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Fusional convergence in childhood intermittent exotropia

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Abstract

Purpose—To evaluate fusional convergence and associations with control in children with intermittent exotropia (XT).

Design—Retrospective case series

Methods—Sixty-four children (median age 7 years) with intermittent XT were identified with measures of angle of deviation, control (using a previously reported 0-to 5-point scale) and fusional convergence at a single examination. Total convergence was defined as the sum of the angle of deviation plus additional convergence in reserve. Mean values were compared with published normals. A fusion reserve ratio was calculated as “convergence reserve divided by angle of deviation.” Relationships of control score with total amplitude, reserve, recovery, and fusion reserve ratio were assessed using Spearman rank correlations.

Results—Convergence differed from normals in children with intermittent XT: total convergence was higher at distance (33 prism diopters [pd] vs 17 pd, $P < 0.0001$) and near (38 pd vs 18 pd, $P < 0.0001$) whereas convergence reserve was lower at distance (7 pd vs 17 pd; $P < 0.0001$). There was a strong correlation between fusion reserve ratio and control score at distance ($R = -0.75$, $P < 0.0001$) and near ($R = -0.66$, $P < 0.0001$).

Conclusions—Children with intermittent XT have subnormal convergence reserves at distance. The fusion reserve ratio correlates well with control and may be useful in grading the severity of intermittent XT.

Assessing fusional vergences may be important in the clinical evaluation of ocular misalignment because it provides information regarding a patient's ability to ‘control’ a latent or intermittent deviation.^{1, 2} In intermittent exotropia (XT), control of the exodeviation may rely on fusional convergence (positive fusional vergence). The ease with which a patient with intermittent XT maintains control of the exodeviation is currently used as an important indicator of severity³⁻⁹ and the finding of poor control is considered an indication for surgical intervention.^{3, 4, 6} Previous studies of intermittent XT have reported different methods for quantifying a patient's ability to control, rating persistence of the exotropia or time to recovery of motor fusion.¹⁰⁻¹⁴ Nevertheless, there are few studies examining associations between fusional convergence and control of the exodeviation in intermittent XT. Convergence has been considered to be normal in children with intermittent XT¹⁵ which would seem to be inconsistent with the hypothesis of a correlation between

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control and fusional convergence. In this present study, we investigate total fusional convergence amplitudes, fusional reserves and fusion recovery in children with intermittent XT, and correlate these measures with exodeviation control.

Methods

Children with intermittent exotropia

Sixty-four children with intermittent XT (aged 3 to 17, median 7 years) and measures of angle of deviation, control, and fusional convergence at a single office exam, were identified in the author's clinical practices. Visual acuity was required to be 20/40 or better in each eye for inclusion (median 20/20, range 20/15 to 20/32 in each eye). We excluded children with convergence insufficiency type intermittent exotropia (near angle more than 10 prism diopters [pd] greater than distance) and those with developmental delay or sensory or paralytic exotropia. Fifty-three (83%) were female, consistent with previously reported female predominance of intermittent exotropia,¹⁶ and race was reported as 'white' for 51 (80%).

Testing procedures

All clinical testing was performed with refractive correction if prescribed (21 (33%) of 64 children), which in all cases was the child's habitual spectacle correction; trial frames were not used. Tests were performed in the following order: control of the exodeviation, angle of deviation, and fusional convergence.

Assessment of control and angle

Control of the exodeviation was quantified using a previously reported 0- to 5-point scale (best to worst control) at distance (3 meters) and then at near (1/3 meter).¹⁴ Levels 3 to 5 on the scale grade the proportion of time any spontaneous exotropia is present during a 30-second period of observation (5= constant tropia) and levels 0 to 2 grade the speed of recovery after a 10-second dissociation (worst of three 10-second dissociations; 0= <1 second recovery).¹⁴ If control was measured more than once over the exam, the worst measure was used for analysis. Median control scores in our cohort of 64 children were 4 (range 0 to 5) at distance and 1 (range 0 to 5) at near.

The angle of deviation was assessed using prism and alternate cover testing at distance (3 meters) and then at near (1/3 meter), and recorded in prism diopters (pd). The median angle of deviation by prism and alternating cover test was 25 pd (range 12 to 45 pd) at distance and 16 pd (range 0 to 40 pd) at near.

