Variability of fusion vergence measurements in heterophoria

Fusion vergence measurements

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Word count: 3369; Number of tables: 2; Number of figures: 3

Disclosures: The authors report no conflicts in relation to this study.

ABSTRACT:

Purpose: The aims of this study were to compare fusional vergence measurements between orthophoria, esophoria and exophoria, and to determine the strength of correlations between fusional convergence and divergence and angle of deviation.

Methods and materials: A cross-sectional study was performed in children with best-corrected visual acuity of 0.0 LogMAR in either eye, compensated heterophoria within 10 prism dioptres, full ocular rotations, presence of fusional vergence and stereopsis (60 seconds of arc or better). Fusional amplitudes were compared between orthophoric and heterophoric children. The fusion reserve ratio was determined as compensating vergence divided by alternating cover test.

Results: Five-hundred and thirty children (7.66±1.20 years) were recruited to this study. The most common heterophoria was exophoria (n=181, 34.2% for near; n=20, 3.8% for distance). Exophoric children had significant lower mean positive fusional vergences (exophoria-orthophoria: p=0.003; exophoria-esophoria: p=0.035) for near (19.54±5.23 base-out) compared with children with orthophoria (20.48±4.83 base-out) and esophoria (22.27±5.60 base-out). Smaller convergence fusion amplitudes were associated with larger angles of deviation at near (r_s=-0.115; p=0.008) and lower fusion reserve ratios were associated with larger angles of deviation at distance (r_s=-0.848; p<0.001) and at near (r_s=-0.770; p<0.001).

Conclusions: Exophoric children have reduced convergence break points when compared with orthophoric and esophoric children. Vergence measurements, taking into consideration the baseline heterophoria, give important information about the ability of the patient to increase their vergence demand and maintain ocular alignment.

Keywords: Esophoria; Exophoria; Fusion; Fusion reserve ratio; Vergence.

INTRODUCTION

Assessing the range of fusional vergence constitutes one of the most important diagnostic tools to provide information about the ability to maintain binocular vision (Ciuffreda, Ciuffreda, and Wang 2006; Fray 2013; Narbheram and Firth 1997). The tendency of the eyes to deviate from bifoveal fixation (phoria) is controlled by fusional vergence; motor fusion being a foundation for eye alignment combined with sensory fusion and stereopsis. When a heterotropia is present the degree of misalignment exceeds the capabilities of fusional vergence. Those with intermittent deviations are likely to be near their motor fusion threshold and have the most to gain by vergence amplitude testing (Arnoldi 2009).

Disparity vergence or motor fusion amplitude measurements should be used to quantify control of an underlying eye misalignment (Arnoldi and Reynolds 2008; Arnoldi 2009). Prism fusion range or vergence amplitude measures the extent to which an individual can maintain fusion in the presence of gradually increasing vergence demands (Melville and Firth 2002). The prism bar or rotary prism is slowly increased until fusion cannot be maintained (break point). This simulates an increase in the strabismic angle and the break point estimates just how much deviation the patient can compensate before eye misalignment. The point at which the blurring occurs is known as the blur point and measures the limits within which accommodation can clear the image of the fixation point in spite of increased convergence (von Noorden and Campos 2002). Then the prism is slowly reduced until fusion is regained (recovery point). The well compensated heterophoria should have a recovery point between 2 to 4 PD below the breakpoint (von Noorden and Campos 2002).

In the presence of a manifest deviation the prism fusion range is measured by first correcting the angle of deviation (Narbheram and Firth 1997) with a prism bar, rotary prism, or on the amblyoscope (Arnoldi 2009) to then determine fusional vergence.

The fusion reserve ratio is another measurement that is referred to as important information about the effect of the underlying angle of deviation (Hatt et al. 2011). According to Sheard's criterion the fusional reserve opposing the heterophoria should be at least twice the magnitude of the angle of deviation (Conway, Thomas, and Subramanian 2012; Scheiman and Wick 2008; Sheard 1930) corresponding to a fusion reserve ratio of 2.0 (Hatt et al. 2011).

