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Treated amblyopes remain deficient in spatial vision: A contrast sensitivity and external noise study

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Abstract

To evaluate residual spatial vision deficits in treated amblyopia, we recruited five clinically treated amblyopes (mean age = 10.6 years). Contrast sensitivity functions (CSF) in both the previously amblyopic eyes (pAE; visual acuity = 0.944 ± 0.019 MAR) and fellow eyes (pFE; visual acuity = 0.936 ± 0.021 MAR) were measured using a standard psychophysical procedure for all the subjects. The results indicated that the treated amblyopes remained deficient in spatial vision, especially at high spatial frequencies, although their Snellen visual acuity had become normal in the pAEs. To identify the mechanisms underlying spatial vision deficits of treated amblyopes, threshold vs external noise contrast (TvC) functions – the signal contrast necessary for the subject to maintain a threshold performance level in varying amounts of external noise ("TV snow") – were measured in both eyes of four of the subjects in a sine-wave grating detection task at several spatial frequencies. Two mechanisms of amblyopia were identified: increased internal noise at low to medium spatial frequencies, and both increased internal noise and increased impact of external noise at high spatial frequencies. We suggest that, in addition to visual acuity, other tests of spatial vision (e.g., CSF, TvC) should be used to assess treatment outcomes of amblyopia therapies. Training in intermediate and high spatial frequencies may be necessary to fully recover spatial vision in amblyopia in addition to the occlusion therapy.

Keywords: Amblyopia; Treatment; Contrast sensitivity function; External noise; Perceptual template model; Internal noise; Perceptual template

1. Introduction

Amblyopia refers to a developmental visual disorder characterized by impaired spatial vision in the absence of any detectable structural or pathologic abnormalities that cannot be corrected by refractive means. Most researchers now agree that amblyopia is a cortical disorder (Barnes, Hess, Dumoulin, Achtman, & Pike, 2001; Daw, 1998; Kiorpes & McKee, 1999). Although only infant and young child amblyopes (<8 years) are treated in most clinical practice, often with the occlusion therapy (Ciuffreda, Levi, & Selenow, 1991; Hug, 2004), a number of reports suggest that perceptual learning – intensive practice in simple visual tasks – can significantly improve the contrast sensitivity and visual acuity in adults with amblyopia (Levi & Polat, 1996; Levi, Polat, & Hu, 1997; Polat, Ma-Naim, Belkin, & Sagi, 2004; Zhou et al., 2006).

Conventional evaluation of the outcome of amblyopia treatments has strongly emphasized tests of visual acuity. Most often, a treatment's success has been defined by reaching either a certain acuity, usually 6/9 or 6/12 (Cascairo, Mazow, Holladay, & Prager, 1997; Hiscox, Strong, Thompson, Minshull, & Woodruff, 1992; The Paediatric Eye Disease Investigator Group, 2002), 20/25 (Regan, 1988), and 6/6 (Fulton & Mayer, 1988; Lithander &

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Sjostrand, 1991; Mintz-Hittner & Fernandez, 2000), or a certain magnitude of acuity improvement (Kheterpal, Jones, Auld, & Moseley, 1996; McGraw, Winn, Gray, & Elliott, 2000; Stewart, Moseley, & Fielder, 2003). In China, achieving a 1.0 MAR or better visual acuity in the amblyopic eye marks an initial success; maintaining such acuity for more than three years qualifies the treatment as a complete success (Child Strabismus & Amblyopia. Prevention Group of Chinese Society of Ophthalmology, 1990).

Although visual acuity tests provide convenient and important evaluations of the resolution limits of spatial vision, it has long been recognized that simple assessments of photopic visual acuity may not predict an individual's performance in other spatial vision tasks, such as target detection or discrimination (Braddick, Campbell, & Atkinson, 1978; Pelli, Robson, & Wilkins, 1988; Watson, Barlow, & Robson, 1983). Many researchers have suggested that the contrast sensitivity function (CSF), which assesses spatial vision over a wide range of spatial frequencies and contrast levels, may be a better tool for detecting and diagnosing deficits in spatial vision (Della Sala, Bertoni, Somazzi, Stubbe, & Wilkins, 1985; Hess, 1979; Hess & Howell, 1977; Jindra & Zemon, 1989; Marmor, 1981; Marmor, 1986; Marmor & Gawande, 1988; Montes-Mico & Ferrer-Blasco, 2001; Wolkstein, Atkin, & Bodis-Wollner, 1980; Woo & Dalziel, 1981; Yenice et al., 2006). Models using the CSF as the front-end spatial frequency filter can account for normal human performance in a wide range of visual tasks, including letter identification (Pelli, Levi, & Chung, 2004) and face recognition (Kornowski & Petersik, 2003). In a recent analysis of 427 adults with amblyopia or with risk factors for amblyopia, McKee, Levi, and Movshon (2003) concluded that two orthogonal dimensions are needed to account for the variations in amblyopic visual performance: one relates to visual acuity measures (optotype, Vernier, and grating acuity) and the other relates to contrast sensitivity measures (Pelli-Robson and edge contrast sensitivity).

