Acta Psychologica 139 (2012) 434–439

Contents lists available at SciVerse ScienceDirect

Acta Psychologica

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

The perceptual span during foveally-demanding visual target localization

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ARTICLE INFO

Article history:
Received 28 December 2010
Received in revised form 16 December 2011
Accepted 30 December 2011
Available online 8 February 2012

PsychINFO classification:
2300 Human experimental psychology
2323 Visual perception
2340 Cognitive processes
2346 Attention

Keywords:
Perceptual span
Processing load
Saccades

ABSTRACT

Foveally-induced processing load deteriorates target localization performance in vision-guided tasks. Here, participants searched for a target embedded among coded distractors. High processing load was effected by instructing some participants to use the coded distractors to guide their search for the target. Other participants (in the low processing load condition) were not apprised of the code. The experiment examined whether increased processing load alters the span of effective processing (i.e. perceptual span) by (a) reducing its size, (b) altering its shape, or (c) reducing its size and altering its shape. The results demonstrated a reduction in the size of the perceptual span, with no significant change to its shape. It is argued that when distractors are processed beyond simply rejecting them as non targets, the perceptual span shrinks with increasing processing load. The findings are discussed in contrast to a general interference theory that predicts a change in vision-guided performance without a shrinking of the perceptual span.

1. Introduction

In the laboratory, visual target localization (VTL) involves freely searching with multiple saccades for a target that is always present in displays (e.g. Greene, Pollatsek, Masserang, Lee, & Rayner, 2010). The laboratory task is meant to simulate instances when one looks for an item that is known to be present somewhere in a visual environment. Applications include the building of biologically-plausible computational search systems (Parkhurst, Law, & Niebur, 2002), human detection of deviant patterns in radiographic airport baggage-screening images (McCarley, Kramer, Wickens, Vidoni, & Boot, 2004), and human detection of hazardous objects while driving a motor car (Crundall, Underwood, & Chapman, 2002). Given the decline in ability to process details at eccentric locations, saccades are required to acquire information from wide areas of the visual field. In between saccades, covert attention mechanisms continually select locations towards bringing the target of interest within a window of high processing resolution. Many attempts have been made to study the resolution window under various names (e.g. functional field of view, visual lobe, conspicuity area, and visual span; see respectively, Ball & Owsley, 1993; Chan & Tang, 2007; Engel, 1977; Jacobs, 1986), by instructing participants to localise, or to identify a target presented briefly at different eccentricities from fixation. Henceforth, the term "psychophysical span" shall be used here to describe the class of resolution windows just mentioned. When increased foveal processing is required to accomplish a task, the size of the span can become smaller (Chan & Tang, 2007; Rantanen & Goldberg, 1999; Williams, 1988). Increased processing load has also been observed to make the span increasingly irregular in shape, with rougher boundaries (Chan & Tang, 2007; Rantanen & Goldberg, 1999). While there is a notable lower visual field advantage in span resolution (Carrasco, Talgar, & Cameron, 2001; He, Cavanagh, & Intrilligator, 1996), increased processing load has been reported to increase the vertical meridian asymmetry (Chan & Tang, 2007; Rantanen & Goldberg, 1999). Finally, increased processing load may also elicit a general deterioration in resolution, without a change to the size of the span (Crundall et al., 2002). All this is important, given that the psychophysical span has been shown repeatedly to account well for performance in VTL (Chan & Tang, 2007; Jacobs, 1986; Najemnik & Geisler, 2008).

A potential limitation for theory-making is the method used to obtain the psychophysical span. Arguably, the processing demands and strategies utilised in a psychophysical span task are not necessarily the same as the demands and strategies adopted when a participant freely scans the visual field with saccades, in search of a target. This is potentially a problem for ecological validity (see Kingstone, Smilek, Ristic, Friesen, & Eastwood, 2003 for a discussion). Hence, a comprehensive understanding of VTL requires that properties of the resolution window are (additionally) assessed in multi-saccadic contexts. In contrast to the psychophysical span, the term "perceptual span" is used here to refer to the resolution window obtained during multi-saccadic tasks. Perceptual span properties have been studied

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doi:10.1016/j.actpsy.2011.12.015

for alphabetic script reading (e.g. Rayner, 1986), morphographic script reading (Inhoff & Liu, 1998), picture viewing (e.g. Saida & Ikeda, 1979), and VTL (Bertera & Rayner, 2000; Greene & Rayner, 2001; Greene et al., 2010; Loschky & McConkie, 2002; Phillips & Edelman, 2008a,b). The technique used in the aforementioned perceptual span studies involves the use of eye tracking systems that quickly update visual display items (within 3–20 ms) in a gaze-contingent moving fovea-centred window (GCMW). Visual artefacts introduced by the transient stimulation are minimal (Inhoff, Starr, Liu, & Wang, 1998; Loschky & McConkie, 2002). In a typical experiment, peripheral information outside the GCMW is consistently perturbed. The GCMW is adjusted to decrease the size of the perturbed peripheral visual field until a significant decline in performance is observed. The largest window size that does not evoke a decline in performance is assumed to reflect the relative size of the perceptual span. Given that VTL is accomplished by continual extraction of information from the perceptual span, it is important to understand shape *and* relative size dynamics of the perceptual span. A limitation of the GCMW method is that, while it addresses relative size dynamics of the perceptual span quite well (e.g. Bertera & Rayner, 2000; Greene & Rayner, 2001), it cannot well map its shape. Given that amplitudes of saccades reflect the *relative distance* (not the maximum distance) over which useful information may be extracted from the peripheral visual field (see Bertera & Rayner, 2000), questions about the VTL perceptual span's shape (Greene et al., 2010) and *relative* size (e.g. Bertera & Rayner, 2000; Cornelissen, Bruin, & Kooijman, 2005; Greene et al., 2010; Phillips & Edelman, 2008a) are well addressed by studying saccade amplitudes.

