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ORIGINAL ARTICLE

Association between interpupillary distance and fusional convergence-divergence amplitudes

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Abstract

Purpose: The purpose of the study was to evaluate the effect of individual differences in interpupillary distance (IPD) on convergence and divergence amplitudes measured at near and at distant fixation targets.

Methods: Ninety-three healthy subjects were enrolled. Group 1 included subjects with smaller than normal IPD (mean IPD = 58.2±1.4; 27 subjects), Group 2 included those with larger than normal IPD (mean IPD = 69.5±1.6; 31 subjects), and Group 3 included those with normal IPD (mean IPD = 63.10±2.22; 35 subjects). Outcome measures were best corrected visual acuity, binocular vision level (TNO test), convergence, and divergence amplitudes at near and at distance.

Results: There was no statistically significant difference between Group 1, 2, and 3 regarding age or clinical characteristics. The differences in gender distribution between Groups 2 and 3 and between Groups 1 and 2 were significant (Chi-square test, p=0.001 for both). There was no statistically significant difference between the groups in the values of near convergence amplitude, near divergence amplitude, and distant convergence amplitude. There was a statistically significant difference between in mean distant divergence amplitude between Groups 2 and 3 (p=0.01).

Conclusion: Differences in IPD can affect an individual's vergence amplitudes and binocular vision level. Especially, the individuals with IPD larger than normal limits have the lowest mean values for all vergence amplitudes, while the normal IPD group had the highest.

Keywords: Binocular vision; convergence amplitudes; divergence amplitudes; fusion; interpupillary distance; vergence amplitudes.

Fusion is the merging of slightly different images from each eye in the cortical visual centers to form a single perception of an object. Fusion can be artificially divided into sensory fusion, motor fusion, and stereopsis. Motor fusion refers to ocular movements that adjust the orientation of the eyes to merge two similar images and is responsible for the amount of fusional amplitude being large or small and it consists of vergence movements.[1,2] Due to the horizontal separation of the two eyes (the interpupillary distance [IPD]), for geometric reasons, each eye receives

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a slightly different image. The sensory fusion of the two unequal retinal images results in a three-dimensional percept. Sensory fusion is defined as the unification of visual excitations from corresponding retinal images into a single visual percept, a single visual image. For sensory fusion to occur, the images not only must be located on corresponding retinal areas but also must be sufficiently similar in size, brightness, and sharpness.[3] Stereopsis, which is considered as the highest standard of binocular vision, is generated by the fusion of binocularly disparate retinal images by convergence.[4] Stereoscopic acuity depends on many factors and disparate stimulation of corresponding retinal areas is the key point. The fine adjustment of the visual axes necessary for binocular fixation is obtained by fusional vergence movements.[3,4] Fusional vergence is the principal mechanism that prevents intermittent deviation from becoming constant. When an individual has insufficient fusional reserve, heterophoria decompensates to heterotropia, disrupting binocular vision and leading to a variety of symptoms.[5,6]

Normal individuals with binocular vision use vergence to maintain fusion as the power of a base-in or base-out prism placed in front of one of their eyes is increased. Inability of the vergence system to compensate for this prismatic power results in diplopia. The tolerable prismatic power and degree of adaptation to increased vergence demand vary considerably between individuals.[7] Prism adaptation involves three different compensatory processes: Postural adjustments (visual capture and muscle potentiation), strategic control (readjustment of target position), and spatial realignment of various sensory-motor reference points. These determine performance in prism adaptation.[8]

If the purpose of the fusion is considered to be the mergence of images from both eyes to a single point--the symmetry point--then the distance the eyes traverse from primary position to the symmetry point, and so the distance between the eyes may also influence an individual's fusional vergence capacity and prism adaptation performance. It is possible that if this distance is outside the normal limits due to individual's anatomical placement of eyes on face, fusion could be negatively affected. However, there is little information available regarding the relationship between IPD, and thus facial anatomy, and fusional vergence range.

Therefore, in the present study, we aimed to evaluate the effects of individual differences in IPD on convergence and divergence amplitudes at near and at distance.