There are two types of vergences systems: fast and slow vergences. The fast fusional range (phasic) is controlled by a fast neural integrator and corresponds to reflex fusion system driven by retinal disparity. This system works with a slow fusional system (tonic), which adapts to the fusional demand (prism adaptation or vergence adaptation) under control of a slow neural integrator to maintain binocular alignment (Cooper 1992; Narbheram and Firth 1997; Schor 1979). One study on vergence adaption highlights the importance of developing a protocol to assess slow fusional vergence, which helps in planning surgical intervention, avoiding angle underestimation in esotropias by revealing latent esotropia with prism adaptation testing or sustained dissociation (Rosenfield 1997).

The degree and type of fusional vergence required for binocular viewing varies directly with the size and direction of the heterophoria (Kim et al. 2010; Sreenivasan, Irving, and Bobier 2012). It is suggested that in the presence of an exophoria there is an increase in the fast fusional convergence while in the presence of an esophoric deviation there is an increase in reflex fusional divergence (compensating vergence) to attain binocular single vision (Scheiman and Wick 2008; Sreenivasan et al. 2012).

Convergence fusion amplitudes have been found to correlate with control of the exodeviation (Hatt et al. 2011). However, type of deviation versus measured fusional vergence does not receive much attention in the literature. A difference has been reported between fusional vergence for eso versus exo deviations with a greater base-out range for esos and greater base-in range for exos (Rowe 2010). However, the difference did not reach significance.

Clearly there are subtle differences in fusional vergence adaptation in the presence of eso versus exo deviations. This raises the question of what order fusional vergence should be measured to provide the essential information on which to base clinical judgements on compensation of deviations. Furthermore, although types of deviation versus fusional vergence have been examined in some studies with adult populations, there have been limited investigations of this relationship comparing orthophoric with heterophoric children. Thus, the purpose of this study has been to (1) compare fusional vergence measurements between orthophoria, esophoria and exophoria; and (2) determine the strength of correlations between fusional vergence and angle of deviation.

MATERIALS AND METHODS

A cross-sectional study was performed with data from typically developing children between ages of 6 to 14 years. The study adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained from the parents to allow inclusion of their child's data in the study. Confidentiality of the given information was guaranteed.

Inclusion criteria included a best-corrected visual acuity of 0.0 LogMAR in either eye, heterophoria within 10 prism dioptres with no decompensation to intermittent strabismus (asymptomatic heterophoria), full ocular rotations, presence of fusional vergence and stereopsis (60 seconds of arc or better). Each child had an orthoptic assessment in an emmetropic state (wearing habitual refractive correction, if required, to achieve inclusion criteria) conducted by the same orthoptist to avoid variability between examiners. Orthoptic assessment included:

- Distance visual acuity with a Sloan letter linear-spaced Good-Lite chart at 3 metres,
- Ocular alignment by alternate cover test at 33cms (0.18 LogMAR) and 6 metres (0.7 LogMAR) with measurement by alternate prism cover test,
- Fusional vergence (convergence and divergence) by prism bar step method at 33cms (0.18 LogMAR) and 6 metres (0.7 LogMAR). Divergence was measured first,
- Stereoacuity with Stereo Butterfly SO-005 test at 40cms,
- Near point of convergence and accommodation by RAF rule, and,
- Ocular movements in cardinal positions of gaze.

Exclusion criteria included children with manifest strabismus, microtropia or abnormal ocular motility.

Values of fusional amplitudes were compared with previously reported mean values for normal children (Jiménez et al. 2004). The fusion reserve ratio was calculated as compensating vergence (base-out in exophoria and base-in in esophoria) divided by prism alternating cover test.

