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Effects of Monocular Blur on Clinical Measurements of Stereopsis and Binocular Contrast Sensitivity

(Kesan Kabur Monokular terhadap Nilai Ujian Klinikal Stereopsis dan Sensitiviti Kontras)

MOHD IZZUDDIN HAIROL, LOSHANE ARUSULEM & WONG JIA YING

ABSTRACT

Visual conditions such as anisometropia, monovision and monocular undercorrection affect the combination of visual input from both eyes. This study investigated the effects of monocular blur, in binocularly normal participants, on stereoacuity and binocular contrast sensitivity. Fifteen young adults (age range between 19 and 23 years old) with normal visual acuity and binocular vision participated in this study. Stereopsis was measured using the TNO test with a series of positive spherical lenses placed before the dominant eye. The procedure was repeated using the Titmus Stereotest on five participants as a control experiment. Monocular and binocular contrast sensitivities were also measured using the Pelli-Robson Contrast Sensitivity Chart. Blur was induced monocularly with a series of positive spherical lenses placed before the dominant eye and binocular contrast sensitivity was re-measured. Stereopsis scores decreased significantly when monocular blur was imposed. Across blur levels, absolute stereopsis scores measured with TNO test were worse than those measured with Titmus stereotest (all $p < 0.05$). However, the ratio of scores obtained without blur and under monocular blur appeared to be similar for both tests. Stereopsis without blur was between 6.82× to 8× better than that obtained with the highest level of imposed monocular blur. Binocular contrast sensitivity score decreased significantly with increasing level of monocular blur ($p < 0.01$). Binocular contrast sensitivity score without blur was 1.62× better than that obtained under binocular viewing with highest level of imposed blur. Stereopsis tests are more sensitive than measurements of binocular contrast sensitivity as an indicator of interocular acuity discrepancies which could occur in anisometropic or monovision patients. However, the choice of stereopsis test is crucial, as the TNO test appears to be more sensitive to monocular blur than the Titmus stereostest.

Keywords: Stereopsis; contrast sensivity; binocular summation; stereoacuity; blur

ABSTRAK

Keadaan penglihatan seperti anisometropia, individu dengan penglihatan tunggal (monovision) dan pembetulan refraktif yang tidak seimbang boleh mempengaruhi gabungan input penglihatan yang diterima daripada kedua-dua mata. Kajian ini dijalankan untuk mengkaji kesan kabur monokular pada persepsi kedalaman (stereopsis) dan sensitiviti kontras pada individu yang mempunyai penglihatan binokular yang normal. Lima belas subjek dewasa (umur antara 19 dan 23 tahun) dengan akuiti visual normal dan berpenglihatan binokular menyertai kajian ini. Stereopsis diukur menggunakan ujian TNO. Satu siri kanta positif (cembung) diletakkan di hadapan mata dominan subjek. Prosedur ini diulang menggunakan Ujian Stereo Titmus ke atas lima orang subjek sebagai kawalan. Kontras sensitiviti binokular pula diukur menggunakan Carta Sensitiviti Kontras Pelli-Robson. Ia diukur dalam keadaan kabur monokular yang diaruh menggunakan satu siri kanta positif yang diletakkan di hadapan mata dominan subjek. Skor stereopsis merosot secara signifikan dengan aruhan kabur monokular. Untuk semua tahap kabur, skor stereopsis merosot lebih teruk apabila diukur menggunakan plat TNO berbanding Ujian Stereo Titmus (kesemua $p < 0.05$). Walau bagaimanapun, apabila skor dalam keadaan kabur dinisbahkan kepada skor yang diperoleh tanpa pengkaburan, keputusan daripada kedua-dua ujian adalah hampir serupa. Skor stereopsis tanpa pengkaburan adalah 6.82× hingga 8× lebih baik daripada skor stereopsis yang diperoleh dengan kabur monokular paling tinggi. Sensitiviti kontras binokular menurun secara signifikan dengan peningkatan tahap kabur monokular ($p < 0.01$). Skor log sensitiviti kontras binokular adalah 1.62× lebih baik daripada sensitiviti kontras binokular dengan pengkaburan monokular tertinggi. Kesimpulannya, ujian stereopsis adalah lebih sensitif berbanding pengukuran sensitiviti kontras binokular, terutamanya dalam penilaian perbezaan akuiti interokular yang boleh berlaku pada pesakit anisometropia atau yang menggunakan sebelah mata sahaja. Pemilihan ujian stereopsis adalah penting dalam penilaian ini kerana plat TNO lebih sensitif terhadap kabur monokular berbanding ujian stereo Titmus.