Materials and Methods

Fifty-eight consecutive subjects with IPD values above or below the accepted normal range[9] and 35 subjects with IPD values within the normal limits were included in the study. All subjects selected for the study were healthy with 20/20 bilateral corrected visual acuity on Snellen chart, binocular vision of at least 240 s arc on TNO test, and no fixed or intermittent heterotropia or any ocular diseases. To get more reliable measurement results, the subjects were chosen among the residents or juniors of ophthalmology in our clinic. Normal IPD ranges were accepted as 59–66 mm in women and 61–68 mm in men.[9] Group 1 included subjects with smaller than normal IPD (mean IPD = 58.2±1.4; 27 subjects), Group 2 included those with larger than normal IPD (mean IPD = 69.5±1.6; 31 subjects), and Group 3 included those with normal IPD (mean IPD = 63.10±2.22; 35 subjects). After a complete ophthalmic examination, all cases underwent fine stereoacuity testing (TNO test, 17th edition). Near convergence amplitudes (NCA) and near divergence amplitudes (NDA) were measured in each subject by placing base-in and then base-out prism bars in front of one eye while the subjects focused on a near fixation target held at a distance of 30 cm. Distance convergence amplitudes (DCA) and distance divergence amplitudes (DDA) were measured as the same way while the subjects focused on a distance fixation target held at a distance of 6 m. The strength of the base-in or base-out bars was increased slowly giving enough time to the subject to fuse. The value just before the minimum amount of base-in and base-out prism bars that cause diplopia or reveal manifest tropia was accepted as the fusional amplitude value. Subjects were tested while using their accustomed refractive correction in glasses or contact lenses.

Statistical analysis was performed with SPSS 26.0 (SPSS Inc., Chicago, IL, USA). $P<0.05$ was accepted as statistically significant. In statistical analysis, numeric variables were tested for normal distribution using Shapiro–Wilk test. Categorical variables were expressed as frequency and percentage and numeric variables as mean and standard deviation. Relationships between pairs of categorical variables were analyzed using the Chi-square test. The Kruskal–Wallis test was used to compare multiple independent means and Dunn's test was used for post hoc comparisons. Level of statistical significance was set at $p<0.05$.

The signed written informed consent for procedures was obtained from each subject. The study was approved by a Local Ethics Committee and the research protocol adhered to the Declaration of Helsinki for research involving human subjects.

Results

There were 27 subjects with below-normal IPD in Group 1, 31 subjects with above-normal IPD in Group 2, and 35 subjects with normal IPD values in Group 3. Mean age was 26.4±4.8 years in Group 1, 25.4±3.7 years in Group 2, and 26.5±2.5 years in Group 3 (Kruskal–Wallis, p=0.077). There were no statistically significant differences between three groups regarding age. The male/female ratio was 8/19 in Group 1, 24/7 in Group 2, and 15/20 in Group 3 (Chi-square test, p<0.05). The differences in gender distribution between groups, especially between Groups 2 and 3 and between Groups 1 and 2, were significant (Chi-square test, p=0.001 for both) (Table 1).

Mean IPD was 58.2±1.4 mm in Group 1, 69.5±1.6 mm in Group 2, and 63.10±2.22 mm in Group 3 (Kruskal–Wallis, p<0.05). Binocular vision level (TNO test) was 58.9±54.2 s arc in Group 1, 82.3±68.8 s arc in Group 2, and 80.6±62.1 s arc in Group 3 (Kruskal–Wallis test, p>0.05). There was no statistically significant difference between the groups in the values of NCA, NDA, and DCA. There was a statistically significant difference in mean DDA between Groups 2 and 3 (p=0.01) (Table 2).

