

Brief Communication

Visual processing of targets can reduce saccadic latencies

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Received 30 August 2004; received in revised form 3 December 2004

Abstract

Normal human saccadic reaction times (SRTs) have been thought to be approximately 200 ms. The present study, using an experimental method that takes advantage of what the saccade system has evolved to do (by instructing subjects to rapidly acquire detailed visual information from the environment), shows that human SRTs are actually on the order of 150 ms. Moreover, when combined with the sensory-based “gap” effect (removal of gaze fixation object prior to target presentation), this method yielded extremely low SRTs. These findings imply that previous approximations of human SRTs may have been too conservative, and that the group of saccades often classified as “express” may instead represent the norm.

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Keywords: Saccades; Reaction time; Task instruction

1. Introduction

Saccades are rapid eye movements that are used to quickly bring the fovea, the portion of the retina that picks up the most detailed visual information, to bear on specific portions of the visual field. Because the ability to acquire high acuity visual information is critical to our successful interaction with the environment, and as the fovea only subtends about three degrees of the visual field (Findlay & Walker, 1999), saccades are produced frequently throughout each day (Bridgeman, Van der Heijden, & Velichkovsky, 1994). However, SRTs have traditionally been measured with tasks that merely require a shift of gaze but not necessarily the acquisition of specific visual information (Kveraga, Boucher, & Hughes, 2002; Niemeier, Crawford, & Tweed, 2003; Pratt & Trottier, 2005; Reulen, 1984). Here, two experiments that required subjects to obtain detailed information from peripheral targets produced dramatic reductions in SRTs. Moreover, this cortically-mediated

effect of task instruction was found to summate with a known sensory-based effect (removal of a fixated object prior to the appearance of a target) to produce extremely short SRTs in humans.

It has long been known that SRTs are sensitive to various “bottom-up” processes arising from changes in sensory information in the visual field—the most robust arising from removing the object of gaze fixation prior to the appearance of a peripheral target (Saslow, 1967). This “gap effect”, so named because of the temporal gap between the offset of the fixation object and the onset of the target, can reduce SRTs from the typical 200 ms down to 120–150 ms (Fischer & Ramsperger, 1984; Reuter-Lorenz, Hughes, & Fendrich, 1991). The effect has been attributed to disinhibition in the superior colliculus (SC); inhibitory activity that maintains gaze on an object is terminated upon its removal, lowering the threshold of SC activity needed for saccade initiation (Dorris & Munoz, 1995). Saccades so affected are at times called “express saccades” (Fischer & Ramsperger, 1984; Fischer & Weber, 1993), although the term specifically refers to a separate population of very short latency saccades in gap trials.

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The present study shows that a “top-down process”, arising from specific task instructions and thus cortically-based, can also dramatically reduce SRTs. Moreover, this top-down process combines with the gap effect to produce consistently shorter human SRTs than any previously found. Most saccade experiments request that subjects simply *look*, as fast as possible, to the appearance of a peripheral target—usually a light emitting diode (LED) or simple (and/or unchanging) geometric configuration of pixels on a computer monitor (e.g., a small dot or square (Fischer & Weber, 1993; Reuter-Lorenz et al., 1991)). Essentially, these tasks require subjects to glance at meaningless, relatively featureless objects as quickly as possible. However, the oculomotor system is specialized to *obtain* detailed information from the visual field to be employed in subsequent actions, the shifting of gaze (i.e., the fovea) being how this is accomplished. Consequently, tasks structured in these terms should be performed better, and in particular yield shorter SRTs. Examining such tasks is the focus of the present study.

2. Experiment 1

In the first experiment, subjects were given two different task instructions in separate blocks. In one condition, as typically done in saccade experiments, subjects were instructed to simply look, as fast as possible, to a peripheral target. In another, however, subjects were instructed to determine whether the central pixel of a peripheral target had been displaced to the left or right.

2.1. Subjects

Nine undergraduate students from the University of Toronto participated in the study in exchange for course credit. All were naïve to its purposes and had normal, or corrected to normal, vision.

2.2. Apparatus

A camera-based eye-tracker (SR Research Eyelink II) with 500 Hz of temporal resolution and accuracy better than 0.5° was used to establish when subjects started a saccade after target onset (SRT). Prior to the experiment, subjects' gaze location was established using nine point calibration in reference to an 80 Hz screen-refresh-synchronised 17" flat CRT set at a resolution of 1600×1200 pixels and located at a distance of 142.2 cm.

