Vision Research 101 (2014) 151–157

Contents lists available at ScienceDirect

Vision Research

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

Unaffected smooth pursuit but impaired motion perception in monocularly enucleated observers

Esther G. González [a,b,c,*], Linda Lillakas [a,c], Naomi Greenwald [a], Brenda L. Gallie [b,d], Martin J. Steinbach [a,b,c]

[a] Vision Science Research Program, Toronto Western Hospital, Toronto M5T 2S8, Canada
[b] Ophthalmology and Vision Sciences, University of Toronto, Toronto M5T 2S8, Canada
[c] Centre for Vision Research, York University, Toronto M3J 1P3, Canada
[d] Cancer Informatics, Princess Margaret Hospital, Toronto M5T 2M9, Canada

ARTICLE INFO

Article history:
Received 22 May 2014
Received in revised form 25 June 2014
Available online 5 July 2014

Keywords:
Eye movements
Smooth pursuit
Motion perception
Motion detection
Monocular vision
Enucleation

ABSTRACT

The objective of this paper was to study the characteristics of closed-loop smooth pursuit eye movements of 15 unilaterally eye enucleated individuals and 18 age-matched controls and to compare them to their performance in two tests of motion perception: relative motion and motion coherence. The relative motion test used a brief (150 ms) small stimulus with a continuously present fixation target to preclude pursuit eye movements. The duration of the motion coherence trials was 1 s, which allowed a brief pursuit of the stimuli. Smooth pursuit data were obtained with a step-ramp procedure. Controls were tested both monocularly and binocularly. The data showed worse performance by the enucleated observers in the relative motion task but no statistically significant differences in motion coherence between the two groups. On the other hand, the smooth pursuit gain of the enucleated participants was as good as that of controls for whom we found no binocular advantage. The data show that enucleated observers do not exhibit deficits in the afferent or sensory pathways or in the efferent or motor pathways of the steady-state smooth pursuit system even though their visual processing of motion is impaired.

1. Introduction

Animal and human studies have amply documented the fact that visual deprivation during childhood affects visual development and that a balanced binocular input during development is a necessary condition for normal adult vision (Barnes et al., 2010; Daw, 1995; Ellemberg et al., 2000; Rakic, 1981; Wiesel & Hubel, 1963, 1965). Amblyopia has often been used as a model for research on monocular deprivation, but amblyopia with its associated abnormal binocular interactions results in different deficits from those produced by the true monocularity stemming from enucleation. In contrast to people with amblyopia (Barrett, Bradley, & McGraw, 2004; Birch, 2013; Kiorpes, 2006; Levi, 2006; McKee, Levi, & Movshon, 2003; Wong, 2012), enucleated observers exhibit intact or enhanced spatial vision (Kelly, Moro, & Steeves, 2013; Steeves, González, & Steinbach, 2008; Steinbach & González, 2006), particularly at low contrast (González et al., 2002; Nicholas, Heywood, & Cowey, 1996; Steeves et al., 2004). In common with, although not as severely as in people with amblyopia, enucleated observers also exhibit deficits in face (Kelly, Gallie, & Steeves, 2012) and in motion perception (Kelly et al., 2013; Steeves et al., 2002). The dissociation between spatial and motion perception is illustrated by the deficits in speed discrimination but not in luminance contrast perception shown by enucleated observers (Kelly et al., 2013). Some, but not all, one-eyed people exhibit deficits and asymmetries reminiscent of those of strabismic and amblyopic observers in optokinetic nystagmus (OKN) (Day, 1995; Reed et al., 1991). These sensorimotor asymmetries are similar to those found in newborn infants and in people with deficient stereopsis (Atkinson & Braddick, 1981; Naegle & Held, 1982; Steeves et al., 1999). In contrast with amblyopia (González et al., 2012), however, enucleation does not adversely affect fixation stability (González, Weinstock, & Steinbach, 2007).

Global motion deficits are significantly related to residual binocular function (Ho et al., 2006; Hou, Pettet, & Norcia, 2008) and abnormal binocular motion sensitive mechanisms have been identified in children with amblyopia (Bedell & Flom, 1985; Ho & Giaschi, 2006; Ho et al., 2006). It is possible that, rather than the lack of stereopsis, it is the abnormalities in the binocular interactions produced by strabismic amblyopia that are the source of the motion perception and OKN deficits since research has often

* Corresponding author at: Vision Science Research Program, Toronto Western Research Institute, 399 Bathurst Street, FP 6-212, Toronto, Ontario M5T 2S8, Canada.

E-mail address: esther.gonzalez@utoronto.ca (E.G. González).

http://dx.doi.org/10.1016/j.visres.2014.06.014
0042-6989/© 2014 Elsevier Ltd. All rights reserved.

found that even the fellow—that is, the better—eye exhibits deficits (Kiorpes, 2006; Levi, 2006). Furthermore, recent research has shown that, at least in anisometropic amblyopia, contrast sensitivity rather than motion detection per se, underlies deficient motion direction discrimination (Qiu et al., 2007). Since enucleated observers show no deficiencies in contrast sensitivity, this population allows us to distinguish the effects of motion perception from other factors affecting ocular motor performance (Kelly et al., 2013).

