Vision Research 100 (2014) 29–37

Contents lists available at ScienceDirect

Vision Research

journal homepage: www.elsevier.com/locate/visres

The time course of top-down control on saccade averaging

J. Heeman[a,*], J. Theeuwes[b], S. Van der Stigchel[a]

[a] Experimental Psychology, Helmholtz Institute, Utrecht University, Utrecht, The Netherlands
[b] Department of Cognitive Psychology, Vrije Universiteit, Amsterdam, The Netherlands

ARTICLE INFO

Article history:
Received 8 November 2013
Received in revised form 20 February 2014
Available online 13 April 2014

Keywords:
Global effect
Saccade averaging
Top-down control
Time course
Task demand
Inter-trial priming

ABSTRACT

When objects in a visual scene are positioned in close proximity, eye movements to these objects tend to land at an intermediate location between the objects (i.e. the global effect). This effect is most pronounced for short latency saccades and is therefore believed to be reflexive and dominantly controlled by bottom-up information. At longer latencies this effect can be modulated by top-down factors. The current study established the time course at which top-down information starts to have an influence on bottom-up averaging. In a standard global effect task two peripheral stimuli (a red and a green abrupt onset) were positioned within an angular distance of 20°. In the condition in which observers received no specific target instruction, the eyes landed in between the red and green element establishing the classic global effect. However, when observers were instructed to make a saccade to the red element during a whole block or when the target color varied from trial-to-trial (red or green), a clear effect of the target instruction on the accuracy of the landing position of the primary saccade was found. With increasing saccade latencies, the eyes landed closer to the instructed target. Crucially, however, this effect was even seen for the shortest saccade latencies (as early as *200 ms*), suggesting that saccade averaging is affected early on by top-down processes.

1. Introduction

When two adjoining stimuli in the same hemifield evoke a short-latency saccade, the saccade tends to land on an intermediate location between these stimuli (Coren & Hoenig, 1972). This effect is known as the *global effect* or *saccade averaging* and occurs when stimuli are presented relatively close to each other (less than 35° angular distance) (Findlay, 1982; Van der Stigchel, Heeman, & Nijboer, 2012; Van der Stigchel & Nijboer, 2011, 2013; Walker et al., 1997). The global effect has originally been explained by a weighted average account. According to this view, all elements in a visual scene evoke a peak of activity in a common saccade map. When the elements are positioned close together these peaks of activity overlap and merge resulting in one vector determining the direction and the landing position of the saccade (Tipper, Howard, & Jackson, 1997). This model assumes that target selection is the result of competitive interaction between groups of neurons that code for the possible targets locations in a common saccade map. In recent years the weighted average account has been extended from a mechanism driven by bottom-up processes only to models that also integrates higher-order information (Fecteau & Munoz, 2006; Findlay & Walker, 1999; Godijn & Theeuwes, 2002; McSorley, Haggard, & Walker, 2006; Meeter, Van der Stigchel, & Theeuwes, 2010; Trappenberg et al., 2001). In these models the activity of each subset of neurons is the result of the integration of low-level visual information and higher-order information. When, based on higher-order information, one of the elements is designated as the target the activity associated with the target location will be enhanced relative to the activity associated with the distractor. If the peaks of activity of target and distractor overlap, the enhancement of activity of the target will result in a saccade endpoint which is shifted towards the target.

Latency has a strong influence on the size of the global effect. In general, saccade averaging is more pronounced for short latency saccades (Edelman & Keller, 1998; Findlay, 1982). Ottes, Van Gisbergen, and Eggermont (1985) showed in experiments in which participants were instructed to make a saccade to a target in the presence of non-targets that saccades landed more accurately on the target when saccade latencies were longer. The global effect completely disappeared when the time between target onset and saccade initiation was longer than 300 ms. In studies with monkeys it has been shown that the likelihood of saccades being averaged was larger for express saccades (with a latency of less than 100 ms) than for slower saccades (Chou, 1999). The early

* Corresponding author. Address: Experimental Psychology, Helmholtz Institute, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands. Fax: +31 30 253 4511.
E-mail address: j.heeman@uu.nl (J. Heeman).

http://dx.doi.org/10.1016/j.visres.2014.03.007
0042-6989/

global effect studies that labeled one of the elements as a target and the other as a distractor found that a task instruction did not reduce the global effect, supporting the claim that the global effect is automatic and cannot be influenced by higher-order signals (Menz & Groner, 1987; Ottes, Van Gisbergen, & Eggermont, 1985). Because of this apparent time course, in which there is a global effect for short latency saccades and no global effect for long latency saccades, the global effect is often considered reflexive and driven by bottom-up processes.

In subsequent years, however, more and more evidence accumulated suggesting that various processes that are considered top-down in origin do influence the saccade landing position. The first researchers to rebut the purely reflexive nature of the global effect mechanism were Coëffé and O'Regan (1987). Their study presented participants a string of letters that contained a target letter marked with an 'x' to which they had to make a fast saccade. In one of their conditions the location of the 'x' remained constant during the entire experimental block. They showed that, even for short latency saccades, this predictability of the location of the target letter decreased the size of the global effect. Eye movements were initiated more accurately towards the target location than in the conditions in which the location of the 'x' was varied. Other evidence that shows that the size of the global effect can be modulated or even abolished by top-down processes came from studies which varied the probability of the target location (He & Kowler, 1989), gave an auditory cue before each trial which provided information about the location of the target (Aitsebaomo & Bedell, 2000), or gave participants the opportunity to pre-examine the possible targets in a scene before getting the final task instruction (Findlay & Blythe, 2009). All of these studies show that additional higher-order information about the target increases saccade accuracy to the target and decreases the global effect (for a review, see Van der Stigchel & Nijboer, 2011).