2.3. Procedure

Each subject completed two blocks of trials: one in which they were instructed to “look as quickly and precisely as possible at the centre of the object when it ap-

pears” (*look condition*) and the other to “indicate as quickly and as accurately as possible which object had appeared” (*look-obtain condition*) in separate blocks of trials. In both blocks, the trial started with the subject gazing at a central fixation cross (0.05° line thickness, 0.4° in diameter cross remained present throughout each trial). The experiment took place in a darkened room and stimuli registered 54.1 cd/m^2 . Targets were presented on a zero-luminance black screen, and were identical (see Fig. 1) save that the middle pixel on the decide targets was shifted either to the left (left-type target) or the right (right-type target) of the midline. Before every trial gaze-offset correction was performed until successful (usually on the first attempt), 600 ms after which a target (0.5° width) appeared 14° in the periphery (randomly either left, right, above, or below the fixation cross) trials in which a saccade was made and terminated further than 1° from the fixation point prior to the target's appearance were discarded. Due to the minute difference between targets in the look-obtain condition, in order to decide whether a left-type or right-type target had been presented, subjects needed to foveate it. Decisions were indicated via a keypress (left for left-type target, right for right-type). As a control, subjects also made a keypress response after each saccadic response in the look condition (terminating the trial), however, instructions were such that this press could be made at subjects' leisure. An error sound was played when subjects made an incorrect keypress, when they broke fixation prior to target onset, and, in the look condition block, when they missed the target (which happened rarely). Each condition consisted of 320 trials (80 in each of the four directions), and the conditions were counterbalanced between subjects.

2.4. Results and discussion

The data from two subjects were removed from analyses due to a high number of errors ($>40\%$ error trials). Of the data from the remaining seven subjects (all over 80% accuracy for target discrimination accuracy), trials analyzed were restricted to those with SRTs greater than 80 ms and lower than 500 ms and those which started within one half a degree of the fixation point (for a discussion of cut-off values, see (Weben-Smith & Findlay, 1991). In addition, trials in which eye movements failed

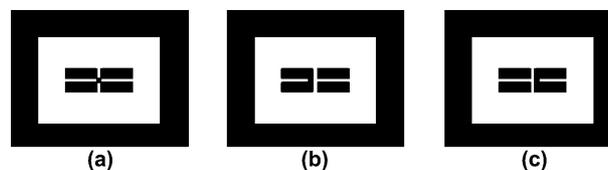


Fig. 1. Target (a) used for look trials, targets (b) and (c) used for look-obtain trials. The rectangular border was not presented, only the central “H” shape appeared on the monitor.

to land within 7° of the target were also removed. Consistent with previous findings (Goldring & Fischer, 1997), SRTs were shorter for horizontal than vertical saccades [$F(1, 5) = 78.280, p < 0.001$] (Fig. 2 shows pattern of mean latencies). Importantly, SRTs were also shorter in the look-obtain condition than the look condition [$F(1, 5) = 7.161, p < 0.05$]. In fact, the SRTs in the look-obtain condition (145 ms) were similar to those typically found with the gap effect despite the fact that the fixation point remained visible throughout each trial. Reduced saccade end-point accuracy could not account for these shorter SRTs ($F_s < 1$).

3. Experiment 2

A second experiment was conducted to determine if the reduction in SRTs found in the first experiment's "overlap" procedure (fixation point visible throughout trial) would also occur within the "gap" procedure (fixation point removed before target presentation). Given that gap trials often yield SRTs below 150 ms, the possibility exists that look-obtain instructions combined with the gap effect will produce shorter human SRTs than previously thought possible.

3.1. Subjects

Eight new undergraduate students from the University of Toronto participated in the study in exchange for course credit. All were naïve to the purposes of the study and had normal, or corrected to normal, vision.

3.2. Apparatus and procedure

The apparatus used was identical to that of the first experiment. The basic procedure was also the same (sep-

arate counterbalanced blocks of look and look-obtain conditions), but now within each block were an equal number of randomly distributed "overlap" (fixation cross remained present) and "gap" (cross removed 200 ms prior to appearance of peripheral target) trials. In this experiment targets appeared only left or right (14°) of the fixation cross across the 320 trials (160 in each condition).

