Vision Research 125 (2016) 49–54

Contents lists available at ScienceDirect

Vision Research

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

# Peripheral contrast sensitivity and attention in myopia

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ARTICLE INFO

*Article history:*
Received 24 December 2015
Received in revised form 27 May 2016
Accepted 30 May 2016
Available online 14 June 2016

*Keywords:*
Myopia
Emmetropization
Periphery
Attention
Contrast
Sensitivity

ABSTRACT

Disruption of normal visual experience or changes in the normal interaction between central and peripheral retinal input may lead to the development of myopia. In order to examine the relationship between peripheral contrast sensitivity and myopia, we manipulated attentional load for foveal vision in emmetropes and myopes while observers detected targets with peripheral vision. Peripheral contrast detection thresholds were measured binocularly using vertical Gabor stimuli presented at three eccentricities (±8°, 17°, 30°) in a spatial 2 alternative forced choice task. Contrast thresholds were measured in young adult (mean age 24.5 ± 2.6 years) emmetropes ($n = 17$; group SE: $+0.19 \pm 0.32$D) and myopes ($n = 25$; group SE: $-3.74 \pm 1.99$D). Attention at central fixation was manipulated with: (1) a low attention task, requiring simple fixation; or (2) a high attention task, which required subjects to perform a mathematical task. We found that at 30° all subjects exhibited lower contrast sensitivity (higher thresholds). In addition, myopes (Wilcoxon, $p < 0.01$), but not emmetropes (Wilcoxon, $p = 0.1$), had a significant decrease in sensitivity at 30° during the high attention task. However, the attention dependent threshold increase for myopes was not significantly greater than for emmetropes (Wilcoxon, $p = 0.27$). Attentional load did not increase thresholds at 8° or 17° for either refractive group. These data indicate that myopes experience a greater decrease in contrast sensitivity in the far periphery than emmetropes when attention is deployed in central vision.

## 1. Introduction

It is known that disruption of normal visual experience may lead to the development of refractive errors (McBrien & Adams, 1997; Saw, 2003; Siegwart & Norton, 2011; Wallman & Winawer, 2004). The failure of emmetropization in certain individuals seems to arise from a multitude of factors combining a predisposing genetic susceptibility with a major role for environmental factors, such as a high education level, an increased amount of near work, near work posture (Saw et al., 2002; Scheiman et al., 2014; Wang, Bao, Ou, Thorn, & Lu, 2013), and decreased time spent outdoors (Deng, Gwiazda, & Thorn, 2010; Dirani et al., 2009; Jones et al., 2007; Rose, Morgan, Ip, et al., 2008; Rose, Morgan, Smith, et al., 2008).

Several groups have argued that a normal ability of the retina to detect and respond to blur and the directional sign of defocus are necessary for normal emmetropization and protection against myopia (Hess, Schmid, Dumoulin, Field, & Brinkworth, 2006; Poulere, Moschandreas, Kontadakis, Pallikaris, & Plainis, 2013; Rosén, Lundström, & Unsbo, 2012) and that myopes show decreased sensitivity to blur (Seidel, Gray, & Heron, 2005; Strang, Day, Gray, & Seidel, 2011). However, there is no general consensus that myopes show greater blur thresholds under normal (binocular) viewing (Schmid, Robert Iskander, Li, Edwards, & Lew, 2002; Taylor, Charman, O'Donnell, & Radhakrishnan, 2009). It is also undetermined whether an abnormal sensitivity to blur is related to the retina's ability to derive blur signals which are known to regulate eye growth and therefore myopia development. We propose this lack of a consensus may be partially due to a lack of consideration of the influence of peripheral vision in blur detection studies.

