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When do you look where you look? A visual field asymmetry

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ABSTRACT

Pre-saccadic fixation durations associated with saccades directed in different directions were compared in three endogenous-attention oriented saccadic scanning tasks (i.e. visual search and scene viewing). Pre-saccadic fixation durations were consistently briefer before the execution of upward saccades, than downward saccades. Saccades also had a higher probability of being directed upwards than downwards. Pre-saccadic fixation durations were symmetric and longer for horizontally-directed saccades. The vertical visual field asymmetry in pre-saccadic fixation durations reflects an influence of factors not directly related to currently fixated elements. The ability to predict pre-saccadic fixation durations is important for computational modelling of real-time saccadic scanning, and the findings make a case for including directional constraints in computational modelling of *when the eyes* move.

1. Introduction

Saccades are ballistic eye movements used to reorient the fovea within the visual field, with pro-saccades directed towards a target and anti-saccades away from a target. Many pro-saccade reaction time (PSRT) studies have revealed an asymmetry in the latency to initiate saccades towards the upper visual field (UpVF) and lower visual field (LoVF). Typically, PSRTs are shorter for saccades directed into the UpVF for humans (Goldring & Fischer, 1997; Hackman, 1940; Heywood & Churcher, 1980; Honda & Findlay, 1992; Miles, 1936; Pitzalis & Di Russo, 2001; Tzelepi et al., 2010) and for monkeys (Schlykowa et al., 1996; Zhou & King, 2002). A representative sample of relevant PSRT studies is presented in Table 1. While the asymmetry has not always been found[1] (e.g., Bonnet et al., 2013; Miller, 1969; Yang & Kapoula, 2006), a preponderance of the evidence supports a vertical visual field asymmetry (VVFA) in PSRTs, such that PSRTs are shorter when saccades are directed into the UpVF.

The high level of experimental control in PSRT tasks has made them attractive to researchers of saccadic mechanisms. The temporal metric of concern in PSRT tasks is usually the time to react with a saccade to the onset of a salient cue. Thus, PSRT tasks are typically more involved with exogenously oriented attention which means they may not be necessarily generalizable to saccadic scanning tasks (e.g. visual search and scene viewing) where observers endogenously direct their attention while engaged in exploration. For saccadic scanning, the temporal metric includes both physiologically-based latencies (e.g. the time required to program the eyes to move) and the amount of time taken to process the fixated element in the visual field (e.g., Nuthmann et al., 2010; Trukenbrod & Engbert, 2014). In effect, saccades in saccadic scanning tasks are driven primarily by endogenous attention, are dependent on task demands, and are not typically driven by salient cues (e.g., Henderson et al., 2007).

Computational modelling of eye movement behavior allows researchers to simulate, and to predict the behavior of humans under various visual information acquisition conditions. While a dominant issue for eye movement modellers has been the issue of where in the visual field we direct saccades (e.g., Najemnik & Geisler, 2009; Parkhurst, Law, & Niebur, 2002; Zelinsky, 2008), there is a growing literature emphasizing the importance of also considering *when* we look where we look (e.g., Henderson, Nuthmann, & Luke, 2013; Mills et al., 2011; Trukenbrod &

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[1] In some studies the problem may have been limited statistical power. For example, although Bonnet et al.'s (2013) study used a large sample (i.e., 145 adults, 19–82 years) each observer made only 8 saccades into the UpVF and 8 into the LoVF. Thus, each individual's data set was probably rather noisy for the asymmetry analysis. Similarly, Miller (1969) speculates that the small number of trials used in their study may have resulted in noisy data. Additionally, we speculate that the methodology used by Miller (1969) may have been a potential limitation. The PSRTs were obtained by inter-scorer agreement on camera-frame counts between the onset of a saccade target light and the first eye movement detected. Finally, it is possible that age was a confounding factor in these PSRT studies. A commonality between the studies by Bonnet (Bonnet et al., 2013) and Yang (Yang & Kapoula, 2006) is that they involved the use of older adults (about 80 years old). Heywood and Churcher (1980) inadvertently listed in their Table 1, a study by Cohen and Ross (1977), as one that did not find the asymmetry, but vertical saccades were not made in the Cohen and Ross (1977) study.

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Table 1
Representative sample of studies that addressed the latency of saccades directed into the upper visual field (UpVF) and lower visual field (LoVF).