Assessment of fusion

Fusional convergence amplitudes were assessed using a 1 to 40 pd fixed horizontal prism bar. An accommodative target was used first at distance (3 meters) and then at near (1/3 meter). To determine the fusional convergence break point, base-out prism was gradually increased, starting with 1 pd, until an exotropia developed with no subsequent recovery of motor fusion. A short time was allowed for spontaneous recovery of fusion after an exotropia occurred. The fusional convergence break point was recorded as the base-out prism strength at which an exotropia developed and could not be re-fused. Base-out prism was then gradually decreased until the induced exotropia could be fused. The prism strength at which re-fusion occurred was recorded as the fusion recovery point. Since children with intermittent XT are often not aware of diplopia when exotropic, convergence break point and recovery point were confirmed by brief cover tests when necessary. Patients who remained fused at 40 pd (8 (13%) of 64 patients, at near only) were arbitrarily assigned a break point of 45 pd for the purposes of analysis, but because it is not possible to determine

the fusion recovery point for these patients, they were excluded from any analysis of recovery. If there was no ability to fuse the exodeviation at the commencement of fusional convergence testing, break point and recovery point were recorded as 0 (total n=17: n=12 at distance only, n=3 at distance and near, and n=2 at near only). All patients were able to demonstrate motor fusion at some point during the examination, but were not necessarily able to fuse at the time of fusional convergence testing.

For this present study of convergence in intermittent XT, we used the following terms and definitions: 1) Patients able to control or motor fuse the exodeviation in free space were assumed to have convergence fusion at least equal to the magnitude of the measured *angle of deviation*; 2) Additional convergence fusion (superimposed on ability to fuse the exodeviation) was measured by determining the fusion break point and termed *convergence reserve*; 3) The sum of the angle of deviation and the convergence reserve was termed the *total convergence amplitude*.

Analysis

Mean and median total fusional convergence amplitude, fusional convergence reserve and fusion recovery were calculated for children with intermittent XT. Values in children with intermittent XT were then compared to previously reported mean values for normal, non-strabismic children¹⁷ using t-tests. Due to low convergence reserves possibly confounding analysis of fusion recovery we also analyzed recovery in a sub-group of patients with at least 10 pd of convergence fusion reserve. The proportion of subjects recovering fusion within 5 pd of the break point were calculated for distance and near. Fusion values for visually normal children were derived from published data¹⁷ from subjects with orthophoria or very small degrees of heterophoria and therefore the reported break point was used to represent both the total fusional amplitude and the fusion reserve.

For children with intermittent XT, correlations of control score with total convergence amplitudes, convergence reserve, and convergence recovery were calculated using Spearman rank correlations. To assess the effect of the underlying angle of deviation, a fusion reserve ratio was calculated as fusional convergence reserve divided by prism alternating cover test (e.g. fusional convergence reserve = 20; angle of deviation = 15; fusion reserve ratio = 1.3). It has been suggested that the fusion in reserve should be twice the magnitude of the angle of deviation (Sheard's criterion)¹⁸ which would correspond to a fusion reserve ratio of 2.0. Spearman rank correlations between fusion reserve ratio and control score were calculated and control scores for patients meeting Sheard's criterion were evaluated. Correlations between angle of deviation and control score were also analyzed.

Results

Children with intermittent XT compared with visually normal children

At both distance and near, the mean total convergence amplitude was significantly greater for children with intermittent XT than for visually normal children (distance: 33 ± 11 pd vs 17 ± 7 pd, $P < 0.0001$; near: 38 ± 13 pd vs 18 ± 8 , $P < 0.0001$, Figure 1). In contrast, mean convergence reserves, were significantly lower at distance fixation for children with intermittent XT than for visually normal children (7 ± 8 pd vs 17 ± 7 pd, $P < 0.001$, Figure 2) but at near fixation there was no difference between children with intermittent XT and visually normal children (21 ± 14 pd vs 18 ± 8 pd, $P = 0.054$, Figure 2). Mean fusion recovery point was significantly lower at distance for intermittent XT children than for visually normal children (2 ± 5 pd vs 11 ± 6 pd, $P < 0.0001$, Figure 3) but there was no difference between children with intermittent XT and visually normal children for mean fusion recovery at near fixation (11 ± 10 vs 13 ± 6 , $P = 0.2$, Figure 3). Of the 22 patients with ≥ 10

pd of convergence reserve at distance, only 8 (36%) recovered within 5 pd of the break point. At near, of the 41 with ≥ 10 pd of convergence reserve at near (and a measured recovery point), only 12 (29%) recovered fusion within 5 pd of the break point.