SPSS statistical software, version 21 (IBM, USA), was used for the statistical analysis. For descriptive purposes, the mean, standard deviation and median were calculated. Non-parametric analysis was used for analysing prism fusion bar measurements because of the unequal step changes. The Kruskal-Wallis test was used to compare fusional vergence measurements between orthophoria, esophoria and exophoria. Spearman's rho correlation test was used to determine the strength of correlations between fusional convergence, fusion reserve ratio and angle of deviation. A p value of less than 0.05 was accepted as significant.

RESULTS

Five-hundred and thirty children were included in this study. The mean age of the children was 7.66±1.20 (range 6 to 14) years. There were 280 females (52.8%) and 250 males (47.2%). The most common heterophoria was exophoria (n=181, 34.2% for near; n=20, 3.8% for distance).

The overall angle of deviation (absolute values) was 1.87±2.63 (range 0-10) for near and 0.13±0.661 (range 0-4) for distance. The median angle of deviation was 4PD (2 to 10PD) at near fixation (n=181) and 4PD (2 to 4PD) at distance (n=20) for exophoric children and 6PD (2 to 10PD) at near fixation (n=22) and 4PD at distance (n=1) for esophoric children. There were no recorded cases of vertical phoria. Near convergence point was 6.04±0.38cms (range 6 to 11) and near accommodation point was 19.74±1.19D (range 10 to 20).

Table 1 details the prism fusion range at near and distance fixation for the overall group plus the separate orthophoria, esophoria and exophoria groups.

Table 1 – heterophoria, fusional amplitudes and fusion reserve ratios.

The overall positive (near=20.23±5.04; distance=13.08±3.19) and negative (near=9.71±1.99; distance=6.98±1.81) fusional amplitudes were greater for near than distance fixation. Mean fusion reserve ratios were 4.33±1.62 (range 2.00 to 7.00) at distance and 4.74±2.54 (range 2.00 to 17.50) at near.

Exophoric children had lower mean positive fusional vergences for near (19.54±5.23 base-out) and distance (12.60±2.44 base-out) compared with children with orthophoria and esophoria (Figure 1). This difference was statistically significant for near (exophoria-orthophoria: p=0.003; exophoria-esophoria: p=0.035). There were no statistically significant differences in other fusional amplitude measurements between the groups.

Figure 1 – heterophoria and mean positive fusional amplitudes for near fixation.

There was a significant but small inverse correlation (r_s=-0.115; p=0.008) between fusional convergence and angle at near (i.e., smaller convergence amplitudes associated with larger angles) independently of the type of deviation. There was a significant but small positive correlation (r_s=0.106; p=0.014) between fusional divergence and angle at near (i.e., higher divergence amplitudes associated with larger angles) independently of the type of deviation. Figure 2, shows the 95% confidence interval for the mean fusional convergence (A) and fusional divergence (B) for near versus angle of deviation for near. The circles represent the mean, and the horizontal lines the endpoints of the confidence interval. For instance, we see in figure 2A that children with an angle of deviation of 4PD have on average a fusional value of approximately 20.00 base-out. In figure 2B, children with an angle of deviation of 4PD and 6PD have on average a fusional value of approximately 10.00 base-in. Table 2, shows the numbers within each angle of deviation category.

Figure 2 – Error bar chart of fusional convergence (A) and fusional divergence (B) versus angle of deviation for near fixation.

Table 2 – number of children within each angle of deviation for near.

There was a strong significant inverse correlation between fusion reserve ratio and angle (i.e., lower fusion reserve ratios associated with larger angles) at distance (r_s=-0.848; p<0.001) and at near (r_s=-0.770; p<0.001). Figure 3, shows the 95% confidence interval for the mean fusion reserve ratio for near versus angle of deviation for near. For example, we see that children with an angle of deviation of 10DP have on average a fusion reserve ratio of approximately 2.00.

Figure 3 – Error bar chart of fusion reserve ratio versus angle of deviation for near fixation.