It is well established that the perceptual span is susceptible to task demands. For example, in alphabetic and morphographic script reading, asymmetry in the reading perceptual span depends on the direction (leftwards, rightwards, or downwards) in which the script is written (Inhoff, Pollatsek, Posner, & Rayner, 1989; Osaka, 1993; Pollatsek, Bolozky, Well, & Rayner, 1981). In effect, the shape of the reading perceptual span is malleable. Given that the size also, of the reading perceptual span decreases with increasing processing load (Rayner, 1998), it too is malleable. With respect to VTL, the size of perceptual span has been shown to decrease when processing load is heavy (Geisler, Perry, & Najemnik, 2006; May, Kennedy, Williams, Dunlop, & Brannan, 1990). Obviously, a comprehensive understanding of VTL requires an understanding of span size *and* span shape modulations (e.g. Chan & Tang, 2007). To date, it is not clear how VTL span shape is affected by processing load in multi-saccadic contexts. Perhaps, given the importance of the lower visual field for monitoring peripersonal body space (Previc, 1990), the lower part of the perceptual span may be more resistant (in terms of its size modulations) than the upper part to increased processing load. Hence, the shape of the VTL perceptual span may be sensitive to processing load. The goal of the present study was to identify foveally-induced processing load effects on the size and shape of the VTL perceptual span. The approach utilised to quantify shape modulation is different from earlier approaches which sought to describe shape in terms of multiple categories of shape indices (Chan & Tang, 2007; Rantanen & Goldberg, 1999). Here, shape modulation (defined by saccade amplitudes in different directions) was assessed within the context of a Processing Load X Saccade Direction ANOVA model. For this, no anchoring reference to a compact geometric shape (e.g. a circle) was required (see Chan & So, 2006; Chan & Tang, 2007; Rantanen & Goldberg, 1999, for descriptions of psychophysical span shape indices). The approach allows for a direct evaluation of changes to VTL perceptual span with increased processing load.

In the present study, a clever search task introduced by Hooge and Erkelens (1998) was utilised (referred to as the Hooge–Erkelens task henceforth). Whereas during the typical search for a target, a simple yes/no decision (the fixated object is/is not the target) may be the trigger to initiate the next saccade (see Rayner, 1998), the Hooge–Erkelens task requires the searcher to additionally process coded target-localization information available each moment in the foveal visual field (see also Greene, 2006). In effect, the task increases processing load in the foveal visual field. Processing load was manipulated by apprising some participants of the coded information, and instructing them to use this knowledge to guide their saccades to the target. Other participants were not apprised of the code. Previous experiments have repeatedly indicated that participants who are not apprised of the code do not decipher the code (Greene, 2006). If processing load is higher when the coded information is utilised, then one of three perceptual span modulations may be expected. One possible result is that increased processing load may simply reduce the size of the span. Such a finding will be congruent with May et al. (1990) who found shorter saccade amplitudes when mental workload was increased. Unlike the May et al. (1990) study however, saccade amplitudes in the present experiment were analysed as a function of saccade direction (i.e. shape of the span). Shape modulations were not accessible in the May et al. (1990) analyses. In the present experiment, for a size-only modulation of the span, average saccade amplitude should be shorter with increased processing load (i.e. main effect of processing load); and processing load should not interact with saccade direction (Fig. 1A). Another possible result is that increased processing load may only alter the shape of the span. In this case, the average amplitude of saccades should not change with increased processing load. Additionally, the processing load factor should interact with saccade direction (e.g. Fig. 1B). A final possible result is that increased processing load may reduce the size *and* alter the shape of the span. In this case, saccade amplitudes should be shorter with increased processing load (e.g. May et al., 1990), and processing load should interact with saccade direction (e.g. Fig. 1 C). Such a finding would add useful knowledge to what is known (e.g. May et al., 1990) about processing load effects on saccade amplitudes (and perceptual span modulations).

2. Method

2.1. Participants

Forty-three students (18–45 years of age) in undergraduate psychology courses at University of Detroit Mercy participated in the experiment. All had normal or corrected-to-normal visual acuity, and were unaware of the purpose of the experiment.

2.2. Apparatus

Movements of the right eye were recorded by an SMI Eyelink eye tracker which sampled eye positions at 250 Hz. A nine-point calibration routine was utilised for each participant. The stimulus displays were presented on a computer monitor and single key-press responses were made on a keyboard.

2.3. Stimuli

Each display contained 24 arrow-head distractors and one open arrow-head (i.e. the target) in a hexagonal matrix (see Fig. 2 for an example). Individual distractors subtended visual angles of .50° in the vertical and horizontal dimensions, and the distance between any two adjacent arrow heads was 2°. The distractors were coded such that each one pointed towards the relative location of the target. For each stimulus presentation, the target's location and its orientation (upwards, downwards, rightwards, leftwards) was unpredictable. The displays have been used before by Greene (2006). Previous experiments indicate that participants who are not apprised of the code do not decipher the code (Greene, 2006).