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ORIGINAL ARTICLE

Correlation between Interpupillary Distance and stereo acuity

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ABSTRACT
Interpupillary distance (IPD) is the only component of stereopsis which can be manipulated to enhance our stereoacuity. The problem is, to the best of our knowledge there are no studies supporting this relationship. The purpose of this study was to find the association between stereoacuity and interpupilary distance. This study is cross-sectional and prospective study. The subjects in this study included students of Twintech International University College of Technology during the study year 2011. There were 23 males and 37 females included in our study within the age group of 18 to 35 years. The type of sampling used was convenient sampling. IPD was measured with Essilor Digital CRD pupillometer. Stereoacuity was measured by Fris by near stereotest. The data was statistically analysed using SPSS for Windows version 16.0 software.We found no statistically significant difference in stereoacuity between three races (p=0.070) and between different age groups (P=0.336), but there was a statistically significant difference in stereoacuity between male and female (p=0.015).The average IPD for female subject was around 2.4 millimetres smaller than male subjects. Using a non parametric correlation we found out there was a significant difference between stereoacuity of different Interpupilary distance (p=0.013). People with smaller IPD can perceive depth in longer distance from the eye compared to people with larger IPD. Furthermore it is concluded that female subjects have both smaller IPD and better stereoacuity compared to male subjects.
Keywords: Accommodation Ocular, Depth Perception, Correlation Study, Interpupillary Distance, Stereoacuity

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INTRODUCTION

Stereopsis is thought to be our sole robust binocular cue to depth. Stereopsis arises from horizontal retinal image disparity between the two foveae or other corresponding retinal points [1].It occurs most accurately when images in each eye are formed on non-corresponding retinal points that are close together [2] Although stereopsis is not essential for perception of depth, it is advantageous in tasks involving complex visual presentations and hand eye coordination [3].

If stereopsis is only a function of binocular disparity, its angular measure should not be affected by observation distance. However observation distance could affect stereopsis if the visual system uses information, such as accommodation, convergence, and cognitive factors, to estimate the perceived distance and incorporates this information to generate a stereoscopic response [4, 5, 6 and 7]. Instereopsis the image differences, or binocular disparitiesare used by the visual system to obtain a percept of depth. These binocular disparities are greater when a given object is viewed at a nearer distance. Each human eye has certain threshold for depth perception. There are different factors that contribute to the threshold of our three dimensional vision. The purpose of this study is to observe the difference in stereoacuity threshold between subjects with larger or smaller interpupilary distance (IPD).

There are several factors that influence stereoacuity. These factors are age, gender, monocular cues, vergence, and viewing distance of the target. Monocular cues to depth cannot be separated from stereopsis. It is not clear
how much of stereoacuity is due to the monocular cue and to what extend do they help the stereopsis. These cues include perspective cues, motion parallax, differential focusing, image overlap, and shading [8].

Like stereopsis, the interpupillary distance is also influenced by several components; which also influence stereopsis indirectly. Before we can discuss these factors, first we should know what IPD is. Interpupillary distance (IPD) is the distance between the centres of the pupils. It obviously determines the stereo separation of the two images which are combined in the brain to produce stereo perception. The factors Influencing IPD are gender, race and age.Mean IPD is important in the design of stereoscopic display devices and the production of stereoscopic content. The measurement of near stereoacuity can be done by several different tests. These tests such as Titmus fly test, Randot stereo vision test, Frisby near stereo test, and Howard dolman test all have their advantages and disadvantages. The disadvantage of the randot and Titmus test is in the usage of goggles which makes the test less natural. On the other hand Fris by has a problem of monocular cue to depth. Howard dolman test while accurate is rare to use.

Fris by stereotest was used to measure the stereoacuity threshold. The stereoacuity threshold was determined from the fixation distance and the interpupillary distance. All Frisbystereotest present 'real depth' objects viewed with natural vision. That is, they do not use stereogram to create depth effects. This avoids the disadvantages that stereogram have for some patient groups. In addition, all FrisbyStereotests have precautions built in to them to minimize the chances of correct responding on the basis of monocular cues. Frisby was chosen out of other available stereo-tests as it is a simple, easy-to-use and durable instrument [9].