Kata kunci: Stereopsis; sensitiviti kontras; penjumlahan binokular; akuiti stereo; kabur

INTRODUCTION

Binocular summation relates to the superiority of binocular to monocular visual performance. Pirenne (1943) found that the threshold of binoculars is about 1.4 times better than monocular threshold for detecting dim light. Matin (1962) suggested neural summation in which input from both eyes add together and create a neural input that leads to a better visual perception. Binocular summation improves the performance of a number of visual functions, such as visual acuity, contrast sensitivity, flicker detection and brightness perception. Campbell and Green (1965) suggest signal-to-noise ratio theory, which binocular vision can enhance the signals while reducing some noise. The most obvious advantages of binocular vision are stereopsis and binocular summation of contrast. For example, Pardhan & Gilchrist (1990) found that binocular contrast sensitivity was 42% higher than monocular contrast sensitivity.

Stereopsis is the binocular perception of relative depth, defined as the awareness of relative horizontal image disparity and usually measured as stereoacuity in seconds of arc (Romano et al. 1975; Ogle 1964). The neural basis of stereopsis can be attributed to the existence of the magnocellular pathway which encodes movement and depth perception (Livingstone & Hubel 1988). Clinical stereoacuity tests are used to determine the smallest amount of recognisable retinal disparity, within a set range of scores in seconds of arc. Measurements of stereoacuity are important in assessing binocular vision status and have widely been used for the detection and management of strabismus, amblyopia and anisometropia (e.g. see Levi et al. 2011 for review).

There is a battery of stereotests that use different designs, stimulus types and disparity range. Random dot stereotests, such as the Dutch organisation for Applied Scientific Research (TNO) stereotest (Lameris Ootech, Ede, Netherlands), are generally considered the gold standard for measuring stereoacuity. The TNO test consists of red-green anaglyphs, in which a flat circular surface has a 60 deg sector that is farther way then the rest of the surface by the amount of the test disparity. A pair of red-green glasses are used to separate the images presented to each eye. The test disparity varies from 480 to 15 seconds of arc. The Titmus Stereotest (Stereo Optical, Chicago, IL, USA), on the other hand, uses black, contoured stimuli. It is based on the presentation of disparate images to each eye, achieved with a cross-polarizing stereoacuity glasses. The image disparity varied from 3,000 to 40 secs of arc.

Contrast sensitivity is a measurement of the ability of the visual system to view static image at different levels of luminance. One of the most commonly used instrument to measure contrast sensitivity in a clinical setting is the Pelli-Robson Contrast Sensitivity Chart (Pelli et al. 1988). The chart uses Sloan letters of a constant size where they are arranged in groups of three. Each successive group decreases in contrast by a factor of $1/\sqrt{2}$. The scores are given in log contrast sensitivity units, ranging from 0.05 to 2.00. In normal observers, log contrast sensitivity scores measured with the Pelli-Robson Chart are known to be better when measured binocularly than monocularly (e.g. Sharanjeet Kaur 1998).

However, stereopsis and binocular summation of contrast sensitivity may be affected in certain visual conditions such as amblyopia, monovision and undercorrection. The effect on stereoacuity is significantly greater when there are disparate levels of blur between the two eyes (Westheimer & McKee 1980). Pardhan & Gilchrist (1990) conducted a study on the effect of monocular fogging on binocular contrast sensitivity using sine wave gratings of 6 c/deg with different amount monocular blur. They found that the maximum binocular summation of contrast sensitivity occurs in a condition without monocular fogging and binocular summation switch to binocular inhibition at a point between 1.50DS to 2.50DS.

In this study, we investigated the effects of monocular blur on stereoacuity assessed using the TNO test. A control experiment, using the Titmus stereofly, was also conducted as the test is widely available and is usually administered on children in the clinic. We also investigated binocular summation of contrast sensitivity using the Pelli-Robson Contrast Sensitivity Chart.

