

Movement hyperacuity in childhood amblyopia

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Abstract

Background—Amblyopia results in deficits in a number of visual functions in both the amblyopic and dominant eye. The present work describes oscillatory movement displacement thresholds (OMDT) in childhood amblyopia.

Methods—The OMDT from the dominant and amblyopic eyes of 50 orthoptic patients (aged 74 (SD 16) months) were compared with those from a group of 24 controls (79 (21) months). OMDT were measured using a forced choice staircase procedure. Subjects were asked to identify which of the computer controlled monitors displayed the oscillating stimulus. Visual acuity and stereoscopic responses were noted from clinical records.

Results—Amblyopic children demonstrating stereopsis showed no significant OMDT deficit in the amblyopic eye. Those children having no stereopsis had elevated OMDT in the amblyopic eye ($p < 0.05$). Results suggest that the dominant eye of children with amblyopia may also have a pattern of visual development which is anomalous (difference in correlation coefficient with age; $p < 0.05$).

Conclusion—OMDT deficits demonstrated in some amblyopic eyes indicate that amblyopia is incompletely described by its "clinical" definition. Results suggest that the dominant eye in those with unilateral amblyopia may not be "normal".

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Monocular amblyopia, the most common cause of reduced acuity in the young,¹ is clinically defined as reduced visual acuity without evidence of organic cause resulting from unequal visual stimulation during a sensitive period of visual development.^{2,3} Estimates of the prevalence of amblyopia in the population vary between 1% and 5% depending on the patient group and criterion differences between studies.⁴ In addition, unilateral disorders are more likely to go undetected leading to prevalence underestimation. In cases of unilateral amblyopia the tacit assumption has been made that the fellow dominant (non-amblyopic) eye is normal. With amblyogenic factors affecting between 2% and 4% of the general population, amblyopia is responsible for the loss of vision in more people than all the ocular diseases and trauma combined.⁵

The main treatment for amblyopia is a period of total or partial occlusion of the dominant eye. Undoubtedly, occlusion therapy is generally successful in restoring to a greater or lesser degree at least some visual function in

amblyopic eyes.^{6,7} Although treatment may be considered clinically acceptable, any parent or child involved in occlusion therapy will testify that a great degree of tolerance is required for good compliance. Of greater clinical importance, however, is the effect of depriving a normal eye of visual stimulation during the sensitive period. A substantial number of studies have described minor deficits in the dominant eye of amblyopes including abnormal pursuit movements,⁸ reduced grating,⁹ and optotype¹⁰ resolution and vernier acuity.¹¹

Although reduced Snellen acuity is the classic clinical hallmark of amblyopia, a number of studies reveal amblyopic eyes to have deficits in other visual functions. These include contrast sensitivity in adults^{12,13} and children,^{14,15} as well as vernier acuity.^{16,17} Such findings have led to a more complex description of amblyopia as "a developmental anomaly involving primarily those cortical mechanisms involved in form and shape perception".¹⁸

Oscillatory movement displacement threshold (OMDT) is the smallest movement of a given stimulus which gives rise to the perception of movement. Studies suggest that they fall into the category of hyperacuities and have been used to describe visual deficits in diabetes mellitus,¹⁹ optic neuritis,²⁰ and glaucoma²¹ even in cases where visual acuity was normal. OMDT is also abnormal in adult strabismic and anisometropic amblyopia.²² The present study compares OMDT in children having normal binocular vision with thresholds obtained from amblyopic and dominant eyes in an age matched group having abnormal binocular vision.

Materials and methods

SUBJECTS

Amblyopic subjects were recruited from children attending the orthoptic clinic of an ophthalmology department of a general hospital and were diagnosed as having strabismic ($n = 41$), anisometropic ($n = 4$), or mixed ($n = 5$) amblyopia, the latter patients having both strabismus and anisometropia. Most ($n = 43$) had either moderate or severe amblyopia (defined as VA $< 6/9$) on initial referral and were either receiving treatment, or had received occlusion therapy in the past. The remainder had mild amblyopia (6/9 or better) which had not received treatment. Details of age at initial referral and occlusion therapy were noted. The mean age of the 50 children was 74 (SD 16) months. Informed consent was obtained from the parents of the children. The 24 age matched control subjects (mean age 79 (21) months) were either siblings of the amblyopes attending the clinics at the hospital ($n = 12$) or