DISCUSSION

In this study fusional amplitudes were compared in orthophoric and heterophoric children. The prevalence of orthophoria was greater for near and distance as in accordance with other studies with similar age group populations (Aring et al. 2005; Walline et al. 1998). The overall positive and negative fusional amplitudes were comparable to other cohorts of normal children (Jiménez et al. 2004), except for positive fusional amplitude for distance which was smaller in the present study. Vergence range is reported as being higher when measured with a peripheral target compared with a central target (particularly for positive fusional range) and normative values should be used to determine normal ranges (Rowe 2010). Our smaller positive fusional amplitude at distance fixation may be due to the use of a smaller (0.7 logMAR) fixation target) but may also be due to assessment in a younger and larger cohort consisting predominantly of exophoric children.

The blur point was not recorded due to the difficulty in obtaining such data when assessing young children.

A shift towards base-out range was seen in esophoric children while a shift towards the base-in range was seen in exophoric children. This result is in accordance with other studies reporting a skewed vergence range in adults with exophorias having a bias towards the divergent range and the reverse for esophoric subjects (Dowley 1990; Kim et al. 2010; Rowe 2010).

In the present study we observed that exophoric children had significant lower positive fusional vergences for near compared with children with orthophoria and esophoria. According to Dowley (1990), exophoric adults have a significant reduced base-out prism adaptive response when compared to orthophorics, while esophorics have a reduced base-in prism adaptive response. For this reason Dowley hypothesized that exophoria exists due to a partial failure of convergence and esophoria due to a failure in divergence. When the exophorias diverge, exophoria may enhance the divergence movement because the natural tendency for the eyes to move outward to its phoria position, resulting in faster divergence dynamics (Kim et al. 2010). However, when convergence is stimulated an inhibition of the natural tendency to diverge occurs, which results in a reduction of convergence peak velocity.

Various studies have found reduced convergence break points in children with intermittent exotropia and poor convergence has been suggested as a marker of severity in intermitent exotropia (Fu et al. 2015; Hatt et al. 2011). Hatt *et al.*(2011), found significantly lower mean convergence break points (defined as convergence reserves) at distance for children with intermitent exotropia when compared with visually normal children. Fu *et al.* (2015) also observed reduced convergence break points for near. However, the researchers used different normal reference values which could lead to the different results. It has been suggested (Rowe 2010) that exophoric subjects may make more use of accommodative convergence in the control of their underlying deviation. In an intermittent exotropia, binocular alignment is achieved by convergence mechanisms, but, if diminished horizontal fusional vergences are present, the control of the deviation may be poor (Hatt et al. 2011; Jampolsky 1970; Scheiman and Wick 2008).

The present findings suggest that heterophoria has an important role within the vergence system and fusion measures should take these findings in consideration. Previous studies investigated the influence of order of horizontal vergence testing on the end results. They concluded that negative fusional vergence should be measured first to avoid affecting this value of vergence recovery in eso deviations by excessive stimulation of convergence, and vice versa for exo deviations and positive fusional vergence (Cooper 1992; Fray 2013; Noorden and Campos 2002; Rosenfield et al. 1995). According to Fray (2013), divergence break and recovery points were significantly affected by the measurement order. Divergence break and recovery points were lower when tested after convergence. The result is that the fusional vergence range is biased in the direction of the first measure (Rowe 2010). Some authors recommend an order of testing such as base-out, base-up, base-in, and base down to prevent vergence adaptation (Noorden and Campos 2002).

Other authors argue that the base of the prism should be placed in the direction opposite to that used to measure the deviation (e.g. divergence amplitudes are necessary to control an esotropia) so as to increase the vergence demand (Arnoldi 2009; Rowe 2010). According to the results of the present study we also recommend that fusional convergence should be measured first in exophorias. It is possible that the first measurement (divergence) done in this study may enhance the divergence movement resulting in inhibition of convergence peak velocity. There was no significant difference in divergence amplitudes when comparing exophoric children with children with orthophoria or esophoria.