Although it is known that saccade averaging is stronger for short latency saccades, the time course of the modulating influence of top-down processes is unknown. It is currently unclear whether there is a gradual built up of top-down influence or whether the time course is more in line with a race-model that follows the winner-takes-all principle. In relation to visual search, Van Zoest, Donk, and Theeuwes (2004) showed that the exogenous process of bottom-up stimulus-driven target selection and the endogenous process of top-down goal-driven selection operate on independent time scales. They suggested that longer latency responses will become increasingly goal-driven at the expense of the bottom-up stimulus-driven response. The present study seeks out to further investigate this assumption by establishing a detailed time course of the interaction between top-down and bottom-up influence on saccades in relation to the global effect. It will therefore be established for which latencies the bottom-up saccade averaging is influenced by top-down task instruction.

To investigate the time course of the modulating influence of top-down processes on the global effect a task was designed in which participants were required to saccade to one of two elements in near periphery with a wide range of saccade latencies. To evoke a wide range of saccade latencies a fixation gap paradigm was used varying the fixation offset and stimulus onset timing between overlap, no-gap or gap trials. The shorter the overlap (or the longer the gap) between fixation offset and stimulus onset the shorter the latency of the saccade (Kopecz, 1995; Saslow, 1967).

2. Experiment 1

The first experiment investigated to what extent the ability of participants to saccade to a specific target element depended on the latency of the saccade. Experiment 1 contained three conditions. An Instruction condition in which the color of the element to which the saccade had to be made was specified and the other element served as a distractor (Double Instruction) and two No Instruction conditions that served as a baseline for the analysis, one in which two elements were presented without a target color instruction (Double No Instruction) and one condition in which only a single element was presented (Single).

2.1. Methods

2.1.1. Participants

Ten naive participants (22–40 years old/average age 31.5 years; 4 male), all naive to the purpose of the experiment, participated in the experiment. All had normal or corrected-to-normal visual acuity. Informed consent was obtained prior to the study in accordance with the guidelines of the Helsinki Declaration.

2.1.2. Apparatus

Participants performed the experiment in a sound-attenuated setting, viewing a display monitor from a distance of 72 cm. Eye movements were recorded by an Eyelink1000 system (desktop system; SR Research Ltd., Canada), an infra-red video-based eye tracker that has a 1000 Hz temporal resolution and a spatial resolution of 0.01°. The participant's head was stabilized with a chin rest, and an infrared remote tracking system compensated for any residual head motion. The left eye was monitored. An eye movement was considered a saccade when either eye velocity exceeded 35°/s or eye acceleration exceeded 9500°/s^2.

2.1.3. Stimuli and procedure

Participants viewed a display containing a gray cross (1° × 1°, 13.3 cd/m^2) on a black background in the center of the display, which was used as fixation point. The fixation point was removed after a random interval of 400–1200 ms. Stimulus onset was either 50 ms or 100 ms before fixation offset (overlap), simultaneous with fixation offset (no gap), or 50 ms or 100 ms after fixation offset (gap). Gap, no gap and overlap trials were counterbalanced and intermixed in a random fashion. The target display was presented for 1100–1200 ms. Afterwards all objects were removed from the display. The stimuli, a red and a green filled circle, had the same size (.75°) and were equiluminant (7.98 cd/m^2). The distance from the central fixation point to the stimuli was 8°. Fig. 1 shows a schematic representation of the trial sequence of Experiment 1. Either one or two elements could be presented. When one element was

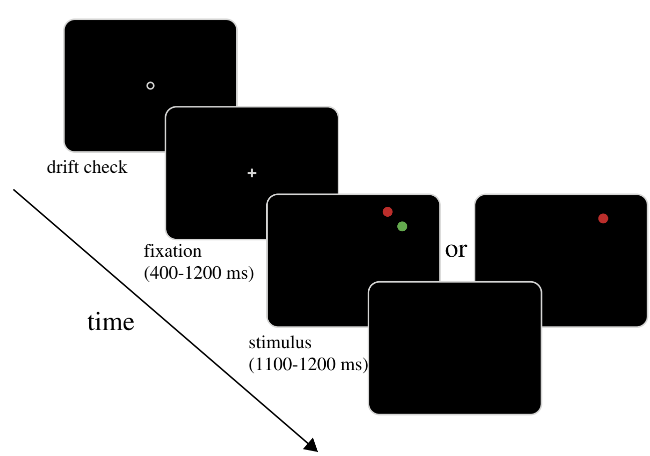

Fig. 1. Schematic representation of the task of Experiment 1 presenting either two peripheral elements or one. The stimulus onset asynchronies were −100, −50, 0, 50 and 50 ms relative to fixation offset.