Correlations between fusional convergence and control score in children with intermittent XT

There was a strong inverse correlation between convergence reserve and control score (i.e. higher reserves associated with lower [better] control scores and vice versa) at distance ($R = -0.75$, $P < 0.0001$) and a moderate correlation at near ($R = -0.57$, $P < 0.0001$, Table 1).

There was a moderate inverse correlation between total fusional convergence amplitude and control score (i.e. higher amplitudes associated with lower control scores and vice versa) at distance ($R = -0.54$, $P < 0.0001$), and a poor correlation at near ($R = -0.30$, $P = 0.02$). There was also a moderate inverse correlation between fusion recovery point and control (i.e. higher recovery point associated with lower [better] control scores and vice versa) both at distance ($R = -0.57$, $P < 0.0001$) and near ($R = -0.58$, $P < 0.0001$, Table 1).

Fusion reserve ratio

Median fusion reserve ratios were 0.07 (range 0.0 to 2.5) at distance and 1.6 (range 0.0 to 30.0) at near. There was a strong inverse correlation between fusion reserve ratio and control score (i.e. higher fusion reserve ratio associated with lower control scores and vice versa) at distance ($R = -0.75$, $P < 0.0001$, Table 1) and at near ($R = -0.66$, $P < 0.0001$, Table 1). At distance, only 2 (3%) of 64 patients met Sheard's criterion (a fusion reserve ratio of ≥ 2.0) and both had good control (1 on the control scale). At near, 28 (44%) of 64 patients met Sheard's criterion: 26 of 28 showed good control (0 or 1 on the scale); one patient showed moderate control (2 on the scale) and one showed poor control (4 on the scale). The fusion reserve ratio was correlated to fusion recovery point at distance ($R = 0.56$, $P < 0.0001$) and near ($R = 0.80$, $P < 0.0001$).

Angle of deviation

There was a correlation between near angle of deviation and near control score ($R = 0.54$, $P < 0.0001$) but there was no correlation between distance angle of deviation and distance control score ($R = 0.03$, $P = 0.8$). There was no correlation between distance convergence reserve and distance angle ($R = 0.005$; $P = 0.97$, Table 1) and there was an inverse correlation (i.e. smaller fusion reserves associated with larger angles and vice versa) at near ($R = -0.54$, $P = 0.0001$, Table 1). There was poor correlation between fusion reserve ratio and angle at distance ($R = -0.17$, $P = 0.2$) and an inverse correlation (i.e. lower fusion reserve ratios associated with larger angles and vice versa) between fusion reserve ratio and angle at near ($R = -0.82$, $P < 0.0001$).

Discussion

In our cohort of children with intermittent XT total convergence amplitudes were greater than those previously published for visually normal children.¹⁷ Nevertheless, convergence reserve and fusion recovery at distance fixation were reduced for children with intermittent XT compared with normals. We found correlations between the exodeviation control score and convergence reserve, fusion recovery and fusion reserve ratio at both distance and near fixation.

There are few previous studies on fusional convergence in children with intermittent XT. In a review of basic and divergence excess types of intermittent XT, Cooper and Medow stated that convergence is normal in children with intermittent XT,¹⁵ although it is not clear how

“convergence” was defined. In this present study, we found that total convergence amplitudes exceed normal values and that, while convergence reserve and fusion recovery were comparable to normals at near fixation, at distance fixation, they were significantly below normal values. Sharma et al⁹ recently reported fusional vergences in 31 children and adults with intermittent XT and also found reduced convergence reserves at distance. Nevertheless, Sharma et al⁹ also found reduced convergence reserves at near whereas we found near convergence reserves were comparable to normals. Although our mean near convergence reserve values in subjects with intermittent XT are similar to those of Sharma et al (21 pd vs 24.1 pd⁹), referenced normal values are higher in the Sharma et al study (27.8 pd⁹) than those used in this present study (18 pd¹⁷), potentially explaining the difference in results. Another potential reason for the difference may be that the Sharma study included adult subjects.

