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Deficient maximum motion displacement in amblyopia

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Abstract

Direction discrimination thresholds for maximum motion displacement (D_{max}) are not fixed, but are stimulus dependent. D_{max} increases with reduced dot probability or increased dot size. We previously reported abnormal D_{max} in the fellow eyes of amblyopic children for dense patterns of small dots. To determine how deficits of D_{max} in amblyopic eyes compare to those in fellow eyes, thresholds were obtained in both eyes of 9 children with unilateral amblyopia and 9 control children. The expected increase in D_{max} was observed for reduced dot probability and increased dot size conditions relative to baseline in both control and amblyopic groups. Both eyes of the amblyopic group demonstrated significant deficits. Our findings implicate abnormal binocular motion processing, which may involve both low-level and high-level motion mechanisms, in the neural deficit underlying amblyopia.

Keywords: D_{max}; Motion; Amblyopia; Feature matching; Spatial frequency

1. Introduction

Amblyopia is a developmental condition that may affect a healthy eye during childhood if it is deprived of normal visual stimulation due to visual deprivation, ocular misalignment (strabismus) and/or unequal refractive errors (anisometropia). Clinically, reduced visual acuity (VA) on standardized tests involving letter or shape recognition is the diagnostic indicator of amblyopia. Unilateral amblyopia is characterized by reduced VA in the amblyopic eye with normal VA in the fellow eye, when tested through an optimal refractive correction.

Motion perception is rarely tested clinically, but emerging research evidence suggests that it is not spared in amblyopic eyes (Buckingham, Watkins, Bansal, & Bamford, 1991; Ellemberg, Lewis, Maurer, Brar, & Brent, 2002; Giaschi, Regan, Kraft, & Hong, 1992; Hess, Demanins, & Bex, 1997; Ho et al., 2005; Ho et al., 2006; Kelly & Buckingham, 1998; Schor & Levi, 1980a, 1980b; Simmers, Ledgeway, & Hess, 2005; Simmers, Ledgeway, Hess, & McGraw, 2003; Simmers, Ledgeway, Mansouri, Hutchinson, & Hess, 2006; Steinman, Levi, & McKee, 1988). It has been suggested that motion perception deficits may provide a measure of neural change and visual loss more sensitive than form perception deficits (Kelly & Buckingham, 1998).

The fellow eye in amblyopia is often assumed to have normal visual function because it demonstrates normal VA. This assumption is likely not valid as numerous studies have reported subtle deficits in form perception (Davis et al., 2003; Kandel, Grattan, & Bedell, 1980; Kovacs, Polat, Pennefather, Chandna, & Norcia, 2000; Leguire, Rogers, & Bremer, 1990; Lewis, Maurer, Tytla, Bowering, & Brent, 1992; Wang, Ho, & Giaschi, in press) and more robust deficits in motion perception (Ellemberg et al.,

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2002; Giaschi et al., 1992; Ho et al., 2005, 2006; Kelly & Buckingham, 1998; Simmers et al., 2003, 2006) in the clinically unaffected fellow eye.

Previously, we investigated performance on global motion, motion-defined form, and maximum motion displacement (D_{max}) tasks in the fellow eyes of children with amblyopia (Ho et al., 2005). Motion-defined form perception was abnormal in the amblyopic group relative to an age-matched control group. D_{max} was abnormal in some children with amblyopia; global motion perception was normal in most children. In that study, only the fellow eyes were tested and the stimulus used to measure D_{max} was a dense display comprised of small dots. D_{max}, however, is highly dependent on the stimulus parameters chosen and may be determined by either spatial-frequency-dependent (low-level) or feature-matching (high-level) motion mechanisms, depending on the stimulus (Nishida & Sato, 1995; Sato, 1998; Snowden & Braddick, 1990).

D_{max} increases with an increase in retinal eccentricity or stimulus size (Baker & Braddick, 1982; Braddick, 1974; Chang & Julesz, 1983a; Nakayama & Silverman, 1984; Todd & Norman, 1995), increase in dot size beyond 15 min (Cavanagh, Boeglin, & Favreau, 1985; Morgan, 1992; Sato, 1990), decrease in dot density (Boulton & Baker, 1993; Eagle & Rogers, 1996, 1997; Ramachandran & Anstis, 1983), and/or increase in the number of frames in the random dot kinematogram (RDK) (Nakayama & Silverman, 1984; Nishida & Sato, 1992; Snowden & Braddick, 1989a, 1989b; Todd & Norman, 1995). D_{max} also increases with low- or band-pass spatial-frequency filtering that eliminates high spatial frequencies from the stimulus (Chang & Julesz, 1983b; Cleary & Braddick, 1990; De Bruyn & Orban, 1989). Overall, D_{max} increases with manipulations that reduce the complexity of the stimulus, and presumably increase the reliance on higher-level feature-matching mechanisms (Sato, 1998).