MATERIALS AND METHODS

PARTICIPANTS

A total of 15 students from Faculty of Health Sciences, Universiti Kebangsaan Malaysia, Kuala Lumpur Campus had been randomly selected to participate in this study. All participants were informed of the nature and objectives of this study and written consent was obtained from them prior to the start of any data collection. All participants had corrected visual acuity of 6/6 or better, with refractive error not exceeding ±3.00D sphere and astigmatism not exceeding -1.00D. All had normal binocular vision without any significant history of ocular or systemic diseases. Data collection were carried out in UKM Optometry Clinic. The conduct of this study had been approved by the Universiti Kebangsaan Malaysia (UKM) Ethical Committee for Medical Research (NN-2015-052). All procedures were in compliance with the conditions set by the Declaration of Helsinki (Human 1974).

MEASUREMENTS OF STEREOACUITY WITH MONOCULAR BLUR

Stereoacuity was measured using the Dutch organisation for Applied Scientific Research (TNO) stereotest (Lameris Ootech, Ede, Netherlands) at a working distance of 33 cm using the participants' dominant eyes. Eye dominancy was determined by the Miles test (Miles 1930). All participants wore full refractive correction, including correction for working distance that took into account the factor of crystalline lens accommodation. Stereoacuity was measured with a series of positive spherical lenses placed before the dominant eye to create a range of monocular blur levels. Six blur levels were tested, achieved with +0.12DS, +0.25DS, +0.50DS, +1.00DS and +2.00DS lenses. For all blur levels, no additional lenses were placed before the non-dominant eye, except the one used for correction of working distance. Five participants were involved in a control experiment, where stereoacuity was measured with the Titmus stereoest (Stereo Optical, Chicago, IL, USA) with the same levels of monocular blur. To avoid memorisation of results by the participants due to the repeated nature of the test administration, the test booklet was rotated randomly for each blur level.

MEASUREMENTS OF BINOCULAR CONTRAST SENSITIVITY WITH AND WITHOUT MONOCULAR BLUR

Monocular and binocular contrast sensitivity scores (without any imposed blur) were measured using the Pelli-Robson Contrast Sensitivity Chart at a distance of 1 metre. Participants wore full refractive correction including correction for the working distance. Scores were recorded in log units as directed in the manual. Next, binocular contrast sensitivity was measured with a series of positive spherical lenses placed before the participant's dominant eye. The lenses used to create the series of monocular blur levels were +0.25DS, +0.50DS, +1.00DS, +2.00DS and +3.00DS. Two readings were taken for each measurement and the mean was taken as the log contrast sensitivity scores.

DATA ANALYSIS

Data were sorted in MS Excel then analysed using SPSS (Statistical Package for Social Sciences) version 21. One-way repeated measures analysis of variance (ANOVA) with Greenhouse-Geisser correction was used to analyse the effects of different levels of monocular blur on stereoacuity and contrast sensitivity. For the stereopsis control experiment, two-way repeated measures ANOVA was used to compare the effects of stereopsis test type and monocular blur level on stereoacuity. Post-hoc tests were carried out to determine the monocular blur levels that caused a significant difference in stereoacuity and log contrast sensitivity score compared to when obtained under binocular viewing without imposed monocular blur.

RESULTS

Figure 1 shows the mean stereoacuity of 15 participants measured with the TNO test across blur levels. Stereoacuity reduced (i.e. units in seconds of arc became larger) as blur level was increased. One-way repeated measures ANOVA with Geisser-Greenhouse correction revealed that the effect of blur level on stereacuity measured with the TNO test was highly significant [$F_{(1.94, 27.17)} = 338.60$, $p < 0.001$]. Except for blur level +0.12D, Bonferroni pairwise comparison revealed that stereoacuity obtained across all other blur levels were significantly different from that obtained without monocular blur (all $p < 0.05$).