To this day there is no study regarding how distinct and accurate we can use our stereoscopic abilities. There have been studies regarding the factors that affect stereoacuity, such as age, gender, and race, but none of these components can be modified, via optical and technological instruments, for us to have enhanced stereopsis. Interpupillary distance is the only component of stereopsis which can be manipulated to enhance our stereoacuity. The problem is, to the best of our knowledge there are no studies proving this relationship. The purpose of this study was to find the association between stereoacuity and interpupilary distance. By establishing the relationship between stereoacuity and interpupilary distance we can make the optician aware about the influence of induced prismatic effect over stereoacuity, so that they can consider the interpupilary distance as an important factor while dispensing lenses for the patients.

METHODOLOGY

This study is cross-sectional and prospective study. The subjects in this study included students of Twintech International University College of Technology during the study year 2011. we selected subjects irrespective of race between 18-35 years age. There were 23 males and 37 females included in our study. The type of sampling used was convenient sampling. All patients were consented before study participation. Participants were included who had a visual acuity better than 6/9 and Stereoacuity ≥ 40 sec of arc. Participants were excluded if they were pregnant, had any ocular pathology, Phoria exceeding 6Δ (prism) esophoria and 6Δ exophoria at near and subjects with any binocular disorder (vergence/ accommodation).All data were collected at Twintech Main campus inside the nursing department under a constant testing environment (Single examiner, constant examination room, instrument and constant illumination which is138 Lux) was maintained throughout the data collection process of this study.

The Snellen chart was used at 6 meter to measure the visual acuity at distance.Objective refraction was performed with Keeler Retinoscope.IPD was measured with Essilor Digital CRD pupillometer. Stereoacuity was measured by Frisby near stereotest (3 plates with different thickness). NPC (Near Point of Convergence) and NPA (Near Point of Accommodation) was measured with the help of RAF (Royal Air Force) rule.

The Frisbystereotest was used because in addition to being more natural the range of stereoacuity in this Frisby test is larger than any other near stereotests available and for a more exact stereoacuity there is a formula available to find the best stereoacuity to the decimal level.The only disadvantage to this test is the existence of monocular cue to the depth. This means if a person has only one eye he or she might be able to pass the test to a certain level. However because we screened our subjects before the stereoacuity was measured this disadvantage did not cause any problem for us.

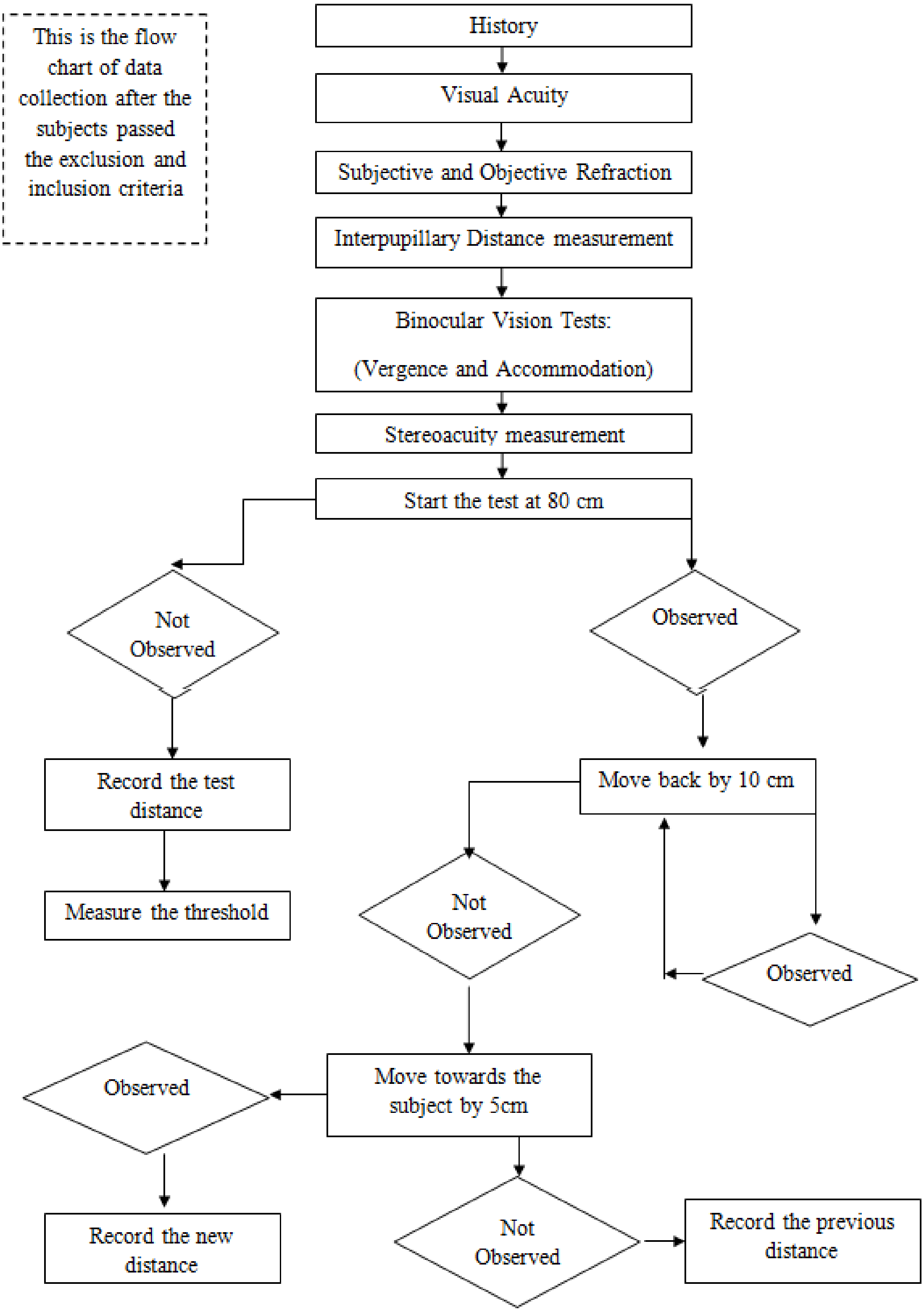
In Frisby near stereotest the disparity is calculated by using the following formula:

$$Disparity = \frac{206264.81(I.Z)}{1.49(d^2)} \text{ Sec of arc}$$

Where: I= interpupillary distance, Z= average plate thickness as measured in mm, 1.49= refractive index of the acrylic plastic, d= viewing distance.

According to Frisby the lowest disparity that the subjects can reliably discriminate is the stereo threshold and this stereo threshold is the measure of stereoacuity. In order to ensure accurate and reliable data, we standardized all the examination and diagnostic procedures, calibrated each instrument every day and its reproducibility were assessed by measuring the data multiple times. The collected data was scrutinized manually before its entry into the computer.

DATA COLLECTION PROCEDURES



The Frisby test has three Perspex plates of varying thickness, each plate comprising four squares, one of which has a circle in depth, which the subject identifies. As it is shown on the flowchart the test starts at 80 cm. On each distance the subject is tested three times to make sure the choices are not by luck. If the subject can identify the circle, the distance between the test and subject will be increased by 10 cm. This process will continue until the subject can't distinguish the circle. Once reported the distance between subject and test will decrease by 5 cm. If the target is detected in this distance then it will be recorded and through the Frisby manual formula the exact stereoacuity is calculated. If not detected, then the previous distance will be recorded.
The data was entered in MS Excel 2007 and the statistical analyses were performed using SPSS for Windows version 16.0 software (SPSS Inc., Chicago, IL, USA).
The results were expressed as median± interquartile range if the variables were continuous and as number (percentage) if the variables were categorical, unless otherwise mentioned.Kruskal-Wallis Test was performed to find correlation between stereoacuity with age and also age with near interpupillary distance. To find the correlation between stereoacuity and genders, Mann-Whitney Test was performed.This test was also used to find the relationship between near IPD and gender. We performed Spearman nonparametric correlation analysis to find out if there was any significant relationship between stereoacuity and interpupillary distance. Finally we performed a linear regression to find out the value of stereoacuity if the IPD was known.

RESULT
This study had total population of 60 subjects out of which 23 were male (33%) and 37 were female (67%). These subjects were within the age group of 18 to 35 and they were divided into three sub groups (18-23, 24-29, and 30-35). The study subjects included four races out of which 50% are Malay, 21.7% Chinese, and 28.3%Indian. In our study, as it is shown above, there were three races included (Malay, Chinese, Indian). We found no statistically significant difference in stereoacuity between three races (p=0.070). Table 2 shows the influence of race in stereoacuity.

TABLE2: STEREOACUITY ANALYSIS BASED ON RACE

Race	N	Mean ± SD	P value
Malay	30	7.383 ± 3.624	
Chinese	13	10.1912 ± 4.231	0.070
Indian	17	9.668 ± 4.513	

* Kruskal-Willis test

Our data shows there is no statistically significant difference in stereoacuity between different age groups (P=0.336). Table 3 shows the influence of age on stereoacuity.

