

Ultra-rapid object detection with saccadic eye movements: Visual processing speed revisited [☆]

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Abstract

Previous ultra-rapid go/no-go categorization studies with manual responses have demonstrated the remarkable speed and efficiency with which humans process natural scenes. Using a forced-choice saccade task we show here that when two scenes are simultaneously flashed in the left and right hemifields, human participants can reliably make saccades to the side containing an animal in as little as 120 ms. Low level differences between target and distractor images were unable to account for these exceptionally fast responses. The results suggest a very fast and unexpected route linking visual processing in the ventral stream with the programming of saccadic eye movements. © 2005 Elsevier Ltd. All rights reserved.

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1. Introduction

The human visual system is very fast and efficient at extracting information about the objects present in complex natural scenes (Potter, 1976; Thorpe, Fize, & Marlot, 1996). The speed of this visual processing can be assessed both by behavioural and neuromagnetic measurements (Thorpe & Fabre-Thorpe, 2002; Thorpe et al., 1996). In go/no-go categorization tasks, human participants initiate manual responses with average and minimum reaction times of about 450 and 250 ms, respectively. However, these measures include both the time of visual processing and response execution (Fabre-Thorpe, Delorme, Marlot, & Thorpe, 2001; Thorpe et al., 1996). One approach to estimate the time for just the visual processing component alone involves analyzing simultaneously recorded

event-related potentials that show differential effects starting to diverge at around 150 ms, sometimes even substantially earlier (Liu, Harris, & Kanwisher, 2002; Mouchetant-Rostaing, Giard, Delpuech, Echallier, & Pernier, 2000). While the interpretation of these differential effects is controversial (Johnson & Olshausen, 2003; VanRullen & Thorpe, 2001b), behavioural measurements avoid this problem.

Eye movements seem particularly well suited for measuring processing speed because some of them can be initiated in only 80–100 ms (Busetini, Masson, & Miles, 1997; Fischer & Weber, 1993; Masson, Rybarczyk, Castet, & Mestre, 2000). However, the visual processing required for such rapid responses is generally relatively simple. To demonstrate more sophisticated visual processing we need a task that requires participants to make some form of decision about the stimulus. Yet, even when natural images are used, oculomotor behaviour still appears to be governed by relatively low level characteristics of the scene (Parkhurst & Niebur, 2003). As a result, remarkably few studies have used eye movements to determine visual processing speed in higher level tasks (Gilchrist, Heywood, & Findlay, 2003; Levy-Schoen, Coeffe, & Jacobs, 1989; Pelz & Canosa, 2001).

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Nevertheless, it has been reported that in a go/no-go animal categorization task, participants can process two images presented in the left and right hemifield as quickly as when only one is present indicating parallel extraction of semantic object descriptions (Rousselet, Fabre-Thorpe, & Thorpe, 2002). We therefore hypothesized that if the differential neuromagnetic signal starting at 150 ms is a neural correlate of visual categorization (Rousselet et al., 2002; Thorpe et al., 1996), participants might be able to saccade to the side with the animal at around 180 ms after stimulus onset, assuming a delay for saccade preparation of 20–25 ms (Schiller & Kendall, 2004). However, in the present study, the fastest reliable eye movements were initiated after only 120 ms, implying that the visual system only needs roughly 95–100 ms to provide an initial first pass analysis of the images based on which a reliable behavioural response can be initiated. Furthermore, our results indicate that the differential ERP effects starting at 150 ms occur once initial stimulus processing has already been achieved.

2. Methods

2.1. Participants

Fifteen volunteers (mean age = 25 ± 3.5 years, 7 women and 8 men) with normal or corrected-to-normal vision performed a 2AFC visual discrimination task. The experimental procedures were authorized by the local ethical committee (CCPPRB No. 9614003). Experiments were undertaken with the understanding and written consent of each participant.