A number of practical measurement instruments have been developed to clinically assess contrast sensitivity in amblyopia (Della Sala et al., 1985; Ginsburg, 1984; Hyvarinen, 1985; Pelli et al., 1988; Regan, Giaschi, & Fresco, 1993). Rogers, Bremer, and Leguire (1987) measured contrast sensitivity of 14 anisometropic and 17 strabismic child amblyopes using the Vistech VCTS 6500-1 contrast sensitivity function board (Ginsburg, 1984) – a wall chart consisting of 40 patches of sinusoidal gratings (five sizes × eight contrast levels), each oriented at +15, 0, or −15° from vertical. Estimating contrast sensitivity from this three-alternative forced-choice identification task, they reported that a subgroup of five amblyopic patients, whose final visual acuity was 20/20 in both eyes after the occlusion therapy, exhibited significantly lower contrast sensitivity in the previously amblyopic eyes (pAEs) than in the previous fellow eyes (pFEs). Using a low-contrast visual acuity test developed for pediatric use, Regan (1988) examined a sample of 37 children (3–8 years old) who had completed occlusion therapy and 15 children (4–8 years old) who were still receiving occlusion therapy. Regan reported three patterns of visual loss: predominant loss at high-contrast acuity, fairly uniform loss at high, intermediate- and low-contrast acuity, and, in two patients, loss at low- and intermediate contrast levels, with relative sparing at the high-contrast level. The subjects in the last category would have been considered "treated" amblyopes, because their visual acuity in the high contrast test was normal. Using the Holladay Contrast Acuity Test (Stereo Optical, Chicago), Cascairo et al. (1997) found that a subgroup of five amblyopes (two anisometropic and three strabismic) with post occlusion-treatment Snellen acuity (measured in high contrast) of 20/20 in both eyes had lower contrast visual acuity (measured in low contrast) scores in the pAEs than the pFEs, although the difference did not reach statistical significance.

In summary, the literature suggests that treated amblyopes can simultaneously exhibit normal Snellen acuities but deficits in contrast sensitivity. However, these studies all used either pattern or letter charts, rather than more carefully controlled psychophysical procedures. Recently, McAnany and Alexander (2005) compared contrast sensitivity functions measured with letter optotypes and grating stimuli. They concluded that the conventional letter tests can yield misleading measures of contrast sensitivity, especially under parvocellular-mediated conditions. Ginsberg (1996) also suggested that gratings are more appropriate than letter optotypes as stimuli for measuring contrast sensitivity. Because contrast sensitivity functions might offer highly valuable diagnosis and treatment information not readily provided by acuity measures, we decided to measure contrast sensitivity functions in treated amblyopes using standard psychophysical procedures with sine-wave grating stimuli.

We recruited five treated child amblyopes (three with strabismus, one with anisometropia and one with both anisometropia and strabismus), who had successfully completed occlusion therapy, all with visual acuity around 1.0 MAR in both eyes. In addition to measuring contrast sensitivity functions in both eyes of each subject, for four of the subjects we also measured threshold vs external noise contrast (TvC) functions – the amount of signal contrast required for the observer to maintain a threshold performance level in varying amounts of external noise – for signal sine-wave gratings at several spatial frequencies.

The external noise approach allows us to de-compose contrast sensitivity in terms of intrinsic limitations of the perceptual system (Burgess & Colborne, 1988; Eckstein, Ahumada, & Watson, 1997; Lu & Dosher, 1999; Pelli, 1985; Pelli & Farell, 1999). This approach has been widely used to characterize and compare system states in normal (Levi & Klein, 1990b; Pelli, 1990) as well as amblyopic vision (Kersten, Hess, & Plant, 1988; Kiorpes, Tang, & Movshon, 1999; Levi & Klein, 1990a; Nordmann, Freeman, & Casanova, 1992; Pelli et al., 2004; Wang, Levi, & Klein, 1998; Watt & Hess, 1987). Using the external noise method, Xu, Lu, Qiu, and Zhou (2006) considered three mechanisms of amblyopia based on the perceptual template model (Lu & Dosher, 1998): increased internal