TABLE3: STEREOACUITY ANALYSIS BASED ON AGE

Age	N	Median ±IQR	P value
18-23	39	7.517 ± 5.664	
24-29	16	10.2765 ± 8.6195	0.336
30-35	5	6.93 3.595	

- Kruskal-Willis test
- *Data represented in median ±IQR*

Our data shows there is a statistically significant difference in stereoacuity between male and female. Table 4 shows the influence of gender on stereoacuity (p=0.015).

TABLE4: STEREOACUITY ANALYSIS BASED ON GENDER

	Mean stereoacuity	**Median± IQR**	**Highest stereoacuity**	**Lowest stereoacuity**	**P Value**
MALE	10.26	9.88 ± 6.0015	19.09	3.5	
FEMALE	7.63	6.72 ± 4.875	17.24	3.17	0.015

- Mann-Withney U
- *Data represented in median ±IQR*

Our data shows there is a statistically significant difference in IPD between male and female. Table 4 shows the influence of gender on IPD size (p=0.014).

Table 5: Gender and Interpupilary Distance Relationship

	Mean NIPD	Median± IQR	Highest NIPD	Lowest NIPD	P Value
MALE	60.78	61 ± 6.5	66	55	
FEMALE	58.35	57 ± 4	65	52	0.014

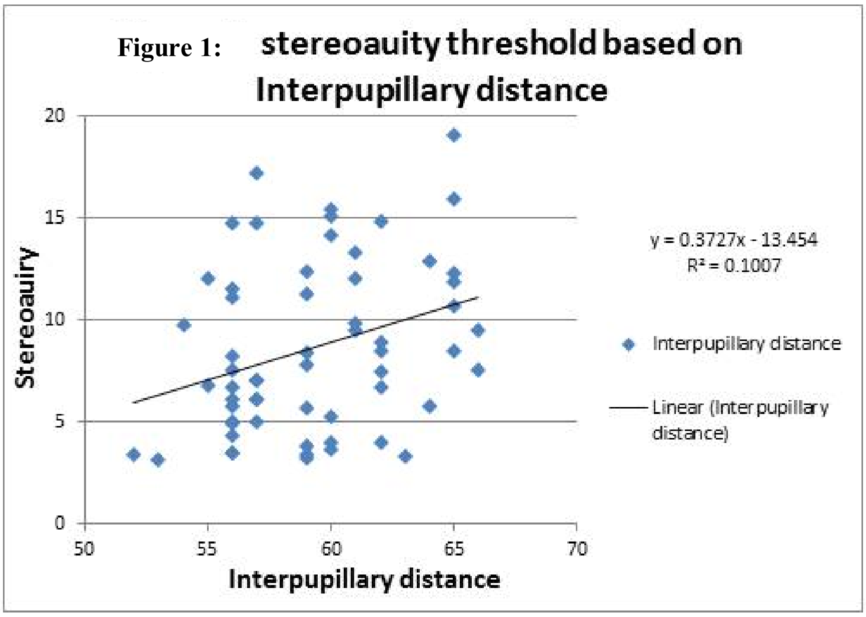
- Mann-Withney U
- *Data represented in median ±IQR*
- This table shows smaller IPD size for female subject. As you can see the average IPD for female subject is around 2.4 millimetres smaller than male subjects. Also females largest and smallest IPD was smaller than males largest and smallest IPD.

Finally the stereoacuity was analyzed based on near interpupillary distance of the subjects. Using a non parametric correlation we found out there was a significant difference between stereoacuity of different Interpupilary distance (p=0.013). Table 6 shows the correlation analysis.

TABLE 6: CORRELATION OF IPD WITH STEREOACUITY

Spearman's rho		NIPD	Stereoacuity
NIPD	Correlation coefficient	1.000	0.318
	Sig(2-tailed)	----	0.013
stereoacuity	Correlation coefficient	0.318	1.000
	Sig(2-tailed)	0.013	----

This table shows a p value of 0.013 which proves a significant difference in stereoacuity between different IPD.
The regression formula was extracted from the figure 1.



From this figure we found out that the relationship between Y (stereoacuity) and X (IPD) is a positive relationship. This is due to the positive value of R^2. This means the higher the value of IPD goes the higher the value of stereoacuity is, which means the stereoacuity will get worsen with higher IPD. From this formula we can calculate the stereoacuity of subjects with their near interpupillary distance from the formula below. This is only possible for subjects with normal binocular vision and no ocular disease.