There is evidence for the importance of peripheral visual input in normal emmetropization and eye growth (Hess et al., 2006; Huang, Hung, & Smith, 2011; Poulere et al., 2013; Rosén et al., 2012; Smith, Hung, Huang, & Arumugam, 2007; Smith et al., 2007; Wallman, Gottlieb, Rajaram, & Fugate-Wentzek, 1987). It has been argued that the range of neuronal responses at various retinal eccentricities may constitute the signal for the sclera to control its growth and promote emmetropization (Guo, Frost, Siegwart, & Norton, 2014; McBrien, Moghaddam, Cottriall, Leech, & Cornell, 1995; Srinivasalu et al., 2015; Wang et al., 2015). Several current models emphasize that retinal cells respond more vigorously to in-focus targets as they move across the retina than when the focus is reduced due to dioptric blur at the fovea

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http://dx.doi.org/10.1016/j.visres.2016.05.004
0042-6989/

(Klaus, Rathum, & Schaeffel, 2015; Thibos & Liu, 2015; Wang et al., 2015). The prolate retinal profile in myopic eyes (Vera-Diaz, McGraw, Strang, & Whitaker, 2005) causes a peripheral retinal defocus when the central retina is in focus. Hyperopic defocus is known to induce myopia in animal studies. This peripheral defocus may cause reduced responsiveness to patterns moving across peripheral retinal regions and induce further eye growth and myopia (Benavente-Pérez, Nour, & Troilo, 2014; Smith, Hung, & Huang, 2009).

Additional evidence supporting the influence of peripheral vision are studies indicating that time outdoors is an environmental factor known to decrease the risk for myopia (French, 2016; He et al., 2015). It is possible that indoor settings provide dioptrically different visual targets and that an abnormal peripheral visual input may disrupt a child's ability to maintain emmetropia. The range of dioptric depths, distances and disparities present in outdoor scenes is far less than in indoor scenes (Flitcroft, 2012; Howe & Purves, 2002; Liu, Bovik, & Cormack, 2008) and therefore require accommodation and convergence over a much smaller dioptric range of distances than indoor scenes. Additionally, a number of studies have observed differences in stress levels and the ability to concentrate in indoor and outdoor scenes (Ulrich, 1984). These findings have been attributed to differences in attentional load, with effortless involuntary attention dominant in outdoor environments and more demanding, capacity-limited directed attention required for tasks in indoor environments (Kaplan & Kaplan, 1989).

An increased demand on perceptual attention in central vision can affect the balance between central and peripheral visual input. Indeed, increasing the level of perceptual attentional load on central vision while foveally-fixating targets, decreases sensitivity (increases detection thresholds) of peripheral stimulus detection (Carmel, Thorne, Rees, & Lavie, 2011; Lavie, 2006; Lavie, 2011; Plainis, Murray, & Chauhan, 2001) and increases detection reaction time (Turatto et al., 1999). The simplest example of this is the Troxler effect in which careful foveal fixation causes patterns in the periphery to fade from view because normal fixation tremors provide too small a movement to allow a steady pattern to repeatedly excite the large retina receptive fields in the periphery.

Collectively, these findings suggest that normal perception of blur is necessary to adequately control the level of blur signals at the retinal level, and that a delicate balance between central and peripheral retinal stimulation may be important in the retina's ability to derive blur signals for normal emmetropization (Hung & Ciuffreda, 2007). In order to examine the effect of attention on peripheral retinal control in myopia we explored the role of central attentional load on sensitivity to signals in temporal and nasal peripheral vision.

## 2. Methods

### 2.1. Subjects

A total of 45 young adult subjects (24.5 ± 2.6 years) participated in this study. Subjects' refractive error (spherical equivalent, SE) ranged from +0.75D to −8.50D (Mean SE: −2.13 ± 2.48D). Of these, 25 subjects were myopes (Mean SE: −3.74 ± 1.99D) and 17 emmetropes (Mean SE: +0.19 ± 0.32D). Criteria for subjects' inclusion were: (1) no history of surgery or eye disease that may have resulted in visual consequences, (2) within 18–32 years of age, (3) best corrected visual acuity (BCVA) 20/20 or better in each eye, (4) not using drugs that may affect their vision, (5) no current binocular vision or accommodative dysfunction, (6) contact lens wearer if myopic refractive correction was greater than −4.00DS, (7) refractive error between +0.75 hyperopia and −14.00DS myopia with $\leqslant$1.50DC of astigmatism or $\leqslant$1.00D anisometropia.