3.3. Results and discussion

The same criteria for analysability as used in the previous experiment resulted in one subject's data being removed (for incorrect task execution). As the fixation point was to be removed in half the trials, the permissible range from which saccades could start was expanded to a full degree in radius. In addition, because gap and task effects might combine in an additive fashion, the SRT lower cut-off was reduced to 60 ms (the upper cut-off remained 500 ms). As can be seen in Fig. 2, a typical gap effect was found in the look condition with SRTs shorter in gap than in overlap trials [$F(1, 4) = 78.1, p < 0.002$]. Replicating the earlier experiment, SRTs were also shorter in the look-obtain condition than in the look condition [$F(1, 4) = 40.5, p < 0.005$]. In addition, the gap effect interacted with the task requirements [$F(1, 4) = 9.7, p < 0.05$] such that the reduction in SRT due to task instruction was greater for overlap trials than for gap trials. Importantly, gap trials in the look-obtain condition produced SRTs averaging 111 ms. Indeed, in this collection of trials, subjects made no anticipation errors as soon as SRTs passed 70 ms (see Fig. 3). These are extremely short latencies reported with "express saccade makers" (Cavegn & Biscaldi, 1996) or in experiments using informative precues (Fischer & Weber, 1998). Certainly, in terms of

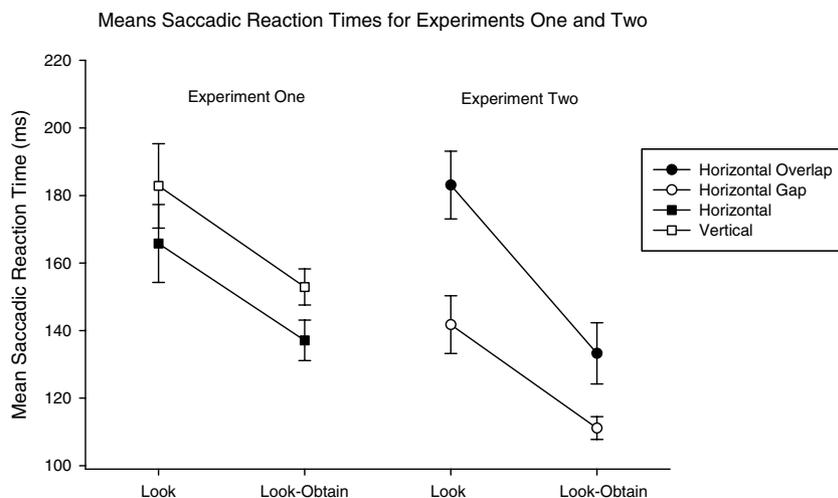


Fig. 2. Mean SRTs for horizontal and vertical saccades (Experiment 1) and gap and overlap saccades (Experiment 2), split by task instruction. Vertical bars indicate one standard error.