Authors	Participants	VVFA (vertical visual field asymmetry)	Short journal name
Miles (1936)	2 Adults	LoVF > UpVF	Psych. Monographs
Hackman (1940)	16 Adults	LoVF > UpVF	J. Exp. Psychology
Heywood and Churcher (1980)	6 Adults	LoVF > UpVF	Quarterly J. Exp. Psychology
Honda and Findlay (1992)	5 Adults	LoVF > UpVF	Perception & Psychophysics
Honda and Findlay (1992)	2 Adults	LoVF > UpVF	Perception & Psychophysics
Goldring and Fischer (1997)	13 Adults	LoVF > UpVF	Exp. Brain Research
Pitzalis and Di Russo (2001)	23 RBD[a] patients 23 LBD[b] patients 22 Normal adults	LoVF > UpVF	Cortex
Zhou and King (2002)	2 Monkeys (*Macaca mulatta*)	LoVF > UpVF	Vision Research
Schlykowa et al. (1996)	Monkeys (*Macaca fascicularis*)	LoVF > UpVF	Neuroreport
Tzelepi, Yang, and Kapoula (2005)	9 Adults	LoVF > UpVF	Exp. Brain Research
Tzelepi et al. (2010)	5 Adults	LoVF > UpVF	Brain Research
Bell, Everling, and Munoz (2000)	2 Monkeys (*Macaca mulatta*)	LoVF > UpVF	J. Neurophysiology
Yang and Kapoula (2006)	22 Young and older adults (20–83 years)	Not present	Exp. Brain Research
Miller (1969)	9 Children (8 years old) 9 adults	Not present	Perc. Motor Skills
Bonnet et al. (2013)	145 Young and older adults (19–82 years)	Not present	Clinical. Neurophysiology

[a] Right brain damaged.
[b] Left brain damaged.

Engbert, 2014). Trying to understand eye-movement behavior under exogenous and endogenous attention-oriented conditions is onerous because of myriad possible influences of bottom-up salient stimulus-related, and top-down task-related factors involved. For example, in Mills et al.'s (2011) study, participants viewed the same real-world scenes (containing different salient stimuli) under different endogenous attention-oriented task instructions (i.e., search the scenes for an embedded target, memorize them in preparation for a recognition test, or, rate them on a pleasantness scale). Their results indicated that differences in task instructions influence how long we fixate before moving our eyes (see also Greene, 2006 for a similar finding with visual search of artificial scenes). Furthermore, Mills et al. (2011) found that task instructions influenced the dynamics of when the eyes moved (as indexed by fixation durations), but not where the eyes moved (as indexed by saccade amplitudes). This dissociation between when and where the eyes move highlights the importance of considering fixation durations in biologically-plausible modelling of eye movements (see also Greene & Rayner, 2001; Rayner & McConkie, 1976 for other examples of a dissociation between fixation duration and other indices during VTL and reading, respectively). In sum, it is reasonable to argue that (i) the visual field asymmetry reported in PSRT tasks do not necessarily generalize to saccadic scanning tasks (e.g., visual search and scene viewing), and (ii) it is important to determine characteristics of when the eyes move, towards comprehensive modelling of saccadic scanning behavior.

In the current study, pre-saccadic fixation durations (PSFDs) were measured while observers performed endogenous attention oriented search tasks. In the present context, a PSFD reflects the time spent fixating a scene location before a saccade is made elsewhere in the field of view. We have not concerned ourselves with partitioning the total duration into its component durations (e.g., eye–brain communication lag time, saccade programming time, visual input processing time). Two kinds of scenes were used in the study. Random dot scenes with no semantic information (other than a pre-defined target) were used in visual search experiments (Experiments 1 and 2). Rorschach images (Exner, 2003) were utilized as scenes in Experiment 3. These images are ambiguous and under-determined from a semantic perspective. With the Rorschach images, the instruction was to view the scene in search of some interpretation. Our random dot and Rorschach image scenes reduced as much as possible, semantic influences and exogenous attention-grabbing information on eye movement behavior. All participants provided written informed consent prior to each experiment.

Two problems were addressed. Of primary interest was whether the VVFA found in exogenous-attention-oriented PSRT experiments (e.g. Honda & Findlay, 1992) are reliably present during endogenous-attention-oriented exploration tasks. The existence of such a VVFA has implications for computational modelling of saccadic scanning. Of secondary importance was whether a VVFA would be found in the probability of executing saccades during saccadic scanning. Such an asymmetry has already been demonstrated for scene viewing (Foulsham & Kingstone, 2010) and visual search (Greene et al., 2010).

2. Experiment 1: fixation durations during visual search in random dot noise

The visual system is set up such that spatial processing is increasingly coarser towards the peripheral visual field. As a result, we are constantly moving our eyes to bring our fovea to bear on positions and objects of interest within our field of view. Of specific concern in Experiment 1 is a kind of visual search behavior we refer to as visual target localization (see also Greene et al., 2010; Zelinsky, 2008). In a visual target localization (VTL) task, an individual searches for a target they know in advance and know to be present in the visual field. This narrow definition of visual search provides a useful starting point for developing computational models of eye movement behavior (e.g., Najemnik & Geisler, 2009; Zelinsky, 2008). The task is simply to search a scene until a difficult to find target is found, or until the scene is turned off after a time limit.

During saccadic scanning, the position of the visual field changes with respect to the current position of the fovea. Honda and Findlay (1992) have shown with supine participants, that the VVFA for PSRTs depends on a fovea-centered vertical plane, not the gravitational vertical plane. In effect, PSRTs are faster for saccades directed upwards than downwards relative to the field of view. Henceforth, we shall refer to saccades into the UpVF as "upward saccades", and saccades into the LoVF as "downward saccades". The primary purpose of Experiment 1 was to assess PSFDs in a VTL task similar to that used by Greene, Brown, and Paradis (2013). If VVFA mechanisms are operational under endogenously oriented saccadic scanning, then PSFDs would be expected to be briefer before upward than downward saccades. A secondary concern of the experiment was to determine if there are asymmetries