Y=0.3727x –13.454 where X is Interpupillary distance and Y is stereoacuity

DISCUSSION

The purpose of this study is to find the relationship between stereoacuity and interpupilary distance. We tried to see if the size of the interpupillary distance has a significant effect on stereoacuity. We achieved this by increasing the Frisbystereotest distance to the point where subject could not distinguish between the squares of the test. Throughout this research two other interesting relationships were proven. First Interpupillary distance and gender, and second the relationship between stereoacuity and gender.

Our data showed that there is a significant difference between male and female subject's interpupillary distance (p=0.014). By calculating the mean and largest and smallest IPD in both genders, we found out that female IPD is generally smaller than male IPD by 2mm ± 1.5 mm. This result is similar to the study of Gender difference in interpupillary distance among Arabs [10] This study which focused on IPD in a larger age range than our study (5 to 45) proved that after 16 years of age the male IPD increases faster than the female to the extent that the average DIPD (distance IPD) and NIPD (near IPD) for both young and older adult males are significantly greater than the corresponding female value. From their data it was deducted that across all age groups the male IPD is 1.96 mm greater than that of the female at near. At far (also across all age groups) the male IPD is 2.42 mm greater than that of the female. Our result also agrees with the result of the study by Neil A. Dodgson about Variation and extrema of human interpupillary distance by stating that the t-value comparing the two genders is 20.2, which is significant at the 99% level. The mean IPD for male subjects are about 2 mm wider than female IPD. He also stated that on an average the difference between near and far IPD is 3 mm therefore the difference on IPD between male and female subjects are 2 mm both at near and distance.

In our study when we compared the three age groups (18-23, 24-29, 30-35) we didn't find any significant difference in stereoacuity among three groups (p=0.336). This results contradicts Zaroff et al's findings where they found out a significant relationship between age and stereoacuity (r=+0.44, P<0.0001). They also found out statistically significant influence of age on stereoacuity threshold (F=13.58, P<0.0001). Due to the nature of our study and the fact that the highest amount of stereoacuity was needed to be measured, the age group of 18-35 was chosen for our study. The reason why we didn't find any significant difference between stereoacuity and age group compare to Zaroff et al study is because of the smaller age range and exclusion of the older age groups. Furthermore it was explained by Zaroff et al in their study that one of the contributing factor for reduction of stereoacuity in older age groups is due to decrease in pupillary size with age(senile miosis) which leads to the reduction of retinal illuminance by 44% and also the retinal sensitivity for the target.Garnham et al, in their study regarding effect of age on stereoacuity as measured by different types of stereotest, stated that there is somereduction in stereoacuity with age in subjects with normalSnellen acuity and no history of ophthalmic disease. In their study Stereoacuity has been measured in 60 normal subjects within the age group of 17–83 years. Garnham et al concluded that overallstereoacuity as measured by all four stereotests declined with age (p<0.001 for all stereotests; Spearman rank correlation. Rho; TNO (r=0.55), Titmus (r=0.56), Frisby near (r=0.62), Frisby distance (r=0.61)). In more details they mentioned the data were analysed by comparing age bands, 17–29, 30–49, 50–69, and 70–83 years. For TNO and Frisby near stereoacuities there was a significant reductionbetween both the 30–49 and 50–69 age groups and between the 50–69 and 70–83 groups. Looking at these two studies we can clearly state that the decrease in stereoacuity has been reported after the age of 40 years [11]. Laframboise noted that normal aging produces a statistically significant deficit in binocular correlation processing. This process is marginally correlated with stereoacuity measures even when stereoacuity floor effects are factored out. The correlation between age and stereopsis is low but significant ($r = 0.33$; $t_{98} = 3.27$; $p<0.01$) and yields a determination factor of 11% [12]. Studies conducted by Schneck et al and Se-Youp lee et al also discuss the effect of age on stereoacuity. The results of these two studies showed statistically significant relationship between age and stereoacuity.

In our study we found out that there is a statistically significant difference in stereoacuity between male and female (p= 0.015). Female subjects have better stereoacuity compare to male subjects in Our study which contradicts the study of Zaroff et al where they found out there is no significant difference in stereoacuity between genders while using 100 ms stimuli for measuring stereoacuity threshold. In our study stereoacuity threshold was measured by increasing the viewing distance, which could be a possible reason for the discrepancy between our and Zaroff et al's study findings [11].

Our study showed no statistically significant difference in stereoacuity between different races (p=0.070) and we could not find any supportive study that either agree or contradict our results.