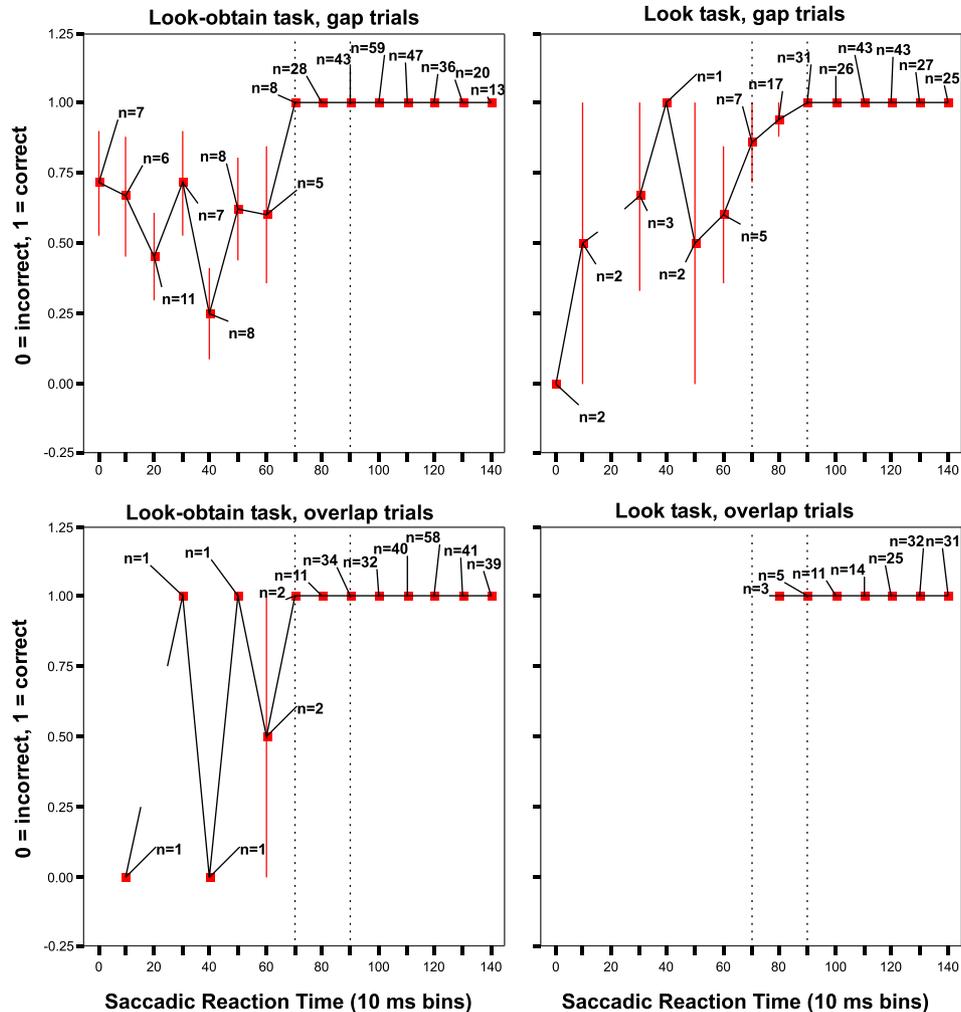


Fig. 3. Mean of correct (1) versus incorrect (0) saccades (these are saccades made in the wrong direction) across all subjects divided by block and gap/overlap condition (Experiment 2). Point labels represent number of trials in each bin. Error bars represent one standard error. Left vertical dotted lines indicate the earliest bin (in any condition) after which point no saccades were made in the wrong direction (i.e., anticipations). Right vertical dotted lines indicate the last bin in which no condition produced saccades made in the wrong direction. This is suggestive of anticipation rates across conditions.

experiments with unpracticed, naïve subjects and no advance information about target location, these are among the shortest SRTs for pro-saccades that have been reported in humans. As before, subjects correctly discriminated at better than 80% accuracy, and many (around half) better than 90%.

4. General discussion

The results from the present two experiments show that a top-down, cortically-mediated process (i.e., task instruction) can have a large facilitatory effect on SRT. The circuit for this effect may be the “direct pathway” connecting frontal cortex structures (such as the frontal and supplementary eye fields (FEF and SEF)) and dorsolateral prefrontal cortex (DLPFC) to the SC via the caudate nucleus (CN) and substantia nigra reticu-

lata (SNpr). This pathway is especially well-suited because (a) DLPFC is involved in executive functions (Guitton, Buchtel, & Douglas, 1985), a category of processes that would include the volitional instantiation of task instructions, (b) the FEF and SEF are involved in saccade selection and execution (Schall & Hanes, 1998), and (c) the pathway is disinhibitory such that more activation from frontal cortex to CN reduces SNpr activation, which in turn diminishes the inhibition going to SC (Munoz & Everling, 2004). In other words, the direct pathway provides a mechanism by which a change in activation in frontal cortex due to task instruction can lead to disinhibition in the SC. As the SC becomes more disinhibited, lower activation values are needed to trigger saccades, and SRTs are reduced. These findings imply that neither task instruction nor gap effect (i.e., removal of fixation object) alone maximally disinhibit the SC. Rather, a top-down task instruction and