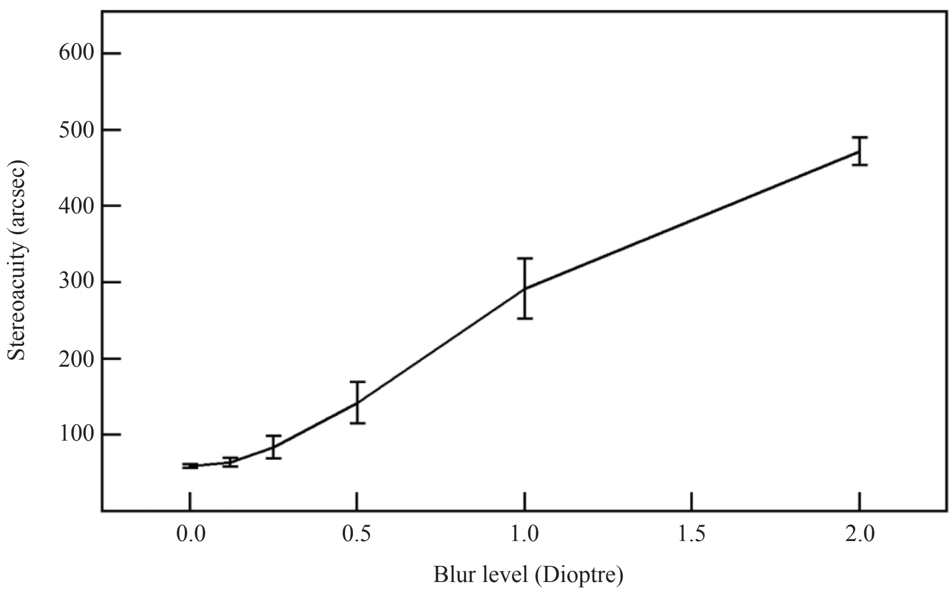

FIGURE 1. Stereoacuity measured with the TNO test, in seconds or arc, across different levels of blur that was imposed monocularly on the participants. The error bars represent ±1SEM

Figure 2 compares mean stereocuity of five participants measured with the TNO test and Titmus Stereotest in the control experiment. Only data from the same five partipants tested with both stereo tests were analysed. For both tests, stereoacuity reduced as the level of monocular blur was increased. However with increasing monocular blur, better stereoacuity scores (i.e., lower stereoacuity in seconds or arc) was obtained when measured using the Titmus Stereotest compared to the TNO test. Repeated measures ANOVA revealed that there was a significant effect of test type used [$F_{(1,4)}$ = 10.44, p = 0.032] and monocular blur [$F_{(1.30, 5.21)}$ = 46.03, p = 0.01] on stereoacuity scores. There was also a significant interaction between the type of test used and monocular blur [$F_{(1.29, 5.12)}$ = 9.01, p = 0.25], that is, the effect of increasing monocular blur on stereoacuity score was significantly dependent on the test used to measure stereopsis.

Figure 3 shows mean binocular scores in log units, across different levels of imposed monocular blur. Monocular and binocular scores of Pelli-Robson contrast sensitivity, without any imposed blur, was 1.68 ± 0.02 and 1.83 ± 0.02 log units, respectively. Increasing level of monocular blur significantly decreased binocular contrast sensitivity score [$F_{(2.53, 35.58)}$ =33.87, p < 0.01]. Post hoc tests revealed that binocular log contrast sensitivity scores under monocular blur levels of +1.00D, +2.00D and +3.00D were significantly lower than that obtained without any imposed blur (all p < 0.05).