The main purpose of this study is to find the relationship between IPD and stereoacuity. First of all we found out that there is a statistically significant relationship between interpupillary distance and stereoacuity (p=0.013). Furthermore we proved that the subjects with smaller IPD have a better stereoacuity threshold. This result contradicts the Kinneth's Right interpretation of stereoacuity and IPD relation. In his Handbook of paediatric Strabismus and Amblyopia, he defined the relationship between IPD and stereoacuity by saying that, the farther apart the two eyes, thegreater the angle of visual disparity and the greater the stereoscopicpotential, which means the larger interpupillary distance have potential for better stereoacuity. However in our study for us to be able to find the stereoacuity threshold the viewing distance of the test have increased to the point until the depth discrimination was not detectable.

Through this method we found out that subjects with smaller IPD can detect the stereoscopic target further than the subjects with larger IPD. This result was also in contradiction with
Kinneth's view. He mentioned that the closer an object is to the eyes, the greater the angle of disparity; therefore, the better the stereoscopic view. As objects move away from the observer, the relative interpupillary distance diminishes as does the visual angle, so stereoscopic vision decreases for distance objects. Kinneth noted that the minimum stereoscopic resolution is a disparityof approximately 30 to 40 sec of arc. But in our results we found out that subjects could detect disparity up to 3.19 sec of arc. This result is far more different than Kinneth's 30 sec of arc. Therefore it could be possible that stereopsis testing conducted by him was not able to measure disparity below 30 sec of arc and the type of stereotest used might not be similar to Frisby near stereoacuity test. In a more recent study by John P. Frisby and Emma Patchick, it was also stated that there is a correlation between stereoacuity and IPD. In more details the study mentioned that the correlation was larger but not significantly so for distance stereoacuities ($r = -0.27$, $p<0.01$) than for near ($r = -0.18$, $p = 0.055$), possibly reflecting thesmaller size of the near group.
In our study not only the IPD was changing, but also the viewing distance was increasing to find the best possible stereoacuity for each subject. What we found out is that the maximum viewing distance of subject with larger IPD is shorter than the maximum viewing distance of subjects with smaller IPD. However Schor and Flom have stated in their study that disparity is inversely proportional to the square of viewing distance. As you change the viewing distance from 1 foot to 100 feet, the disparity will change by a factor of 10000 times. That is the same object displacement needed to see a same depth difference at 1 foot must be increased by 10000 times to be seen at 100 feet. So this finding supports our study with regard to Frisby near stereotest formula. As it has been stated the higher the viewing distance goes the lower the disparity will be and according to that formula this means the subject has a better stereoacuity. Furthermore from the Frisby formula we know that smaller IPD will make the disparity amount smaller when the viewing distance is constant [2].
There were some limitations to this study. The age group of this study was smaller than other studies regarding stereoacuity. Because of this we could not prove an already proven relationship between age and stereoacuity.Garnham et al,2007, studied the Effect of age on adult stereoacuity as measured by different types of stereotest. In this study a single experienced observer has measuredstereoacuity in a large group of patients across the whole adult age range using a battery of stereotests available inclinical practice. This has confirmed that there is some reduction in stereoacuity with age in subjects with normalSnellen acuity and no history of ophthalmic disease; Stereoacuity normally worsens with age but the age where it starts to do so is above 50 years old. In our study the age group was only from 18 to 35 years of age which is the best years for stereoacuity for healthy eyes.
Although the Frisbystereotest is the most suitable test among all of the near stereotest available, the fact that the best stereoacuity available on it is 20 seconds of arc is a limitation for this particular study. The best test would be a computer generated stereotest which could be as refined as 2 seconds of arc.
The interpupillary distance has a significant effect on stereoacuity in a sense that in the longer viewing distance of the stereotest and subject, the smaller IPD has the better stereoacuity threshold. This means people with smaller IPD can perceive depth in longer distance from the eye compared to people with larger IPD. Furthermore it is concluded that female subjects have both smaller IPD and better stereoacuity compared to male subjects.
It is our recommendation an experiment in a way where first stereoacuity is measured on different subjects and then IPD is manipulated on the same subject, to see the effect on stereoacuity, will have more interesting results. In the clinical aspect we will recommend the clinicians to keep in mind about the IPD while measuring stereoacuity for their patients while using Frisby near stereo test. To have more accurate measurement of stereoacuity the IPD must be included to the calculation. Our study was concentrated on relationship of IPD and stereoacuity only, we did not include the age and viewing distance factor to our calculation. Therefore it is recommended that future study should include age and viewing distance to find out the stereoacuity by taking into consideration of all the contributing factors.
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The authors denies any conflict of interest with publication of this manuscript.

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