The role of convergence in the control of intermittent XT is currently unclear. Kushner has associated control of the underlying exodeviation to fusional convergence demonstrating that, in most cases, the exodeviation becomes more pronounced when fusional convergence is suspended.^{19, 20} Ability to control the exodeviation would therefore indicate the presence of greater than normal convergence amplitudes, as any fusional convergence measurable during binocular fusion would be added to the convergence required to fuse the underlying exodeviation. We have adhered to this standard approach by equating total convergence amplitude to the magnitude of the underlying exodeviation (if the exodeviation can be fused) plus the convergence reserve. Nevertheless, we recognize that there are several inherent problems with the notion of tonic fusional convergence being used to control an exodeviation. First, the manifest exodeviation appears to be all-or-nothing, whereas convergence effort appears to vary from moment to moment. Second, retrieval of fusion is thought to be accomplished by blink-induced vergence saccades,²¹ and “saccadic convergence” is a physiologic oxymoron. Finally, given that intermittent XT is thought to be accompanied by a facultative temporal suppression scotoma, the stimulus for fusional convergence of an exodeviation remains unclear. If total convergence (exodeviation + convergence amplitude reserve) is indeed excessive in intermittent XT, one would expect that, immediately following successful surgical realignment, the convergence amplitudes would remain abnormally high, approximating the sum of the previous exodeviation plus the previous convergence reserves. Future data on convergence amplitudes immediately following surgical realignment of intermittent XT would aid our understanding of fusion mechanisms and how convergence should be defined, although the effect of surgery itself on fusional convergence remains unknown. Alternatively, it is possible that an extra-vergence tonus mechanism, as described by Posner,²² will ultimately fit best with the observed findings in intermittent XT.

Despite uncertainties regarding the physiologic role of convergence in intermittent XT, several of our findings are noteworthy. We found a strong correlation between convergence reserve and control, suggesting that exodeviation control may be influenced by the amount of convergence available in reserve. Previous reports on the variability of a single measure of control, made the possibility of a correlation between control and fusion seem unlikely. It is therefore interesting that despite potential variability in control and fusion measurements, we found strong correlations between control and convergence reserve and control and the fusion reserve ratio. The improved fusional control often observed at near fixation may be attributable to the added effects of proximal, tonic, and accommodative convergence. Further study of fusional convergence in intermittent XT is required, but it seems possible that the amount of convergence in reserve may be an indicator of severity.

In children with intermittent XT, fusional convergence ability may change not only with fixation distance, but also with the type of visual stimulus and the type of visual

environment. It has been reported that fusional amplitudes in intermittent XT are greater when viewing a stereo target¹⁵ and also that they are reduced during intense light exposure.²³ This potential effect of fixation target and luminance on fusional vergences should be considered in the clinical evaluation of intermittent XT and when confronted with discrepancies between the clinical evaluation and parental report. Further study of variability in measures of fusional convergence in intermittent XT may help establish its usefulness in categorizing the severity of intermittent XT and in monitoring change over time. It should be noted that in this present study, testing conditions were uniform across all subjects and, therefore, differences between subjects were not due to differences in the testing environment.

The concept that fusion capacity is directly related to an individual's ability to compensate for an underlying deviation is well known in other types of strabismus such as fourth nerve palsy, Graves' eye disease and convergence insufficiency type exodeviation. In the management of convergence insufficiency, Sheard's criterion is often cited, which states that a phoria should be opposed by twice its magnitude in fusion reserve to be adequately compensated.¹⁸ Likewise for intermittent XT, it may be that good control of the underlying exodeviation is associated with a minimum convergence reserve or a fusion ratio dictated by the magnitude of the underlying deviation. In this present study, the strongest correlations were between the control score and the fusion reserve ratio, suggesting that the fusion reserve ratio may be a useful tool for the evaluation of intermittent XT.

Recovery of fusion normally occurs within 2 to 4 pd of the fusion break point but it has been suggested that in some patients with intermittent deviations, the difference between fusion break and recovery may be more marked.⁴ While we found that children with intermittent XT showed lower mean fusion recovery values at distance than normals, these lower recovery values could be confounded by lower convergence reserves. Nevertheless, when we analyzed fusion recovery data in patients with ≥ 10 pd of convergence reserve, recovery occurred within 5 pd of the fusion break point in only 36% at distance fixation and 29% at near fixation. These data support the suggestion that intermittent deviations often have relatively poor ability to recover fusion, and are consistent with our finding of a correlation between recovery and control.