The heterophoria measurement using the alternate cover test can also influence the measurements results. According to Cooper (Cooper 1992) the alternate occlusion represents an initial elimination of fast fusional vergence followed by a longer decay of the slow fusional vergence response. Conversely the unilateral cover/uncover test permits fusion to reoccur. If the patient has good strong vergence adaptation they are unlikely to be symptomatic as the slow fusional vergence system compensates the constant demand of the fast fusional vergence system. It is proposed that heterophorias also should be measured before vergence amplitudes to avoid the shift in the lateral phoria towards the direction of the prism duction (Cooper 1992). Base-out prisms have a greater effect in changing the heterophoria, resulting in a shift towards esophoria.

No correlation was found between distance fusional convergence and distance angle. The results of this study are in accordance with Hatt *et al.* (2011) who studied a cohort of children with intermittent exotropia. Also, similar to our results, smaller fusion reserves were associated with larger angles and vice versa at near (Sreenivasan et al. 2012). However as the present study recruited children with heterophoria angle of deviation ≤ 10DP the strength of the correlation was lower. Lower fusion reserve ratios were associated with larger angles and vice versa at distance and near.

There is insufficient evidence to propose that the presence of an intermittent exotropia signals a deficit in the slow vergence system (Liebermann et al. 2012) which is not able to eliminate the constant demand on the fast fusional vergence system. This topic warrants further investigation.

It should be noted that, in the present study, testing conditions were uniform across all subjects and, therefore, differences between children were not attributable to differences in testing environment. Measurements were not compared with different target sizes or fixing either eye. Furthermore, test-retest and inter-observer measurements were not undertaken. Thus it is not possible to compare the results of this study with all published literature. Regarding deviation magnitude and measurement error, it is unlikely that measurements have been affected. As smaller deviations are measured using smaller prism increments, they typically have less measurement error (Pediatric Eye Disease Investigator Group 2009). However, as the values of fusional amplitudes increase, variation also increases - the Clement Clark prism bar has unequal step sizes, ranging from 1DP at the lower end of the scale to 5DP at the higher end. A measurement error could potentially influence the measurement.

CONCLUSIONS

In conclusion this study showed that exophoric children have reduced convergence break points when compared with orthophoric and esophoric children. Vergence measurements, which take into consideration the baseline phoria, provide important information about the ability of the patient to increase the vergence demand and maintain ocular alignment. Our assessment recommendations are to use the same target size and measurement methods across visits so that fusional vergence measures can be compared as like-with-like results. For eso deviations, the base-in range should be measured first as an indicator of divergence control whereas for exo deviations, the base-out range should be measured first to indicate the convergence control.

Lower fusion reserve ratios were associated with larger angles in children with compensated heterophorias, indicating the need to explore this relationship further with additional research.

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Table 2 – heterophoria, fusional amplitudes and fusion reserve ratios.

Heterophoria	Fusional amplitudes	Mean	Std. Deviation	Median	Range
Overall	**Near**				
	PFV	20.23	5.04	20.00	10.00-40.00
	NFV	9.71	1.99	10.00	4.00-20.00
	FRR	4.45	2.56	4.00	1.00-17.50
	Distance				
	PFV	13.08	3.19	12.00	6.00-35.00
	NFV	6.98	1.81	8.00	2.00-12.00
	FRR	4.24	1.72	4.00	1.50-7.00
Orthophoria	**Near**				
	PFV	20.48	4.83	20.00	10.00-40.00
	NFV	9.57	1.96	10.00	4.00-20.00
	Distance				
	PFV	13.10	3.22	12.00	6.00-35.00
	NFV	6.97	1.83	8.00	2.00-12.00
Esophoria	**Near**				
	PFV	22.27	5.60	20.00	16.00-35.00
	NFV	9.64	2.11	10.00	6.00-14.00
	FRR	1.95	0.92	1.67	1.00-5.00
	Distance				
	PFV	14.00	0.00	14.00	14.00
	NFV	6.00	0.00	6.00	6.00
	FRR	1.50	0.00	1.50	1.50
Exophoria	**Near**				
	PFV	19.54	5.26	18.00	10.00-40.00
	NFV	9.96	2.02	10.00	4.00-16.00
	FRR	4.75	2.55	4.17	2.00-17.50
	Distance				
	PFV	12.60	2.44	12.00	8.00-18.00
	NFV	7.20	1.20	8.00	6.00-10-00
	FRR	4.38	1.65	4.00	2.00-7.00

Legend: PFV – positive fusional vergence; NFV – negative fusional vergence; FRR – fusion reserve ratio

Table 2 – number of children within each angle of deviation for near.

