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Stereoacuity and Binocular Visual Acuity in Prism-Induced Exodeviation

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Abstract

Background—Intermittent exotropia may be controlled by accommodative or motor convergence. Previous studies have reported that reduced binocular visual acuity in intermittent exotropia is due to the accommodation required to control the deviation. In order to test this hypothesis, we simulated convergence stress by inducing exodeviations in normal volunteers to investigate whether the transition from non-fused to fused is associated with a gradual or immediate transition in stereoacuity and binocular visual acuity.

Methods—Convergence stress was induced in 25 visually normal adults with 40pd base out prism and reduced stepwise in increments of 5pd until 20pd, and 2pd thereafter. Stereoacuity (Frisby Davis Distance (FD2) and the Distance Randot (DR)) and binocular visual acuity were measured at each step. For each subject, the recovery of fine stereoacuity (less than or equal to 60 seconds of arc) was categorized as immediate (nil to fine) or gradual (nil to moderate to fine).

Results—24 of 25 (96%) showed gradual recovery of fine stereoacuity on either FD2 or DR. Median binocular visual acuity at baseline, first level of fusion, and subsequent levels was 20/15.

Conclusion—Under convergence stress, the transition from non-fused to fused is accompanied by a gradual recovery of fine stereoacuity in most individuals, consistent with some studies of patients with intermittent exotropia. Nevertheless, this degradation of stereoacuity was not associated with decreased binocular visual acuity, suggesting that accommodative convergence may not be recruited to restore and maintain binocularity under conditions of convergence stress.

Introduction

The most common form of exotropia is intermittent exotropia occurring in approximately 1% of children.¹ In intermittent exotropia, manifest divergent misalignment is most often seen for distance fixation but may also occur at near fixation. Defining the severity of intermittent exotropia is controversial,² but probably requires consideration of the angle of deviation, binocular function, and control (the proportion of time the deviation is manifest and the ease of re-fusion after dissociation). There is currently no good understanding of the relationship between these parameters.

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No conflicting relationships exist

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It has been suggested that for an individual patient with intermittent exotropia, as control deteriorates, distance stereoacuity deteriorates.³ Others report distance stereoacuity to be either dichotomously normal or absent in intermittent exotropia.⁴ In order to model what might be occurring in patients with deteriorating intermittent exotropia, we designed an experiment in which we induced exodeviations using base out prism in normal adults. We specifically investigated whether degradation of distance stereoacuity occurred and if recovery was an immediate or gradual process as the magnitude of the exodeviation was reduced. We postulated that prism induced exodeviations would stress the convergence system, and in some ways, mimic intermittent exotropia.

The mechanism for degraded distance stereoacuity in intermittent exotropia has been suggested to be control of the deviation by accommodative convergence which secondarily reduces binocular visual acuity.⁵ We therefore measured binocular visual acuity, in addition to distance stereoacuity, to investigate whether prism induced exodeviations are controlled by accommodative convergence.

Subjects and Methods

Subjects

Twenty-five subjects aged 18 and older with normal stereoacuity (at least 40 seconds of arc assessed by Preschool Randot®), normal visual acuity (best corrected acuity 20/20 Snellen or better in each eye; interocular difference of less than or equal to one line), no prior history of amblyopia and no strabismus or strabismus surgery, were enrolled in the study. Informed consent was obtained from each study participant. The study was approved by an institutional review board and data were collected in an American Health Insurance Portability and Accountability Act compliant manner.

Methods

Induction of Exodeviation (Convergence Stress)—For each subject, exodeviations were induced with base out prisms worn in trial frames or clipped over the patients' glasses. We postulated that these exodeviations would stress the convergence system. Subjects with spectacles were tested with habitual optical correction in glasses or contact lenses. The initial level of testing of 40 prism diopters (pd) of exodeviation was achieved by placing a 20 pd prism over each eye. Trial lens prisms were used for testing. Subsequent levels of 35, 30, 25, 20, 18, 16, 14, 12, 10, 8, 6, 4, 2 pd and then 0 were tested by placing 1 or 2 prisms of equal, or near equal, magnitudes in the trial frames. Testing was performed in this order (highest to lowest prism) to reduce the potential bias of remembering the stereo targets of the Distance Randot® tests between tests. Presence/absence of diplopia, control of exodeviation, binocular visual acuity, and distance stereoacuity were assessed at each level using a standardized protocol as detailed below. Testing started immediately on placement of the prisms with no period of adaptation. Nevertheless, since control was assessed first, there was approximately one minute before binocular visual acuity and stereoacuity testing began. Subsequent prisms were placed immediately without any period of recovery between tests. The entire testing protocol took 60–90 minutes.