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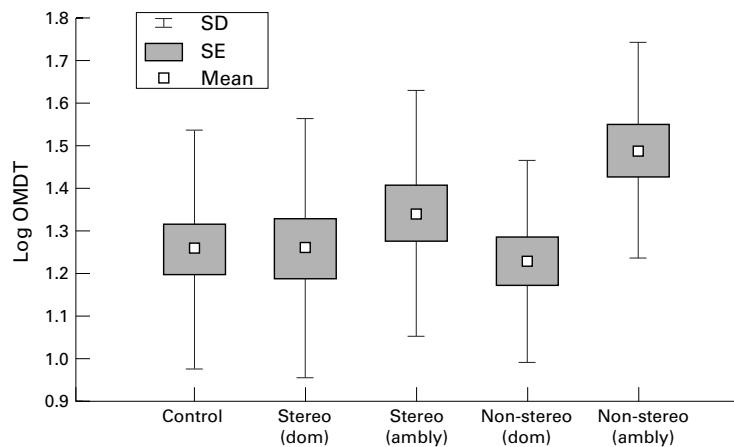


Figure 1 Mean log oscillatory movement displacement threshold (OMDT) in dominant and amblyopic eyes in stereopositive and stereonegative children compared with normal controls.

recruited from local schools ($n = 12$), who had no history of eye problems.

PROCEDURE

For the determination of OMDT the subject viewed two CRT monitors controlled by a computer. Each monitor displayed a vertical bar stimulus (10 minutes of arc wide by 100 minutes of arc high) at a 3 metre viewing distance. One of the bars (right or left at random) oscillated laterally in a sinusoidal displacement at 4 Hz. A staircase procedure was used to determine threshold using an initial amplitude of oscillation of 3 minutes of arc. Displacement oscillation was altered in response to the detection of the moving stimulus in a forced choice procedure with decreasing step size from 1 minute of arc to 1 second of arc over eight reversals, the final four reversal amplitudes being averaged to determine the OMDT. The first eye tested was varied at random. For 12 of the 24 controls both eyes were examined but for the remaining 12 only one monocular result was obtained from right or left eye, again at random.

Visual acuity (VA) results were taken from the orthoptic assessment evaluated using Snellen, Sheridan-Gardiner linear, or Sheridan-Gardiner single letter acuity appropriate for the child's age. Although logarithmic charts have significant advantages over the clinical tests used, visual acuity was not remeasured in order to avoid fatiguing the child whose OMDT was obtained immediately following the routine orthoptic appointment. The response to stereoscopic stimuli from orthoptic records was noted as "present" or "absent" for 37 of the children using the clinical tests Frisby, TNO, or Titmus fly.

Results

With logarithmically transformed data, all OMDT measures could be safely assumed to be normally distributed using the Shapiro-Wilks test for normality. The results given below are the back transformed data. Preliminary studies, together with the results from the 12 control subjects, indicated no significant

practice effect, with the first and second measurement reflecting equal performance.

OMDT IN THE AMBLYOPIC EYE

Amblyopic eyes had significantly higher OMDT (mean 25.4 seconds of arc) than the dominant eye (mean 18.3 seconds of arc; t test for dependent samples, $t_{49} = 2.85$; $p < 0.05$), agreeing with the findings of Buckingham *et al.*² in adult amblyopes.

On closer inspection it was revealed that the presence or absence of gross stereoacuity had a significant impact upon the relation between the mean OMDT in the dominant and amblyopic eyes. Children who failed to show stereopsis ($n = 17$) showed a significant OMDT deficit in their amblyopic eye compared with the dominant eye (amblyopic eye mean 30.2 seconds of arc, dominant eye 16.6 seconds of arc, $t_{16} = 3.23$, $p < 0.01$). Conversely, children demonstrating stereopsis ($n = 20$) had similar OMDT thresholds in the amblyopic (mean 21.9 seconds of arc) and dominant eye (mean 18.6 seconds of arc, $p = ns$). Results are presented graphically in Figure 1. The y scale is log OMDT (in seconds of arc).

VISUAL ACUITY

Although it may be suspected that those having deeper amblyopia might exhibit greater OMDT deficits, no significant non-parametric correlation was found between visual resolution and OMDT. Given the rather crude methods of acuity measurement and the dissimilarity of the OMDT function, perhaps it is not surprising that no relation was found.

Both the amblyopic and the dominant eyes of children who display stereopsis have significantly better visual acuities than those who do not (amblyopic eyes, median acuity with stereopsis 77 seconds of arc, without stereopsis 142 seconds of arc; Kolmogorov-Smirnov test for non-parametric independent samples, $p < 0.01$; dominant eyes, with stereopsis 64 seconds of arc, without stereopsis 84 seconds of arc, $p < 0.01$). Even given the limitations of the visual acuity measurement, this may be interpreted as further evidence that in some cases the dominant eye of amblyopes does not perform as well as may be expected.