Heterophoria	Angle of deviation	Frequency	Percent
Orthophoria	0	327	100
Esophoria	2	1	4.5

	4	9	40.9
	6	7	31.8
	8	3	13.6
	10	2	9.1
	Total	**22**	**100**
Exophoria	2	22	12.2
	4	88	48.6
	6	51	28.2
	8	17	9.4
	10	3	1.7
	Total	**181**	**100**

Figure 1 – heterophoria and mean positive fusional amplitudes for near fixation.

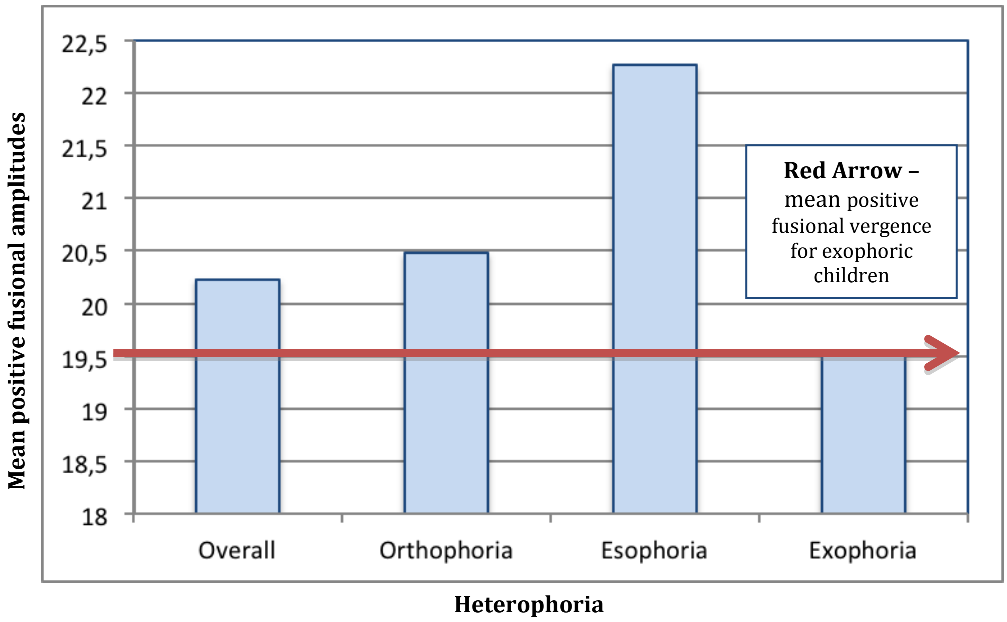
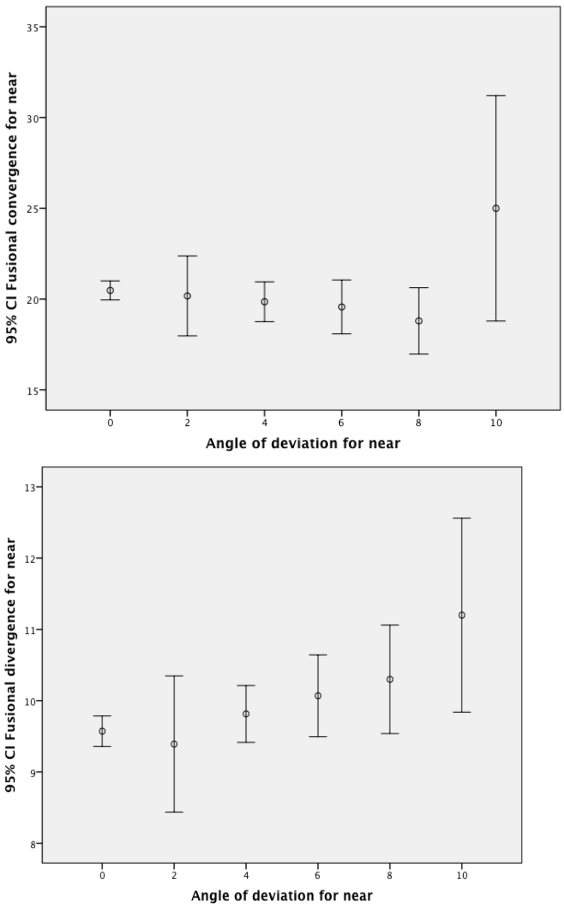


