



Modulation of antisaccade costs through manipulation of target-location probability: Only under decisional uncertainty



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ARTICLE INFO

Article history:

Received 20 March 2013

Received in revised form 4 September 2013

Available online 19 October 2013

Keywords:

Antisaccades

Saccade latency

Saccadometry

Probability

Decision making

ABSTRACT

Latencies of *antisaccades* made in the direction opposite to a peripheral target are typically slower longer than of *prosaccades* towards such a target by 50–100 ms. Antisaccades have proved to be an important tool for diagnostic purposes in neurology, psychology and psychiatry, providing invaluable insights into attentional function, decision making and the functionality of eye movement control. Recent findings have suggested, however, that latency differences between pro- and antisaccades can be eliminated by manipulating target-location probabilities. Pro- and antisaccades were equally fast to locations where a target rarely appeared, a finding that may be of promise for more elaborate diagnoses of neurological and psychiatric illness and further understanding of the eye movement system. Here, we tested probability manipulations for a number of different pro- and antisaccade tasks of varied difficulty. Probability only modulated antisaccade costs in a difficult antisaccade task involving decisional uncertainty with low target saliency. For other tasks including standard ones from the literature, target-location probability asymmetries had minimal effects. Probability modulation of antisaccade costs may therefore reflect effects upon decision making rather than saccade generation. This may limit the usefulness of probability manipulations of antisaccades for diagnostic purposes in neurology, psychology and related disciplines.

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1. Introduction

Visual acuity is by far the best at the fovea and declines quickly with increased retinal eccentricity. For high visual resolution stimuli of interest must be projected onto the fovea. Here the eye movement system plays a central role, generating saccades that shift the center of gaze to targets of interest. Two types of saccades are often compared. Prosaccades are made towards a target while antisaccades are made in the opposite direction (e.g. to the right if a stimulus is displayed on the left). Antisaccade latencies are typically considerably longer than prosaccade latencies (Everling & Fischer, 1998; Hallett, 1978; Kristjánsson, 2007), a difference called the antisaccade cost.

Antisaccades are an important diagnostic tool in neurology, psychiatry and psychology since they can be predictive of various neurological disorders and are easy to administer (Antoniades et al., 2013). While predictive of neurological dysfunction, they are, however, not always discriminative for different disorders. Findings where the antisaccade cost can be manipulated are therefore of great interest, since they open up the possibility that

differential effects might be seen for different disorders. Recent findings indicate that modulation of target-location probability¹ can eliminate antisaccade costs (Liu et al., 2010; see also Liu et al., 2011). Liu et al. found that for saccades made to low-probability locations, there was little or no difference in latency between pro- and antisaccades. However, their task was not a typical antisaccade task but involved target uncertainty where the correct location needed to be determined with odd-one-out visual search once the task to be performed had been determined from a central saccade-type indicator.

Probabilities of saccade target-locations have been manipulated before. Carpenter and Williams (1995) tested prosaccade performance with probability ratios ranging from .50/.50 to .95/.05 finding that saccades towards high-probability locations had shorter latencies than towards low-probability locations. Dorris and Munoz (1998) found that latencies of prosaccades performed by rhesus monkeys were shorter (by ≈ 19 ms) towards high- than

¹ Here we define probabilities by ratios. For example, .75/.25 means that the target appears on 75% of the trials to the left of central fixation, and consequently, the remaining 25% of the trials the target appears to the right of central fixation. Of the total prosaccades 75% are made to the left while 75% of the total antisaccades are made to the right. The opposite ratio is denoted in our terminology with .25/.75 and equal probabilities by .50/.50.

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low-probability locations. Koval, Ford, and Everling (2004) tested antisaccades using 3 different probability ratios (.80/.20, .50/.50, .20/.80). The antisaccade latencies were significantly shorter for high- than low-probability target-locations and the number of erroneous prosaccades (saccades towards rather than away from the target) increased. Further support for the effects of probability manipulations comes from Noorani and Carpenter (2012). In their experiment they used the same probabilities as Koval, Ford, and Everling (2004) and found that latency decreased and error rates increased in the high, compared to the low probability condition.

1.1. Current aims

In addition to providing information about brain mechanisms for saccade generation, saccadic probability effects are of interest for another reason. The antisaccade is an important part of the toolbox of neurologists, neuropsychologists, and psychiatrists to name a few (Antoniades et al., 2013; Hutton & Ettinger, 2006; Kristjánsson, 2007; Leigh & Kennard, 2004). New paradigms (e.g. Liu et al., 2010; ; Liu et al., 2011) where differences in latencies between antisaccades and prosaccades are modulated therefore rightly generate great interest. A drawback is that the task tested by Liu et al. may be very challenging for a number of patient groups. Their task differs from typical saccade tasks since when the task display appears, the odd-one-out target must be found, and an anti- or prosaccade (based on a central saccade-type indicator) made consequently. With this in mind we investigated under what conditions such probability effects occur. We conducted 5 experiments, increasing task complexity gradually experiment by experiment to find conditions where probability manipulations affect pro- and antisaccade latencies. Experiments (4A and B) were more or less exact replications of experiment 2 in Liu et al. (2010). Our aim was to test effects of target-location probability on pro- and antisaccades and whether such effects occur in simpler tasks that are easier to administer to patient groups in an effort to develop paradigms that may more accurately probe different disorders or distinguish between them.

