbaum M, Cheung A, Halperin J (2004) Response inhibition in adolescents diagnosed with attention deficit hyperactivity disorder during childhood: an event-related fMRI study. Am J Psychiatry 161:1650–1657
Trappenberg TP, Dorris MC, Munoz DP, Klein RM (2001) A model of saccade initiation based on the competitive integration of exogenous and endogenous signals in the superior colliculus. J Cogn Neurosci 13:256–271
Zhang M, Barash S (2004) Persistent LIP activity in memory antisaccades: working memory for a sensorimotor transformation. J Neurophysiol 91:1424–1441