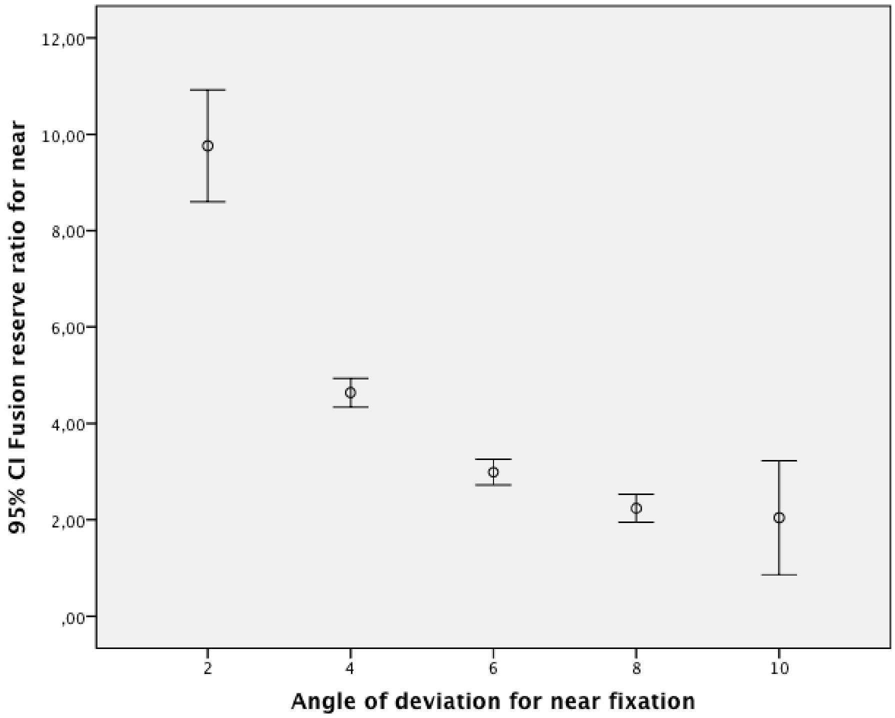
Figure 2 – Error bar chart of fusional convergence (A) and fusional divergence (B) versus angle of deviation for near fixation.

A B



Legend: 95% confidence intervals are shown for the mean fusional convergence (A) and fusional divergence (B) for near versus angle of deviation for near. The circles represent the mean, and the horizontal lines the endpoints of the confidence interval. In figure 2A children with an angle of deviation of 4PD have on average a fusional value of approximately 20.00 base-out. In figure 2B, children with an angle of deviation of 4PD and 6PD have on average a fusional value of approximately 10.00 base-in.

Figure 3 – Error bar chart of fusion reserve ratio versus angle of deviation for near fixation.



Legend: 95% confidence intervals are shown for the mean fusion reserve ratio for near versus angle of deviation for near. The fusion reserve ration falls with increasing angle of deviation - children with an angle of deviation of 10DP have on average a fusion reserve ratio of approximately 2.00.