Measurement of Stereoacuity—Distance stereoacuity (3 meters) was evaluated using both the Frisby Davis Distance test (FD2) and the Distance Randot® test (DR). Other tests of distance stereoacuity were not used (e.g. Baylor Visual Acuity Tester or the American Optical Vectograph) due to relative general unavailability of these tests. FD2 stereoacuity was tested at 200, 160, 80, 40, and 20 seconds of arc (arcsec) using the method of Holmes and Fawcett⁶ with a monocular phase at 200, 160, and 80 arcsec. The only difference to the Holmes

and Fawcett testing procedure was that the first time we tested at 200 arcsec, 4 of 4 correct were required to pass to reduce the likelihood of correctly guessing to one in 256.

The DR⁷ was assessed at disparities of 400, 200, 100, and 60 arcsec at 3 meters. Two correct responses at each disparity level were required to pass each level.⁷ Testing stopped when an incorrect response was given at any level. Test booklets were folded in half so that only 1 image was visible at any given time in an effort to reduce association between images at any given level, thus reducing the ability to pass a level by guessing.

Testing of stereoacuity at the initial 40pd level started with the greatest disparity (200 arcsec for the FD2 and 400 arcsec for the DR). For subsequent prism steps, stereoacuity was tested starting one step greater than passed with the previous prism, or with the greatest disparity. If a subject transitioned from double to single (not fused to fused) during testing at a given level of prism, stereoacuity was retested. If a subject was single and detected the finest disparities on both the FD2 and the DR for two consecutive prism magnitudes, testing was stopped.

Evaluation of Control—Control of exodeviation was evaluated at each prism step for distance only (3 meters) using the Mayo Control Score,⁸ a six point scale quantifying control from 0 (phoric) to 5 (constantly tropic). Level 1 is refusion in 1–5 seconds after a standard 10 second cover. Level 2 is refusion in greater than 5 seconds after a standard 10 second cover. Level 3 is tropia less than 50% of the time during a standard 30 second observation. Level 4 is tropia greater than 50% of the time during a standard 30 second observation. The target used for this assessment was a 20/200 E at 3 meters.

Measurement of Visual Acuity—Visual acuity was measured in the subjects' habitual spectacle correction (if any) with both eyes open using linear Snellen type optotypes on a Baylor Visual Acuity Tester at each prism step tested. The visual acuity was recorded as the lowest level where at least half the letters were correctly identified. When the subject was fusing, this would be correctly termed binocular visual acuity, but under higher prism strengths, subjects had diplopia and therefore such measurements represent monocular visual acuity of the fixing eye.

We did not measure cycloplegic refractive error in each of our subjects because we did not believe that latent hypermetropia would influence our results. We measured the visual acuity at every prism step, specifically to assess whether accommodation was being used to control the exodeviation. Accommodation would manifest as blur on a distance target, whether or not there was latent hypermetropia. Latent hypermetropia would only be an issue if the subject were using his or her entire accommodative reserve to clear a distance target. Since none of our subjects had symptoms of near blur prior to or after the study, we can assume that none were using their entire accommodative reserve to clear a distance target, and therefore, our experimental design allows us to test the hypothesis that exodeviations are controlled by accommodative convergence.

Statistical Analysis—Distance stereoacuity scores were grouped into three categories, fine, moderate, and nil. Stereoacuity was classified as “fine” if less than or equal to 60 arcsec, “moderate” if greater than 60 arcsec and less than or equal to 200 arcsec, or “course/nil” if greater than 200 arcsec or unable to pass any level. Recovery of stereoacuity in subjects was categorized as “immediate” if fine stereoacuity was achieved at the first level of fusion (Figure 1), otherwise recovery was categorized as “gradual” when the stereoacuity recovered to moderate before fine (Figure 2).

Each subject was classified as “immediate” or “gradual” on the FD2 and the DR: the proportions of “gradual” and “immediate” recoveries on each test were compared using

McNemar's test. The prism magnitudes at which fine stereo was first achieved with the FD2 and the DR were compared by a Wilcoxon signed-rank test.