OMDT IN THE DOMINANT EYE

The mean OMDT of the dominant eye of all amblyopes had equable thresholds to the monocular controls (dominant eye mean 18.3 seconds of arc; control eye mean 17.9 seconds of arc, t test for independent samples, $p = ns$). However, examination of Figure 2 reveals a slightly more complex pattern than that which may be assumed from the mean thresholds. The relation between OMDT and age for the fixing eyes differs from either the amblyopic or normal control eyes, which show a significant and well correlated improvement with age over the range measured (dominant eye $r = -0.017$, $p = ns$; amblyopic eyes $r = -0.31$, $p < 0.05$; control eyes $r = -0.48$, $p = 0.018$). The thresholds obtained in the dominant eye are not related to the age of the child (see Fig 2).

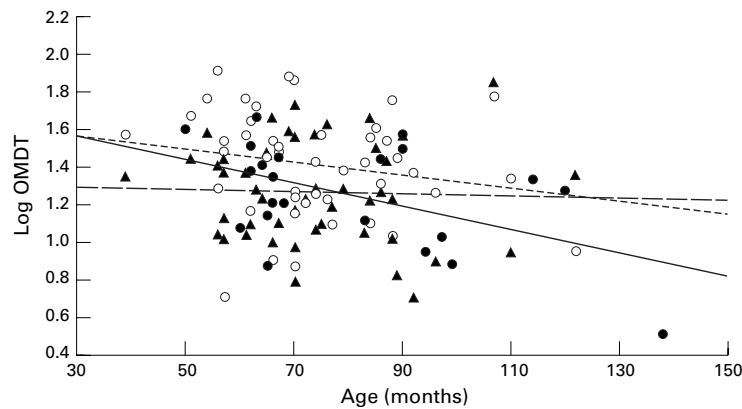


Figure 2 Log oscillatory movement displacement threshold (OMDT) shown as a function of age for amblyopic (○), dominant (▲) and normal control eyes (●). Best fit lines are drawn for normal control (solid line) and amblyopic (dotted line) eyes, which show significant correlation with age. There is no significant correlation between OMDT and age in dominant eyes, although an indication of the best fit line is given (broken line).

The correlation of OMDT with age in the dominant eyes of children who display gross stereoscopic responses on commonly used clinical tests is significantly different from that of control eyes (stereopositive dominant eyes $r = 0.24$, $p = \text{ns}$; correlation difference $p = 0.021$). No such difference was found in the absence of stereoscopic responses.

The performance of amblyopic and dominant eyes in children who had undergone patching was comparable with that of children who had received no treatment. Nor was there any evidence that the age at referral or visual acuity at the time of testing significantly affected OMDT.

Discussion

OMDT IN AMBLYOPIC EYES

The data presented demonstrate a deficit in OMDT in the amblyopic eyes of children, in agreement with deficits described in adult amblyopia²² and other visual functions described in the introduction.¹²⁻¹⁷ The underlying changes in anatomy and physiology in amblyopia are still somewhat unclear, while their relation with anomalies in demonstrated visual function is even more ambiguous.

Unilateral visual deprivation results in substantial changes within the neural visual pathways²³ with a marked shift in ocular dominance towards cortical cells that are monocularly driven by the dominant eye. Binocular deprivation does not result in overall atrophy, as may be anticipated, but with a more "normal" distribution of monocularly and binocularly driven cells, and it seems that anatomical changes may be due less to stimulus deprivation than the effect of binocular competition.

The presence of gross stereopsis indicates a reasonable degree of binocular integration and those children demonstrating stereopsis had equal OMDT thresholds in the amblyopic and dominant eyes. In contrast, children displaying no stereopsis—that is, those with the greatest binocular competition, had significantly reduced thresholds in the amblyopic eye.

OMDT and stereoscopic responses are both thought to be primarily mediated by the mag-

nocellular pathways.²⁴ In contrast, visual acuity is served by the parvocellular system. Our results may suggest that, regardless of the deficits demonstrated in the parvocellular system, the status of the magnocellular system produces degraded stereopsis and OMDT in some children, but normal OMDT in others. There is evidence that, in humans, the magnocellular and parvocellular pathways have differential development²⁵ and may well have different sensitive periods.

In macaques, it seems that the later the time of onset of deprivation, the less marked is the bias towards the dominant eye²⁶ with deprivation in adult monkeys causing no disturbance. This led to the establishment of the concept of the sensitive period. It is during this sensitive period that the main treatment for amblyopia—namely, occlusion therapy, is thought to have the best prognosis. Occlusion of the good eye, particularly during the sensitive period, usually results in an improvement in the vision of the amblyopic eye⁶ presumably by breaking down the competitive input from the dominant eye.