2. General method

2.1. Equipment

A high-speed video eyetracker (250 Hz) from Cambridge Research Systems (2006) with a spatial accuracy of 0.125–0.25° and a horizontal range of $\pm 40^\circ$ and a vertical range of $\pm 20^\circ$ measured eye position. The eyetracker uses infrared technology and dual first Purkinje reflection to keep track of gaze. The observers' head was stabilized with a head and chin rest. Viewing distance was 53 cm. The stimuli appeared on a 100 Hz 19" Hansol CRT screen (model: 920D resolution: 1280 \times 1024) controlled by a 2.33 GHz PC. Experiments were run in a soundproof booth where the only illumination came from stimulus screen and the LCD screen used by the experimenter. Experimental programs were written in Matlab utilizing the Psychtoolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997). Extensions from the Video Eyetracker Toolbox (2008) controlled the eyetracker and recorded eye movements. The observers were not trained in the experimental tasks but the task was explained to them by running demos showing all the experimental conditions but, importantly, the observers were not informed of the probability manipulations beforehand.

2.2. Analyses

A saccade was considered to have started at time point $N - 1$ when eye velocity at time point N exceeded 30 deg/s (Leigh &

Zee, 2006) and the angular distance between N and $N - 1$ exceeded 1° (Rolfs, Knapen, & Cavanagh, 2010). If the initial amplitude of a saccade exceeded 1° in direction opposite to what it should be, the saccade was considered invalid. Saccades with landing-points within 4° around the intended target location were considered valid. The first point after the velocity of the saccade dropped below 30 deg/s defined the landing-point (Leigh & Zee, 2006; Walker et al., 1997). The dominant eye (determined by the pointing method; Greenberg, 1960) of each participant was tracked. Saccadic latency was defined as the time from stimulus onset until saccade onset. Saccades with latencies shorter than 80 ms (100 ms in experiments 4A and B) were excluded from statistical analyses (Becker, 1991; Edelman, Kristjánsson, & Nakayama, 2007; Rolfs & Vitu, 2007). In experiments 1 through 3, trials with latencies deviating more than 3 SD from each participants mean were excluded (see procedure and results of experiment 4A and 4B for their criteria). Besides using traditional repeated measures ANOVAs in our analyses we used a random effects model (Bates, 2010) which takes into account individual variability and has more power than ANOVA, especially when there is variability in latency distributions between observers (Bates, 2010). In the random effects model we used the .50 probability as baseline. Furthermore we fitted our data to ex-Gaussian distributions (Ratcliff, 1993) since response time distributions tend to be positively skewed. We used the egfit.m (Lacouture & Cousineau, 2008) function in Matlab to fit the data and to estimate the three parameters of the ex-Gaussian distribution. The μ -parameter is the mean, and σ the standard deviation, of the normal part. The τ -parameter is the mean of the exponential part of the distribution (Matzke & Wagenmakers, 2009; Ratcliff, 1993). All participants were volunteers from the University of Iceland, receiving course credit for participation, and gave written informed consent before participation. The research was approved by The Icelandic National Bioethics Committee (11-054).

3. Experiment 1 – testing probability effects upon pro- and antisaccades in a standard task

3.1. Method

3.1.1. Participants

Twenty naïve students (15 female, aged from 20 to 53 years, $M = 26.6$ years, $SD = 7.4$ years) participated.

3.1.2. Stimuli

The color and shape of the fixation point indicated whether observers were to make anti- or prosaccades. For half of the observers the fixation point (a red square; 0.7° , 8 cd/m^2 ; $\text{RGB} = [20222]$) indicated that a prosaccade should be made while a blue circle (0.7° ; 6 cd/m^2 ; $\text{RGB} = [00255]$) signaled an antisaccade.² This was reversed for the other observers. Both stimuli had a smaller dark-gray ($<1 \text{ cd/m}^2$; $\text{RGB} = [000]$) square in the middle. The target was a white square (0.7° ; 39 cd/m^2 ; $\text{RGB} = [255255255]$) with a smaller dark-gray ($<1 \text{ cd/m}^2$; $\text{RGB} = [000]$) square at center.

3.1.3. Procedure

The fixation point was visible for 600–1600 ms (randomly determined for each trial) after which the experimental program automatically checked if the observer was fixating the fixation point or not. When fixation on the fixation point was confirmed, the fixation point disappeared and the target stimulus appeared

² In the blocked task the color of the fixation point followed the same rule as in the interleaved task but the observers were told at the beginning of each block whether to make anti- or prosaccades.

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