There are few data on the effect of intermittent XT treatment on fusional convergence. Sharma et al⁹ reported that pre-operatively fusional vergences were subnormal in subjects with intermittent XT whereas post-operatively fusion was comparable to normals. The authors concluded that surgical realignment led to significant improvement in fusional amplitudes. Nevertheless, in the study by Sharma et al, both pre- and post-operative fusion data were collected *after* the angle of deviation had been corrected using prisms (i.e. reported fusion data represent convergence reserve). The decrease in angle of deviation (due to surgery) would necessarily increase the amount of convergence in reserve if the total amplitude remained unchanged. Regarding non-surgical treatment, our finding of a strong correlation between convergence reserves and control may have potential treatment implications if distance convergence exercises could be used to augment convergence amplitudes and improve control.

There are several weaknesses to this study. Our results may have been different had we used an alternative normal population for comparison. Nevertheless, we chose previously published data from a large cohort that matched our intermittent XT population for age and included values for fusion break and recovery. Also, we did not consistently record the blur point due to difficulties obtaining such data when assessing young children. We recognize that information regarding blur may be important in understanding fusional capabilities in children with intermittent XT and intend to pursue this in future studies. Measuring

convergence fusion *after* measuring angle of deviation and arbitrarily assigning a value of 45 pd for patients who remained fused at 40 pd could both have resulted in under-estimation of true convergence capabilities. Nevertheless, we still found increased total convergence amplitudes and normal convergence reserves at near and we chose to avoid possible confounding of vergence after-effect on angle measurements by measuring angle before fusion.

We found convergence reserves were subnormal in children with intermittent XT, particularly at distance fixation whereas total convergence amplitudes were often higher than normal values. Convergence reserve, fusion recovery, and the fusion reserve ratio correlate well with a measure of exodeviation control and therefore these fusion measures may aid evaluation of severity in children with intermittent XT.

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Figure 1.

Total fusional convergence amplitude at distance and near in children with intermittent exotropia (n=64). Mean total amplitude (horizontal line) was significantly higher in children with intermittent exotropia, at both distance and near, compared with previously published normals (distance: 33 ± 11 pd vs 17 ± 7 pd; near 38 ± 13 pd vs 18 ± 8 pd, $P < 0.0001$ for each comparison).

Figure 2.

Fusional convergence reserve at distance and near in children with intermittent exotropia (n=64). At distance, mean convergence reserve (horizontal line) was significantly lower in children with intermittent exotropia compared with previously published normals (7 ± 8 pd vs 17 ± 7 pd, $P < 0.001$) but at near mean convergence reserve was comparable between children with IXT and normals (21 ± 14 pd vs 18 ± 8 pd, $P = 0.054$).

Figure 3.

Fusional convergence recovery at distance (n=64) and near (n=56) in children with intermittent exotropia. At distance, mean convergence recovery (horizontal line) was significantly lower in children with intermittent exotropia compared with previously published normals (2 ± 5 pd vs 11 ± 6 pd, $P < 0.001$) but at near mean convergence reserve was comparable between children with IXT and normals (11 ± 10 pd vs 13 ± 6 pd, $P = 0.2$).

Table 1

Correlations between the control score, angle and fusion measures in children with intermittent exotropia

	Distance fixation			
	Total fusion amplitude	Fusion reserve (break point)	Fusion recovery	Fusion reserve ratio
Control score	*R= -0.54 P <0.0001	R= -0.75 P <0.0001	R= -0.57 P <0.0001	R= -0.75 P <0.0001
Angle of deviation	R= 0.63 P <0.0001	R= 0.005 P=0.97	R= -0.21 P=0.09	R= -0.17 P=0.2
	Near fixation			
	Total fusion amplitude	Fusion reserve (break point)	Fusion recovery	Fusion reserve ratio
Control score	R= -0.30 P=0.02	R= -0.57 P <0.0001	R= -0.58 P <0.0001	R= -0.66 P <0.0001
Angle of deviation	R= 0.03 P=0.8	R= -0.54 P=0.0001	R= -0.46 P=0.0003	R= -0.82 P <0.0001

* Correlations using Spearman rank tests