Refractive status was determined by open-field autorefraction. Subjects were classified into two refractive groups: emmetropes, defined as having a refractive error- spherical equivalent (SE)- between +0.75 to −0.25D (SE); and myopes, those subjects with refractive error between −0.50 to −14.00D (SE).

This research followed the tenets of the Declaration of Helsinki; informed consent was obtained from all subjects after explanation of the nature and possible consequences of the study, and was approved by the New England College of Optometry's Institutional Review Board.

### 2.2. Procedure

Following a vision screening that included an ocular history questionnaire, autorefraction (Grand Seiko WR-5100K), axial length (AL) (Zeiss IOL Master) measurements, Snellen VA, and an ocular health evaluation, subjects were asked to perform the psychophysical tasks.

All myopes were corrected with soft contact lenses. Subjects were tested binocularly as this is the normal condition during myopia development. Subjects viewed the target in a 152.4 cm 8-bit LCD display viewed at 100 cm presented on a uniform gray background (50 cd/m$^2$ mean luminance) under mesopic room lighting conditions. Subjects performed two different peripheral contrast detection threshold tasks in a random order.

Each task was identical in that subjects were asked to determine whether a peripheral stimulus was presented to the right or to the left of their central fixation by pressing the left or right arrow keys, respectively, on a keyboard. Stimuli were Gabor patches with vertical gratings of spatial frequency ($\omega$) and a standard deviation ($\sigma$) for the overall patch width that were m-scaled for eccentricity (Rovamo & Virsu, 1979). Gabor stimuli were presented within a Gaussian temporal window ($\sigma_t = 133$ ms) at one of three eccentricities randomly interleaved in a single run of 150 trials: 8° ($\sigma = 0.25°$, $\omega = 3.08$ c/deg), 17° ($\sigma = 0.5°$, $\omega = 1.63$ c/deg), and 30° ($\sigma = 0.5°$, $\omega = 1.03$ c/deg). Stimuli were briefly ($\sigma_t = 133$ ms) presented at the required eccentricity on either the right or left side (at random) of the subject's central fixation. The contrast of the Gabor stimulus was under the control of a 3 down, 1 up adaptive staircase (Wetherill & Levitt, 1965) designed to converge on a contrast that produced 79.4% correct target detection. The detection task was performed two times under low and two times under high attention load conditions in a random order.

For the "low" attentional load condition, subjects were asked to look straight ahead at a fixation target in the center of the screen while performing the detection task. For the "high" attentional load condition, subjects performed the same peripheral detection task while simultaneously performing an additional mathematical task at fixation. The math task was a simple equation in the form 'A#B = C'; where *A* and *B* were integers randomly drawn from the interval (McBrien & Adams, 1997; Rose, Morgan, Smith, et al., 2008), # was a mathematical operator (+, −, ∗, / at random across trials) and the result, C, was an integer that was correct on 50% of the trials. On incorrect trials, a random error between −4 and +4, excluding 0, was added to the correct result. Each of the 5 symbols ('A', '#', 'B', '=', 'C') was presented sequentially at fixation in black (0.1 cd/m$^2$) 16pt Arial font for 80 ms, for a total of 400 ms, centered on the mid-time point of the Gabor stimulus. Subjects answered the mathematical task using the up and down arrow keys for correct or incorrect, respectively. Subjects could answer the peripheral stimulus task and the central mathematical task in either order.

### 2.3. Statistical analyses

Contrast detection thresholds and 95% confidence intervals were calculated from the 75% correct estimate of the cumulative