In order to further examine the recovery of fine stereoacuity, we looked at the proportion of fine, moderate and nil distance stereoacuity at first fusion and incrementally-reduced prism magnitudes thereafter. Subjects were compared by nominally setting the point of first fusion (recovery of single vision) at zero. This allowed comparison of subjects despite fusion being achieved at different magnitudes. The increments were dictated by the subsequent lower magnitude: most were even-numbered integers; odd-numbered increments were rounded up to the nearest even integer for analysis due to the low number of patients at odd integers. In this analysis of proportions, using data with a low denominator might yield non-representative proportions, so rather than omit these data, we combined them with the nearest even integer data.

Results

Twenty-five subjects aged 20 to 44 years (median age = 25 years) were enrolled in the study. Fourteen (56%) were male and 20 (80%) were Caucasian. As expected, all subjects were diplopic with 40pd base out prism.

Recovery of Distance Stereoacuity with Decreasing Convergence Stress

Most subjects had a gradual recovery of stereoacuity. Twenty-four out of 25 (96%) showed gradual recovery of distance stereoacuity on either the FD2 or the DR. A greater proportion of subjects had gradual recovery (23 of 25 (92%) as measured with the FD2 (Figure 3) and 14 of 25 (56%) as measured with the DR) (Figure 4) ($p=0.007$, McNemar test). An immediate recovery occurred in two of 25 subjects (8%) with the FD2 and 11 of 25 (44%) with the DR. The median stereoacuity at initial fusion was similar between FD2 and DR (median 160 arcsec for the FD2 and 100 arcsec for the DR ($p=0.7$), range 20 arcsec to nil for the FD2 and 60 arcsec to nil for the DR). Subjects achieved fine distance stereoacuity at a median of 4pd higher on the DR than the FD2 (quartiles -2pd and 8pd, $p=0.07$, Wilcoxon signed rank).

Prism Magnitude at First Fusion

Overall, the median prism at which recovery of single vision occurred was 20pd (quartiles 16pd, 20pd, range 10pd-30pd) for both the FD2 and DR. We compared the median prism power at the point of recovery of single vision between patients with immediate ($n=11$) and gradual ($n=14$) recovery on the DR. This analysis was not done with the FD2 due to the small number of subjects with immediate recovery on the FD2. Recovery of stereoacuity occurred earlier in those that were gradual than those who were immediate (median 20pd vs. 16pd, range: 14–30 vs. 10–20, $p=0.02$, Wilcoxon signed rank).

Control

While seeing double, each subject had a control score of 5 (constant tropia during a 30 second observation period). At the first level of prism at which recovery of single vision occurred, each subject had a control score of 1 (1–5 second re-fusion after a 10 second cover). For the remainder of the prism levels, subjects had control scores of either 1 or 0. Interestingly, no subjects had a control score of 2, 3, or 4 (intermittently tropic or slow recovery when dissociated).

Visual Acuity with Decreasing Convergence Stress

Median binocular visual acuity at baseline (no convergence stress) was 20/15 (range 20/15 to 20/20). While diplopic median visual acuity was 20/20 (range: 20/15 to 20/30). At initial fusion

(maximal convergence stress) and at all subsequent levels after fusion (decreasing convergence stress), median binocular visual acuity remained 20/15 at all steps.

Discussion

By experimentally inducing exodeviations in normal subjects, we found that stereoacuity was reduced (rather than normal) at the point of first fusion in most subjects, and that this was not associated with reduced binocular visual acuity.

Under conditions of convergence stress, one plausible mechanism of maintaining binocularity is increased accommodative convergence.^{5,9} If accommodation is used, then we would expect reduced distance binocular visual acuity, and this has been reported in a subset of patients with intermittent exotropia.⁵ Nevertheless in our study, we found that while subjects displayed decreased stereoacuity, median binocular visual acuity was 20/15 suggesting that accommodative convergence is not recruited in controlling exodeviations. It is accepted that convergence of the visual axes and accommodation are not inextricably linked,¹⁰ and in our study, normal subjects with prism-induced exodeviations use a mechanism of convergence that does not include accommodative convergence.

Other mechanisms of reduced stereoacuity under conditions of convergence stress are possible. Temporary anomalous retinal correspondence (ARC) has been described in normals undergoing forced convergence.^{11, 12} Studies of increasing convergence stress have reported reduced levels of stereoacuity and proposed that small shifts in retinal correspondence can occur without disrupting Panum's fusional process.^{11, 12} Such ARC could explain degraded stereoacuity to moderate levels. Our study did not specifically address whether temporary ARC-like change occurred in our subjects.