It is generally accepted that the younger the patient the greater the optimism for a good prognosis, hence the emphasis on preschool vision screening.²⁷ In addition to the cosmetic factors associated with strabismic amblyopia, the social implications for the sufferers of amblyopia include restricted career option and, of greater clinical concern, the conclusion that patients with amblyopia are at increased risk of blindness.²⁸

Despite the well founded anatomical background of the importance of early detection, the sensitive period for reversal of amblyopia remains contentious. A retrospective study by Epelbaum *et al*³ demonstrated that the efficacy of the treatment depended on the age at the start of the treatment and was maximum if initiated before 3 years. By 12 years, recovery of acuity was negligible. Rutstein and Fuhr⁶ described better success rates for children under 8 years of age though no child over 10 years attained acuity levels better than 6/12. In contrast, there are descriptions of adults and older children who, by design or default, have been forced into using their amblyopic eye for fixation²⁹⁻³¹ and have experienced significant improvement in visual acuity at more mature ages. Animal models have shown a good recovery of resolution acuity despite relatively late reverse occlusion and persistent cortical abnormality²⁴ raising an important point regarding the differences between functional and anatomical recovery—that of the complexity of the relation between anatomical and displayed behavioural effects of deprivation.

Amblyopia is usually measured in terms of visual acuity, though differences in the developmental pattern of a variety of visual functions are well founded. The onset of binocular correlation, for example, is substantially different from that of stereopsis.³² Anatomically, different parts of the visual system display differing degrees of plasticity, the retina showing no effect of experimental deprivation and the striate cortex displaying much more dramatic

abnormal responses than the lateral geniculate nucleus with early manipulation. Even within the striate cortex, animal studies have established that different layers of striate cortex develop at different rates.³³ The idea that functional specialisation occurs within the visual cortex is well documented²⁵ and it seems plausible that a different sensitive period for normal movement displacement thresholds may result in permanent degradation of these thresholds while reduced visual acuity, processed in a different way, may still be reversible.

The disparity between visual acuity, other visual thresholds, and the underlying anatomy suggests that resolution acuity, used as a test of functional recovery, is unsuitable as an overall descriptor of amblyopic abnormality. Other measures, such as OMDT, may be more sensitive to neural changes than are resolution measures and may, therefore, describe visual loss which is not immediately apparent from Snellen acuity. Indeed, presented results show no relation between the visual acuity and OMDT (even taking into consideration the limitations imposed by the resolution measurement technique) and may be reflective of this.

OMDT IN THE DOMINANT EYE OF AMBLYOPIC CHILDREN

In common with other studies⁸⁻¹¹ presented, results suggest that there may be some differences in the dominant eye of the amblyopic subjects in comparison with control eyes. The cause of these differences remains a matter for speculation. Although mean OMDT was not significantly different, the control eyes improve significantly with age (as do the amblyopic and binocular functions), while the thresholds of the dominant eye of the amblyopes without stereopsis do not. The cause of these deficits is speculative. A reduction in visually evoked potential responses from the fixing eye (latency and amplitude) has been shown during the course of occlusion therapy in 5-6 year olds³³ and visual acuity in the dominant eye was noticeably reduced, albeit temporarily, at the end of periods of full time occlusion in children up to 12 years of age.³ Giasche *et al*³⁴ found that children with amblyopia demonstrated deficits in their motion defined form processing in the dominant eye while adult amblyopes displayed no such difficulty. Illustrations of visual function changes occurring on cessation of occlusion therapy have been reported. It is well known that a regression occurs in many treated amblyopic eyes to a greater or lesser extent on cessation of occlusion³⁵ and the visual acuity loss reported by Epelbaum *et al*³ in the occluded eye was only temporary. Although the worst possible outcome of occlusion therapy has to be occlusion amblyopia the relation between occlusion and dominant eye deficiency is very unclear. Lewis *et al*³⁶ found no relation between duration of patching and visual function in the dominant eye and Leguire *et al*³⁷ described deficits in fellow eyes which have never undergone patching. Most of the children in this study had undergone

occlusive therapy and it is tempting to speculate that, in the absence of stereopsis, the OMDT in the dominant eye may be affected by the treatment. However, no evidence was found that the vigour or duration of patching had any effect. This may support the alternative theory of dominant eye deficit—that is, that amblyopia is a disruption occurring at cortical levels. Abnormalities are, therefore, likely to be demonstrated in both amblyopic and dominant eyes. It seems possible that a combination of underlying anomaly and occlusive intervention may be the reason why dominant eyes do not perform as “normal” in the short and long term.

Two main findings arise from the present data. Firstly, that OMDT is significantly reduced in amblyopia when binocular interaction is sufficiently disrupted to prevent stereopsis. Secondly, that the presence of gross stereoacuity may also indicate anomalous OMDT in what, otherwise, would be considered to be the “normal” eye. These conclusions are in support of the growing evidence that amblyopia is incompletely described by its “clinical” definition and that deficits in the dominant eye may be demonstrated by strict psychophysical examination.

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