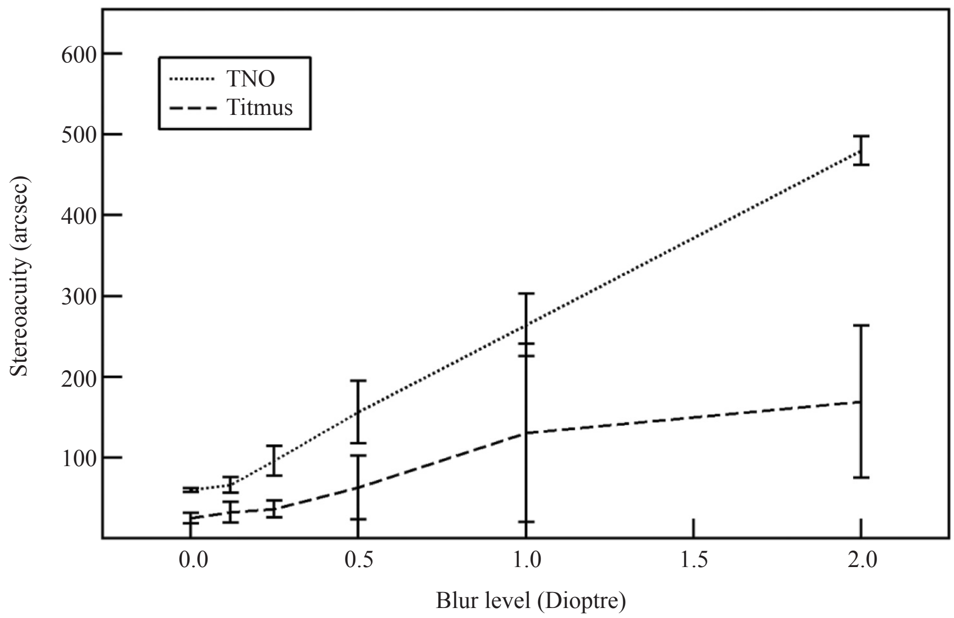

FIGURE 2. Mean stereoacuity measured in five participants with TNO test (dotted line) and the Titmus Stereotest (dashed line) across different levels of monocular blur in a control experiment. The error bars represent ±1SEM

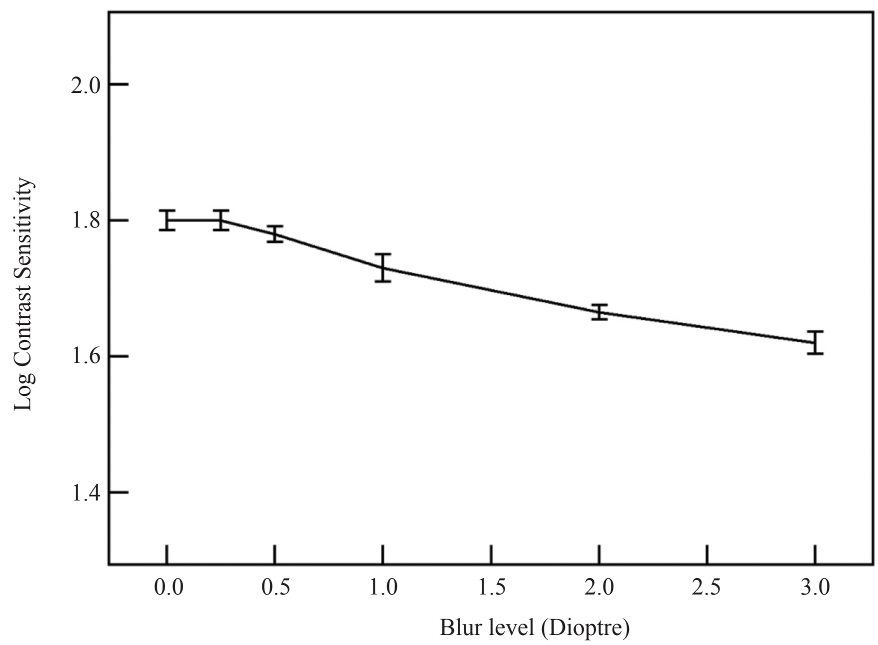

FIGURE 3. Binocular contrast sensitivity scores, in log units, measured with the Pelli-Robson contrast sensitivity test across different levels of imposed monocular blur. The error bars represent ±1SEM

Figure 4 plots the ratio between binocular viewing without blur and binocular viewing with imposed monocular blur, as a function of blur level. For any level of imposed monocular blur, a ratio bigger than the value of 1 means the test score was better during binocular viewing without any imposed blur lens. For stereopsis measured with the TNO test, the results between the main experiment in 15 participants (circular data points) and the control experiment with five participants (square data points) were very similar. For TNO test and Titmus Stereotest, performance ratios across blur levels were statistically similar, as there was no interaction between test type and blur level [$F_{(1.35, 5.38)} = 0.56, p = 0.54$]. However at the largest blur level of +2.00D, participants performed better with the Titmus Stereotest (no blur:blur ratio of 6.26 ± 0.92) compared to TNO test (no blur:blur ratio of 8.04 ± 0.23). For contrast sensitivity scores, the no blur:blur ratio was 1.69 ± 0.15 at the highest level of imposed monocular blur. The no blur:blur ratio for contrast sensitivity scores, for 15 (white diamonds in Figure 4) and five participants (filled diamonds in Figure 4) were similar.

