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Comparing the fixational and functional preferred retinal location in a pointing task

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ABSTRACT

Patients with central vision loss (CVL) typically adopt eccentric viewing strategies using a preferred retinal locus (PRL) in peripheral retina. Clinically, the PRL is defined monocularly as the area of peripheral retina used to fixate small stimuli. It is not clear if this fixational PRL describes the same portion of peripheral retina used during dynamic binocular eye–hand coordination tasks. We studied this question with four participants each with a unique CVL history. Using a scanning laser ophthalmoscope, we measured participants' monocular visual fields and the location and stability of their fixational PRLs. Participants' monocular and binocular visual fields were also evaluated using a computer monitor and eye tracker. Lastly, eye–hand coordination was tested over several trials where participants pointed to and touched a small target on a touchscreen monitor. Trials were blocked and carried out monocularly and binocularly, with a target appearing at 5° or 15° from screen center, in one of 8 locations. During pointing, our participants often exhibited long movement durations, an increased number of eye movements and impaired accuracy, especially in monocular conditions. However, these compensatory changes in behavior did not consistently worsen when loci beyond the fixational PRL were used. While fixational PRL size, location and fixation stability provide a necessary description of behavior, they are not sufficient to capture the pointing PRL used in this task. Generally, patients use a larger portion of peripheral retina than one might expect from measures of the fixational PRL alone, when pointing to a salient target without time constraints. While the fixational and pointing PRLs often overlap, the fixational PRL does not predict the large area of peripheral retina that can be used.

1. Introduction

Central vision loss (CVL) can have a variety of causes, with the most common being age-related macular disease (AMD), which affects 2–3% of the US population over the age of 50 and primarily disrupts vision in the fovea and parafovea (Friedman et al., 2004; Jager, Mieler, & Miller, 2008; Zarbin, 2004). Since the fovea provides the highest visual acuity, CVL can dramatically impair one's day-to-day functioning in tasks such as driving, object recognition and reading.

Fully sighted individuals consistently use their foveae to gather task relevant visual information over time (Land & Hayhoe, 2001). When CVL disrupts the foveae, information must instead be gathered in the peripheral retina, but it is not clear if a consistent retinal locus is always used. Under conditions of monocular, head-fixed viewing, CVL patients engage in eccentric viewing where they may often use a preferred retinal locus (PRL), i.e. a favored region in the peripheral retina that can be used for fixation (Crossland, Culham, Kabanarou, & Rubin, 2005; Fletcher & Schuchard, 1997; Schuchard, 2005; Timberlake et al., 1986; White & Bedell, 1990). Questions remain as to why the fixational PRL develops where it does, and the efficiency with which it can be aimed at new locations with saccades.

Stability, selection and use of PRLs all vary with duration of impairment, the nature of retinal damage and training (Crossland, Engel, & Legge, 2011; Crossland et al., 2005; Fletcher & Schuchard, 1997; Kabanarou et al., 2006; Schuchard, 2005;

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Schuchard, Naseer, & de Castro, 1999; Tarita-Nistor, González, Markowitz, & Steinbach, 2009; Vingolo, Salvatore, & Cavarretta, 2009). However, PRL use is not well documented during the everyday life of maculopathy patients. In particular, little is known of binocular visual behavior guiding the manipulation of objects. Prior studies have largely focused on reading and visual search paradigms viewed monocularly with head and body movements constrained (Kabanarou et al., 2006).

Many portions of peripheral retina may be suitable for eccentric viewing, dependent on task demands and the visual properties of the objects being viewed. In natural scenarios, do subjects reliably use only a small patch of peripheral retina as a 'pseudo-fovea'? Or is there variability in size and location of the PRL, and if so, how does this impact performance?

Fully sighted subjects foveate areas of a scene related to the current task and image properties (Land & Hayhoe, 2001; Land, Mennie, & Rusted, 1999). Several studies examining PRL use suggest a similar link with task demands and stimulus properties. For example, Lei and Schuchard (1997) found subjects used different PRLs when fixating a stimulus of high or low brightness. Duret, Issenhuth, and Safran (1999) and Deruaz, Whatham, Mermoud, and Safran (2002) both found subjects who used multiple PRLs to read text and altered the PRL selected dependent on text size in the former study. Timberlake, Sharma, Grose, and Maino (2006) reported that some subjects used PRLs for reading that differed from the PRL used to maintain fixation on a small stimulus. Similarly, Crossland, Crabb, and Rubin (2011) observed age-related macular degeneration subjects that used PRLs that differed between fixation of a point stimulus and fixation of a word.