We recently showed that the horizontal saccades of enucleated observers are comparable to those of binocularly normal controls in terms of accuracy and peak velocity and comparable to the controls' monocular saccades which are slightly slower than their binocular saccades (González et al., 2013). These data suggest that the early enucleation does not result in slower visual processing in the afferent (sensory) pathway, or in deficits in the efferent or motor pathways of the saccadic system.

The objective of this study was to study the characteristics of closed-loop smooth pursuit eye movements in monocular individuals and to compare their performance with that in two tests of motion perception. One test involves relative motion (Bowns, Kirshner, & Steinbach, 1994) and the other involves motion coherence (Steeves et al., 2002). The test of relative motion used a brief (150 ms) small stimulus and a continuously present fixation target to preclude pursuit eye movements (Gellman, Carl, & Miles, 1990; Westheimer, 1954). The motion coherence trials had a duration of 1 s which allowed a brief pursuit of the stimuli. The smooth pursuit data were obtained with a step-ramp smooth pursuit procedure known to produce slower accelerations than sinusoidal tracking (Lisberger et al., 1981; Rashbass, 1961).

2. General methods

2.1. Subjects

This research study was approved by the University Health Network's Research Ethics Board and conducted in accordance with the tenets of the Declaration of Helsinki. All adult participants gave their informed consent as did the parents or guardians of minors. Children 7–15 years of age also gave their verbal assent.

2.1.1. Monocularly enucleated group

Fifteen observers (12 women; mean age = 31.27, SD = 17.99 years; range = 7–72 years) who had been unilaterally eye enucleated early in life due to retinoblastoma, a rare paediatric cancer of the eye (Dimaras et al., 2012), participated. Fourteen of them were unilateral cases and had a normal remaining eye. The single observer with a bilateral diagnosis had a clear macula and tumor scars in the far periphery only. Age at enucleation (AAE) ranged from 4 to 75 months (median = 18 months).

2.1.2. Control group

The control group consisted of 18 participants (13 women; mean age = 30.17, SD = 16.17 years; range = 8–68 years) closely age-matched to the enucleated group. All had normal or corrected to normal visual acuity and a stereopsis score of at least 40 s as measured by the Fly Stereotest (available in the public domain at http://www.stereooptical.com). For the monocular condition they all used their preferred eye, which was the left eye for four of them.

Table 1 shows the demographic information of the two groups.

Table 1
Characteristics of participants in the enucleated and control groups.

Enucleated group				Control group	
Viewing eye	Age (yrs)	AAE	Diagnosis	Monocularly viewing eye	Age
R	7	25	Unilateral	R	8
R	13	20	Unilateral	R	15
R	14	75	Unilateral	R	18
L	15	71	Unilateral	L	19
L	17	8	Unilateral	R	19
L	21	16	Unilateral	R	21
R	29	12	Bilateral	R	22
R	31	10	Unilateral	L	24
L	31	4	Unilateral	R	24
R	34	20	Unilateral	R	25
L	37	24	Unilateral	R	27
L	44	18	Unilateral	L	29
R	50	27	Unilateral	L	34
R	54	9	Unilateral	R	34
R	72	14	Unilateral	R	42
R	54				
R	60				
R	68				
Mean	31.27	23.53			30.17
SD	17.99	21.16			16.16
Median	31	18			25

Note: AAE = age at enucleation in months.

2.2. Equipment

Motion perception and smooth pursuit stimuli were both presented on a Samsung monitor (Sync Master 900 NF; Samsung, Seoul, South Korea) with a 34.4 × 26 cm useful field of view, a resolution of 1024 × 768 pixels, and a refresh frequency of 120 Hz. Stimuli were generated by a Macintosh laptop computer (smooth pursuit) and an iMac desktop computer (motion tests), using VPixx, a graphics and psychophysical testing software (VPixx Technologies Inc., Saint Bruno, QC, Canada). All participants were tested in a well-illuminated room and wore their optical correction, if any was needed.

2.3. Data analysis

Given the wide age range of the participants, the effects of stimulus direction (motion perception and smooth pursuit) and velocity (smooth pursuit) were adjusted for differences in age. This was done by means of partial correlations and univariate analyses of covariance (ANCOVAs). For the enucleated group, AAE in months was also used as a covariate. Alpha level was set at 0.05 for all statistical tests and a Greenhouse–Geisser correction for violations of the sphericity assumption applied to the results of the ANCOVAs.

3. Motion perception

3.1. Procedure

All participants were tested at a viewing distance of 300 cm. Before testing, they were asked to read a message ("HELLO") in uppercase characters subtending 5 arcmin^{-1} in height and with a stroke width of 1 arcmin^{-1} (equivalent to 20/20 or 6/6 in Snellen optotypes). For those unable to read it, the viewing distance was reduced until they were able to do so. This was done for two participants in the enucleated group who viewed the stimuli at 150 and 250 cm, respectively. The stimulus parameters were adjusted in order to account for their viewing distance adjustment.

3.1.1. Relative motion

Trials began with a central 1° red dot on a gray background. This fixation dot was shown for 1 s after which a 6° × 6° black square filled with a drifting random dot kinematogram of white dots 0.01° in diameter appeared behind it. After 150 ms the fixation