Another possible explanation for reduced stereoacuity under forced convergence is a temporary compromise of fine motor adjustments necessary for fine stereopsis. This mechanism has been proposed by Mireskandari¹³ et. al. in patients with macular hole and Holmes et. al. in intermittent exotropia.¹⁴ In our otherwise normal subjects, such a temporary compromise of fine motor fusion may explain why most subjects in our study achieved only moderate stereopsis at initial fusion.

The observation that some subjects had gradual recovery of distance stereoacuity while others had immediate recovery suggests that there may be individual variability in mechanisms of recovery. The mechanisms of some resulted in partially degraded stereoacuity and others resulted in immediate recovery of fine stereoacuity. The eleven subjects who had immediate recovery of stereoacuity on the DR fused at lower levels of convergence stress than those who had a gradual recovery (median of 16pd for immediate, versus median of 20pd for gradual). This suggests that more of those who fused under conditions of greater convergence stress used mechanisms that diminished their ability to perceive fine disparities. Further work is needed to determine whether individuals use different mechanisms to control or to maintain alignment under conditions of convergence stress.

Another interesting finding was that performance on the FD2 differed from performance on the DR. Under equal amounts of convergence stress, subjects were more likely to achieve fine stereoacuity on the DR than the FD2. This would not have been predicted based on a prior study of patients with intermittent exotropia that reported better distance stereo performance on the FD2 than the DR.¹⁴ One potential explanation for this discrepancy may be the difference in disparities tested. The smallest disparity measurable on the current version of the DR is 60 seconds of arc, rather than 40 and 20 seconds of arc on the FD2, and we did not test 60 seconds of arc on the FD2. Therefore, subjects had to perceive smaller disparities on the FD2 in order to achieve "fine stereoacuity." Another possibility for this discrepancy between the FD2 and

the DR is testing order. The FD2 was tested first, possibly allowing for adaptation and better DR performance. The issues of testing order and adaptation could be addressed in future studies.

It is unknown whether our experimental paradigm of base-out prism-induced convergence stress in normals represents the clinical condition of intermittent exotropia. Control of the exodeviation in our subjects only appeared to represent the extremes of intermittent exotropia, those who were constantly tropic (control score = 5) or those with good control (control scores of 0 or 1). Since our model did not induce intermediate control in normals, its direct applicability to patients with intermittent exotropia may be limited. In addition, there appears to be a subgroup of patients with intermittent exotropia who have limited or no capacity for stereoacuity,⁴ and clearly our model does not represent this group. Nonetheless, our experiment did induce exodeviations associated with convergence to maintain fusion, and it seems to be plausible that patients with intermittent exotropia experience similar conditions. In addition, patients with intermittent exotropia tend not to experience diplopia when tropic, in contrast to our subjects, and therefore the stimuli to fuse may differ.

Future studies of prism-induced convergence stress in strabismic and non-strabismic subjects are needed. Our study would have been strengthened by repeat evaluation of immediate recovery vs. gradual recovery, but it is still noteworthy that some subjects had gradual and some had immediate recovery. A future study with reversed test order so that the DR is tested prior to the FD2 would determine if adaptation occurs during testing, such that smaller disparities are detected with the second test. Reversing the order of prisms tested from least to greatest may more realistically emulate a decompensating intermittent exotropia over time. Also, repeating the study in patients with intermittent exotropia would further elucidate the relationships between controlling exodeviations, stereoacuity, and binocular visual acuity.

Most normal subjects controlling prism-induced exodeviations display a gradual recovery of stereoacuity. Our study suggests that the use of accommodative convergence does not explain decreased stereoacuity when induced exodeviations are controlled.

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Figure 1.

A typical example of immediate recovery of distance stereoacuity as tested on either the Frisby Davis Distance or the Distance Randot. Stereoacuity at the level of first fusion (single vision) was ≤ 60 seconds of arc ("fine").

Figure 2.

A typical example of gradual recovery of distance stereoacuity as tested on either the Frisby Davis Distance. Stereoacuity at the level of fusion (single vision) was > 60 seconds of arc ("moderate").

Figure 3.

Proportion of subjects with fine (≤ 60 seconds of arc), moderate (80–400 seconds of arc), and nil stereoacuity measured with the Frisby Davis Distance, plotted in relation to their first level of fusion (single vision).

Figure 4.

Proportion of subjects with fine (≤ 60 seconds of arc), moderate (80–400 seconds of arc), and nil stereoacuity measured with the Distance Randot, plotted in relation to their first level of fusion (single vision).