These studies suggest that the extent and location of a PRL can shift due to task demands and stimulus properties. However, they were tested in controlled circumstances with monocular viewing and restrictions on head and body movements. In a study allowing hand movements, Timberlake, Grose, Quaney, and Maino (2008) and Timberlake, Omoscharka, Grose, and Bothwell (2012) studied PRL use in a set of manual tasks, e.g. tracing an outline with one's hand, but this was limited to a monocular view where the participant watched a live video of their hand movements via a scanning laser ophthalmoscope (SLO). They found that most often the subject directed his fixational PRL to points of manipulation but would occasionally use other retinal locations. Sullivan, Jovancevic, Hayhoe, and Sterns (2005) and Sullivan, Jovancevic-Misic, Hayhoe, and Sterns (2008) presented data from a single Stargardt's patient wearing a mobile eye tracker allowing full range of body movements. Instead of a small PRL, they found that the subject tended to use a large portion of a visual quadrant for manipulation and would even switch quadrants contingent on task demands. However, they did not sufficiently characterize visual fields or PRLs of this patient, and behavior from a juvenile macular degeneration patient may not generalize to other forms of CVL.

Current evidence suggests that fixational PRL use may not be completely representative of functional PRL use, e.g. the portion of retina a stimulus subtends while a participant engages in an interaction with it (Sullivan et al., 2005, 2008). To address this hypothesis, we examined the visual function and visuo-motor behavior of four individuals with varying types of CVL. We measured monocular fixational PRLs and compared them to participants' task or functional PRLs during pointing, i.e. the portion of peripheral retina used while subjects pointed to a target on a computer monitor in monocular and binocular viewing conditions. Our experiment included three sections: measuring patient visual fields in an SLO and using a computer monitor, measuring the fixational PRL in the SLO and finally measuring the task PRL in the aforementioned pointing task. We compare the fixational and pointing PRLs, with a particular examine how stimulus location may influence pointing PRL use.

2. Method

2.1. Participants

Four male patients with low vision were recruited to engage in multiple visits for testing. Subjects gave informed consent in accordance with HIPAA and the Code of Ethics of the World Medical Association (Declaration of Helsinki) as determined by Smith-Kettlewell's institutional review board. All patients had varying degrees of central visual field loss, Table 1 provides relevant details on each participant. Participants' P1 and P4 normally wore optical correction. However, because of poor eye tracking with the lenses, tests using the monitor and eye tracker setup, described below, were conducted without correction. All subjects were right-handed. While all subjects had at least some experience with low vision therapy for adaptation, e.g. household adaptations and/or mobility help, none had received extensive eccentric viewing training. What training was experienced was limited to instruction in using eccentric viewing heuristics.

2.2. Visual fields

Before measuring PRLs, we first characterized subjects' monocular and binocular visual fields. The pattern of visual field disruption can differ greatly between patients and even between the two eyes in a single patient, so it is useful to document the nature of each subject's visual impairment to have a context for where the PRL is placed with respect to visually functioning retina. We used two different experimental setups to perform perimetry, the first utilized used a Rodenstock Model 101 SLO (Rodenstock GmbH, Munich, Germany) and the second utilized a computer monitor and eye tracker setup.

In our monocular SLO setup, we used "Smart Micro-Perimetry" software (MMTest, San Francisco, CA, USA) (MacKeben & Gofen, 2007) that allows perimetry with real-time eye tracking to ensure gaze-contingent stimulus presentation. This software allows for gaze-contingent rendering of stimuli, improving data reliability when fixation is unstable (as is common in CVL). This allows on average accuracy of 0.1° in controlling the location of visual stimuli on the retina. During field testing subjects were instructed to hold gaze still on a fixation cross (spanning 2° with a 0.25° stroke width), except P4 who requested that the stimulus be enlarged by 2× for OS and 3× for OD. In all cases, the non-tested eye was patched. Visual fields were captured monocularly by having subjects press a button when they detected a small suprathreshold point stimulus, 0.1°, briefly presented around their visual field in a standardized pattern where stimuli appeared every 2 s. Typically 135 points were presented in a predetermined diamond shaped pattern that would cover the scotoma and optic disc. For some patients, points were manually placed to ensure good coverage of the scotoma border. The SLO provides a presentation field of view of ~27° × 18°; the fixation cross was placed in a location onscreen that allowed the subject to fixate with a PRL while allowing the majority of the optic disc to appear on screen so that the disc could be used later as a localization reference. If the participant detected the stimulus they clicked a handheld response button.

In the second monocular field test setup, a binocular tabletop eye tracker (Eyelink 1000, SR Research, Ottawa, Ontario, Canada) and a 17″ computer touchscreen monitor (ELO Touch Solutions, Milpitas, CA, USA) were used. The tracker ran in binocular mode at 500 hz tracking both pupil and corneal reflections. The monitor was viewed from 40 cm and subtended 36° × 30° of visual angle. Presented stimuli were rendered at a pixel resolution of 1024 × 1280 at 60 hz. All stimuli were presented using Matlab (Mathworks, Inc, Natick, MA, USA) and the psychophysics toolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997). The