The stimulus used in our previous study (Ho et al., 2005) would likely be processed by a low-level mechanism. Recent studies on amblyopia, however, suggest that high-level motion processing is more impaired than low-level motion processing (Ho et al., 2006; Simmers et al., 2005, 2006). Our aim with the current study was to investigate the effects of stimulus manipulations on D_{max} in amblyopic children, and to compare performance in amblyopic and fellow eyes. Most studies investigate D_{max} using 2-frame RDKs that may have less in common with true smooth motion than multi-frame RDKs (De Bruyn & Orban, 1989). We used large field 4-frame RDKs to determine whether the increase in D_{max} typically observed by increasing dot size or reducing dot probability also holds true for children with amblyopia. We determined D_{max} for a baseline condition, a reduced dot probability condition, and an increased dot size condition. Dot sizes were selected to fall in a range above 20 min, below which changes in dot size have little effect on D_{max} (Cavanagh et al., 1985; Morgan, 1992; Sato, 1990).[1]

The high-level motion system is also hypothesized to exhibit an effect of stimulus onset asynchrony (SOA) consistent with Korte's third law (Sato, 1998) which states that D_{max} increases as SOA increases (Korte, 1915). We, therefore, measured D_{max} for each of the three conditions at three different SOAs in order to explore high-level motion mechanism involvement. Throughout this study, we refer to low-level mechanisms as spatial-frequency-dependent and high-level mechanisms as feature-matching (Nishida & Sato, 1995; Sato, 1998). To clarify, this distinction differs from the stimulus-based mechanisms used by Cavanagh and Mather (1990). They describe low-level and high-level mechanisms as those involved with first-order stimuli (luminance- or color-defined) and second-order stimuli (motion- or stereo-defined), respectively. The former definition is most appropriate for this study as all motion stimuli used were first-order.

2. Methods

2.1. Subject selection

To rule out potential confounds related to maturation of performance on the D_{max} task, all children included in this study were over the age of 8 years. D_{max} for dense displays of small dots has been shown to mature at around age 7–8 years (Parrish, Giaschi, Boden, & Dougherty, 2005).

2.1.1. Control group

A total of 18 control children were tested, ranging in age from 9 to 15 years. All children included had distance and near monocular line VA equivalent to or better than, respectively, 6/6 or 0.4 M (Jose & Atcherson, 1977). Eighteen children participated in Experiment 1, and 9 of these children participated in Experiment 2. Distance line VA was measured using the Regan 96% contrast letter chart and near VA was measured using the University of Waterloo near vision test card. The Regan 96% contrast letter chart was used to measure VA because it has letter spacing designed to minimize crowding effects and has a logarithmic progression of letter size (Regan, 1988). Both acuity cut-off values represent letter size with detail of 1 min when measured at 6 m and 40 cm, respectively. Stereoacuity was required to be equivalent to or better than 40 s of arc. Stereoacuity was assessed using the Randot Stereotest (Stereo Optical Co., Inc.). All subjects had normal contrast sensitivity across a range of spatial frequencies when assessed with the Functional Acuity Contrast Test (Vistech Consultants, Inc.). No subject had a history of ocular pathology or abnormal visual development.

[1] The spatial frequency content of a random dot pattern is determined by dot size (Julesz, 1971). Altering dot probability without changing dot size does not alter spatial frequency content but reduces the overall power (energy) of the global frequency distribution which is essentially low pass with a cut-off equal to the reciprocal of the dot size (i.e. the sampling interval). Dot density of a random dot pattern can be reduced in several ways: decreasing dot probability, increasing dot size (sampling interval), or low-pass filtering (Eagle & Rogers, 1996). Each of these changes to a random dot pattern has a different effect on the cut-off and amplitude (power) of the global frequency distribution of that pattern: decreasing power in the first case, and decreasing the low-pass cut off in the latter two cases described above. In our experiments, we are manipulating dot density by decreasing dot probability in Condition 2 and increasing dot size for Condition 3, relative to the baseline condition (Condition 1).