2.2. Experimental set-up

Participants were seated in a dimly lit room with their heads stabilized by a forehead and chin rest. Monochromatic natural scenes were presented on a video monitor (640 × 480, 100 Hz) on a black background at a distance of 80 cm resulting in an image size of 10° H × 14.5° V. The mean grey-levels of the target vs. distractor images were comparable.

Eight hundred and forty commercially available photographs were used, of which half were targets including a wide range of animals in their natural environments (mammals, birds, insects, reptiles, and fish); the remainder were distractors that included pictures of forests, mountains, flowers, and seascapes as well as man-made environments such as buildings and statues. Similar to a former study employing a go/no-go categorization task (Fabre-Thorpe et al., 2001), half of the images were seen only once, whereas the remainder were presented repeatedly. This manipulation allowed us to look for stimulus-specific learning effects.

2.3. Protocol

Two natural scenes were flashed for 20 ms centred at 6° in the left and right hemifield (see Fig. 1). The task was to make a saccade as fast as possible to the side where an

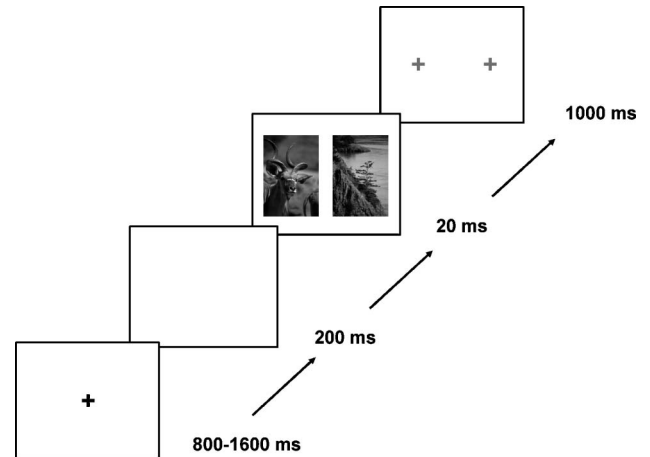


Fig. 1. Choice saccade task. After a pseudo-random fixation period, a blank screen (gap period) for 200 ms preceded the simultaneous presentation of two natural scenes in the left and right hemifields (20 ms). The images were followed by two grey fixation crosses indicating the saccade landing positions.

animal had appeared. Targets were equiprobable in both hemifields. The fixation point disappeared after a pseudo-random time interval (800–1600 ms) leaving a 200 ms-time gap before the presentation of the images. This gap period generally serves to accelerate saccade initiation (Fischer & Weber, 1993; Saslow, 1967). After presentation of the images, two fixation crosses were presented for 1 s at $\pm 6^\circ$ to indicate the two possible saccade landing positions. The participants performed 10 blocks of 80 trials resulting in 200 trials per condition and participant (200×2 hemifields × new vs. repeated images = 800 trials).

2.4. Response recording and detection

Eye position was recorded by horizontal EOG electrodes (1 kHz, lowpass at 90 Hz, notch at 50 Hz, baseline correction [−400:0] ms; NuAmps, Neuroscan) and stored on a PC. Saccadic reaction time (SRT) was determined off-line as the time difference between the onset of the images (time = 0) and the start of the saccade (see Fig. 2). As a first criterion, the difference signal between the left and right EOG electrodes had to exceed an amplitude threshold of $\pm 30 \mu\text{V}$ (Fig. 2, black circle). Then, the saccade onset time was automatically determined as the nearest signal inflection preceding this point (Fig. 2, green circle). Each trial was verified by the experimenter to make sure that only the largest inflection (if any) was taken as a real saccade. Of the original 800 trials per participant, certain trials had to be rejected because of poor signal quality, with a mean rejection of 17% trials ($n = 137$) ranging from a minimum of 3% ($n = 26$) to a maximum of 34% ($n = 271$) (see Table 1).

To determine a value for the minimum SRT we divided the saccade latency distribution of each participant into 10 ms time bins (e.g., the 120 ms bin contains latencies from 115 to 124 ms) and searched for the first bin to contain significantly more correct than erroneous responses. This

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