Table 1. Gender and age distribution between the groups

	Group 1	Group 2	Group 3	p-value
IPD values, mm (Mean±SD)	58.2±1.4	69.5±1.6	63.10±2.22	<0.05*
n	27	31	35	
Age, years (Mean±SD)	26.4±4.8	25.4±3.7	26.5±2.5	0.077*
Gender, n (%)				
Male	8 (29.6)	24 (77.4)	15 (42.9)	0.001**,a
Female	19 (70.4)	7 (22.6)	20 (57.1)	

Group 1: Subjects with below-normal interpupiller distance (IPD); Group 2: with above-normal IPD; Group 3: with normal IPD values, a: statistically significant difference in gender distribution in Group 1 (female dominance) and Group 2 (male dominance) compared to control group (Group 3). *Kruskal–Wallis; **Chi-square test. SD: Standard deviation.

Table 2. Difference between the groups in the values of binocular vision level (TNO test), NCA, NDA, DCA, and DDA

Parameter	Group 1 (n=27)	Group 2 (n=31)	Group 3 (n=35)	p-value
NCA (PD)	34.1±11.8	32.9±11.4	37.3±9.3	0.109
NDA (PD)	15.4±3.2	13.9±3.4	15.9±3.9	0.100
DCA (PD)	19.1±7.3	18.1±7.3	23.7±10.7	0.062
DDA (PD)	8.5±3.3	8.3±2.2	9.5±2.0	0.010*
TNO test (second arc)	58.9±54.2	82.3±68.8	80.6±62.1	0.051

NCA: Near convergence amplitude; NDA: Near divergence amplitude; DCA: Distant convergence amplitude; DDA: Distant divergence amplitude; PD: Prism diopter. *Statistically significant between Groups 2 and 3 (<0.05, Kruskal–Wallis Test).

Discussion

For normal binocular vision, it is crucial that the compensatory fusional processes are active and sufficient. Diplopia will occur if a visual stimulus is focused on different parts of the retina. However, if the horizontal difference remains within the Panum fusional area, the object will be perceived both as a single object and with stereopsis.[3] This involves fusional vergence. Individuals with motor fusion insufficiency are at higher risk of deviations. Deviations of various etiologies usually remain latent if the degree of deviation is within the person's fusional amplitude. Diplopia resulting from intermittent or permanent manifest deviation is unavoidable when vergence mechanisms are insufficient.[5]

Various factors affecting fusional vergence amplitude have been described. In addition to normal differences between individuals, variation can also be seen in the same individual due to tiredness/wakefulness state, toxic agents, neuromuscular changes, or differences in visual level.[3] However, there are no studies in the literature about the role of anatomic factors in these inter-individual variations.

Studies have shown that although IPD increases with age, the near convergence/distance ratio remains stable throughout life. It has been proposed that the oculomotor control systems governing convergence compensate for the gradual changes in IPD.[10,11]

In our study, we investigated whether this has an effect on the fusional vergence amplitudes and/or binocular visual acuity of individuals with unusually large or small IPD. We found that distant and near convergence and divergence amplitudes were lower in cases with IPD beyond the normal range. However, the only statistically significant difference was in DDA between individuals with large IPD those with normal IPD. DDA was significantly lower in individuals with unusually large IPD compared to those with normal IPD. The high IPD group had the lowest mean values for all vergence amplitudes, while the normal IPD group had the highest.

When we examined the groups in terms of binocular vision acuity levels, the low IPD group had the best binocular vision. TNO values were worse in the high IPD group, but the difference was not statistically significant.

Consistent with our study, Aslankurt et al.[12] previously reported a statistically non-significant trend toward higher TNO values (i.e., lower stereopsis) in individuals with large IPD. Bosten et al.[13] also found a weak positive correlation between IPD and TNO.

All of the subjects in our study had visual acuity of 20/20 on Snellen chart and none had intermittent/fixed strabismus or eye movement restriction.

As a limitation, there is a difference in gender distribution in below normal IPM (female dominance) and above normal IPM (male dominance) groups. This may be due to anatomical differences between genders.

Conclusion

Our results indicate that differences in IPD can affect an individual's vergence amplitudes and binocular vision level. As far as, we know that this is the first study that focus on probable influence of IPD on vergence measures. A detailed understanding of this relationship can only be achieved through further studies including large sample populations.

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