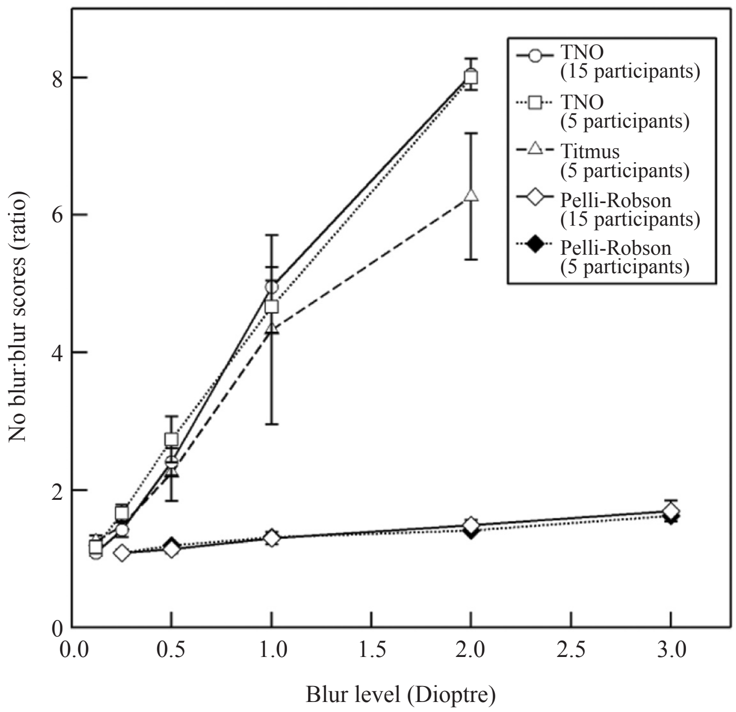

FIGURE 4. No blur to blur scores ratio for stereopsis tests and contrast sensitivity, calculated as a function of imposed monocular blur. Data from five participants in control experiments are also shown

DISCUSSION

EFFECTS OF MONOCULAR BLUR ON CLINICAL MEASUREMENTS OF STEREOPSIS

Stereoacuity is significantly degraded by monocular fogging, even with one eye is blurred by only +0.12D. Our results are in line with those of Donzis et al. (1983); Lovasik & Szymkiw (1985); Goodwin & Romano (1985); Schmidt (1994) and Lam et al. (1996). These researchers concluded that monocular blur, which results in monocular visual acuity loss would have a significant impact on stereoacuity. Studies have found that monocular fogging between +0.50DS and + 1.00DS is sufficient to decrease stereoacuity (Ong & Burley 1972; Brooks et al. 1996; Westheimer & McKee 1980; Lovasik & Szymkiw 1985). One study reported a decrease in stereoacuity with monocular fogging as low as +0.12DS (Larson & Lachance 1983).

We found that there was a significant difference in stereoacuity when measured with TNO test and Titmus stereotest. Better stereoacuity can be measured with the Titmus Stereotest than the Stereofly. It has been reported that in stereopsis tests such as the Titmus, there are monocular cues that help to identify the target (Okuda et al. 1977; Walraven 1975). On the other hand, the TNO test contains no monocular cues (Walraven 1975) and typically gives lower stereoacuity scores (that is, worse stereopsis performance) than other non-random dot stereotests, such as the Titmus stereotest (Hall 1982; Garnham & Sloper 2006). As the random dots in the TNO test are of high frequencies, uncorrected monocular refractive error may act as a low pass filter such as it selectively attenuates higher spatial frequencies (Wood 1983; Westheimer & McKee 1980). However, with our adult participants, we found that the relative increase in stereoacuity scores with increasing monocular blur was statistically similar between the TNO test and Titmus stereotest. As seen in