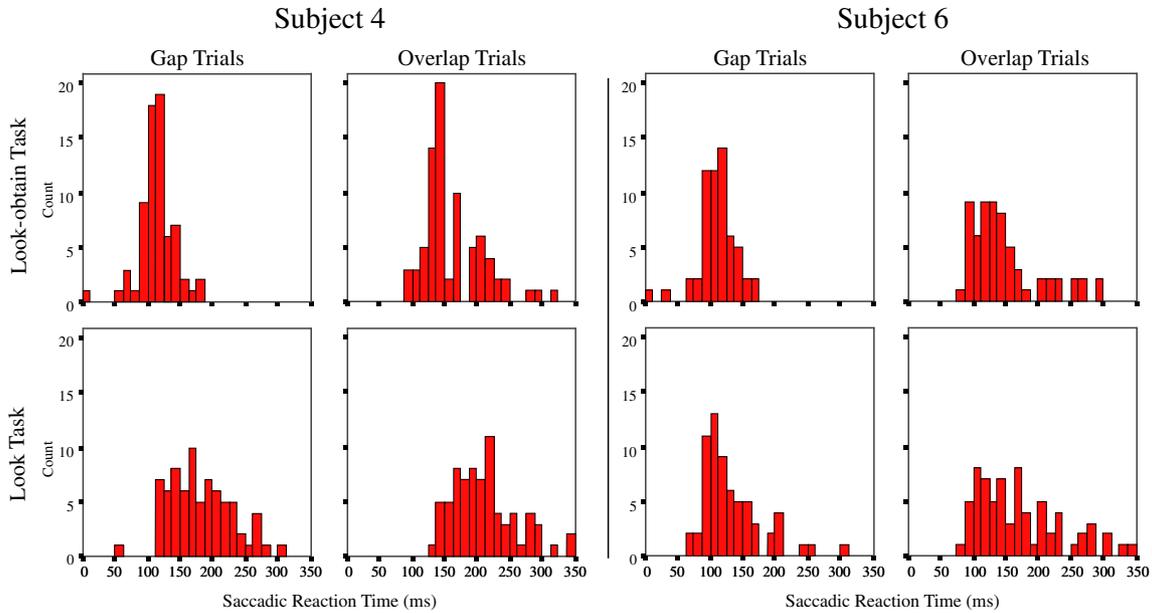


Fig. 4. SRT distributions, in bins of 8 ms, from subjects four and six (Experiment 2). Unimodality suggests a global shift toward shorter SRTs due to task instruction.

the sensory gap-effect are combined to inhibit SNpr activity, which in turn maximally disinhibits the SC. Given that lesions to the SC eliminate performance of “express” saccades (Schiller, Sandell, & Maunsell, 1987), how the “look-obtain” paradigm would interact with such lesions remains an open, and very interesting, question especially since the present paradigm has essentially abolished so-called “regular” saccades.

The proportion of correct to incorrect saccades for shorter reaction times is presented in Fig. 3, and suggests that while subjects are more likely to make anticipation errors when given “obtain” task instructions, these errors disappear early, with none occurring above the 70 ms mark. We can thus conclude that the reduction found in SRTs is not caused by a prevalence of anticipatory saccades, and further that the lower SRT threshold set for look-obtain gap trials was justified. Such short SRTs are comparable to dwell times found in free-scanning situations which often fall in the 50–100 ms range (Findlay, Brown, & Gilchrist, 2001). Since theories surrounding the speed of such eye movements currently account for short dwell times by postulating that the planning of multiple saccades takes place in parallel, the demonstration that saccade planning and execution can take place in as little as 75 ms may account somewhat for the extreme brevity of dwell times.

Finally, it is worth noting that a simple overrepresentation of “express” saccades (specifically, a separate and faster population of saccades (Fischer & Ramsperger, 1984)) is not responsible for the very short SRTs found here. As shown in Fig. 4, gap trials in the look-obtain task are unimodal and narrowly distributed (standard error was 3.4 ms for gap trials and 8.2 ms for overlap tri-

als in the look-obtain task, while in the look task standard error was 9.7 ms in both conditions). The set of slower “normal” saccades (150–250 ms) normally found in gap trials are simply not present. Since task instructions can affect the whole distribution of SRTs, perhaps “express saccades” may reflect more natural latencies while “normal” saccades are conversely those inadvertently slowed by experimental instructions. This notion is lent further support by a common finding in anti-saccade experiments (in which subjects are instructed to look away from a suddenly appearing target)—anti-saccade direction error SRTs (in which subjects inadvertently saccade *to*, instead of opposite, a presented target) are found to lie very close to the 100 ms mark (Munoz & Everling, 2004). The present findings thus highlight the importance of considering the typical use of processes under study in experiment design.

Acknowledgment

This work was supported by a grant from the Natural Sciences and Engineering Research Council of Canada (419206) to Jay Pratt.

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