Figure 4, monocular blur up to 1D resulted in similar ratio of degradation of stereoacuity measured with the two tests. Indeed, it has been suggested that even if monocular cues are present in Titmus stereotest, proper instructions by the examiners can minimize the effect to give a more accurate stereoacuity score (Garnham & Sloper 2006; Donzis et al. 1983). What this tells us is that although raw stereoacuity scores are better when tested with the Titmus than the TNO, the detrimental effects of monocular blur on both tests are similar. An interesting observation was with 2D monocular blur, it is observed that the Titmus stereotest gave a better stereoacuity score than the TNO, although not statistically significant. This suggests that a bigger difference in the ratio of stereoacuity scores between the two tests may be found had we measured it with a larger range of monocular blur and perhaps with a larger number of participants.

THE EFFECTS OF MONOCULAR BLUR ON CLINICAL MEASUREMENTS OF BINOCULAR CONTRAST SENSITIVITY

Our participants' monocular and binocular log contrast sensitivity scores were 1.68 ± 0.02 and 1.83 ± 0.02 respectively, similar to a previous report in a local population (Sharanjeet Kaur 1998). We found binocular contrast sensitivity to be better than monocular sensitivity by 19.75%. Pardhan & Gilchrist (1990) reported that binocular contrast sensitivity was 42% higher than the monocular level using sine gratings. In addition, Rabin (1995) also reported that there was an average increase of 40% in contrast sensitivity measured in binocular condition compared with monocular condition. The lower improvement of contrast sensitivity measured binocularly with the Pelli-Robson Chart, compared to other tasks, is not surprising as there are differences in test scoring, scale and tasks between these studies.

Maximum binocular summation of contrast sensitivity occurs in the absence of monocular fogging. Increasing monocular fogging results in a decrease in binocular summation of contrast sensitivity. This result agrees with those of Pardhan et al. (1990) found that the maximum binocular summation of contrast sensitivity occurred in the absence of monocular fogging. In addition, their study also showed that binocular contrast sensitivity decreases with illuminance difference until it reaches the level of binocular inhibition. Besides, Pardhan and Gilchrist (1991) also showed that binocular summation decreased with an increase in interocular difference of refractive error. Indeed, our results showed that, binocular contrast sensitivity reduced to monocular performance when one eye was blurred with a spherical lens of at least 1D.

SENSITIVE TEST TO DETECT THE EFFECT OF INTEROCULAR DIFFERENCE IN REFRACTIVE ERROR/IMAGE CLARITY

Our results suggest that stereoacuity measurement is a better indicator for detecting conditions where there are interocular difference in refractive error or retinal image clarity, than comparing the difference between monocular and binocular contrast sensitivities. However, care must be taken in which stereotest is being administered to detect this difference. Absolute stereopsis scores are always better with the Titmus stereotest than the TNO test, with the TNO scores appearing to reduce a lot more with increasing monocular blur. However, the ratio of scores obtained without blur and with monocular blur appeared to be similar for both tests. The TNO test may become more sensitive to monocular blur when the interocular difference in refractive error is at least 2D. Stereopsis without blur was found to be between 6.82 × to 8 × better than that obtained with the highest level of imposed monocular blur. However binocular log contrast sensitivity score without blur was only 1.62 × better than that obtained under binocular viewing with the highest level of imposed monocular blur.

CONCLUSION

The results of our study show that monocular blur affects stereoacuity more than binocular contrast sensitivity. Stereoacuity is more sensitive to differences on uncorrected refractive (hence retinal image clarity) compared to binocular contrast sensitivity. Clinically, our results suggest that stereopsis test should be administered to more sensitively evaluate conditions such as monocularly undercorrected refractive error, monovision and anisometropia, especially in child patients with higher risks of developing certain eye conditions such as amblyopia.

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Mohd ‘Izzuddin bin Hairol
Loshane Arusulem
Wong Jia Ying
Optometry & Visual Science Program
School of Healthcare Sciences
Faculty of Health Sciences
Universiti Kebangsaan Malaysia
Jalan Raja Muda Abdul Aziz
50300 Kuala Lumpur

Corresponding author: Mohd ‘Izzuddin bin Hairol
Email:
Tel: 03-92897495
Fax: 03-26910488

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