Binocular Vision and Stereopsis

Monday, May 7, 2012, 1:45 PM - 3:30 PM
Hall B/C - Poster Sessions

Program Number: 1776 Poster Board Number: A118
Presentation Time: 1:45 PM - 3:30 PM

Binocular Concordance is Essential for the Preservation of Stereopsis

Janice M. Wensveen, Earl L. Smith, III, Li-Fang Hung, Ronald S. Harwerth
College of Optometry, University of Houston-Main Campus, Houston, TX.

Purpose: Previously, we established that brief daily periods of normal vision could preserve stereopsis in monkeys reared with optical strabismus. In this experiment we examine the importance of binocular concordance during the daily periods of normal vision.

Methods: Starting at 4 weeks of age, eight infant monkeys were reared with a total of 30 prism dipters base-in split between the eyes. Two monkeys wore prisms continuously for 4-6 weeks. Four monkeys wore prisms, but for 2 hours each day the prisms were replaced by clear plano lenses to provide concordant binocular vision. The duration of treatment was 4-6 weeks for 2 monkeys and 16 weeks for 2 monkeys. Two additional monkeys wore prisms for 16 weeks and for 2 hours each day the prisms were removed, but binocular disparity was disrupted by placing a diffuser lens over the right eye and a clear plano lens over the left eye. Five normally reared monkeys provided control data. Behavioral methods were employed to measure spatial contrast sensitivity, eye alignment, interocular suppression, and stereopsis with Gabor and random dot targets.

Results: Stereopsis was largely preserved by 2 hours of daily concordant binocular visual experience in both monkeys that were prism-reared for 4-6 weeks, and in one monkey prism-reared for 16 weeks. When binocularity was disrupted during the 2 hour daily period when the prisms were removed, stereopsis was not preserved. Interocular suppression prevented both monkeys from performing dichoptic judgments of position or depth, despite exhaustive training. One monkey showed normal monocular contrast sensitivity, and the other monkey showed moderately reduced contrast sensitivity of the eye that viewed through the diffuser.

Conclusions: During early visual development the effects of normal vision outweigh the effects of abnormal vision, but what constitutes ‘normal’ vision depends on whether the developing visual function is monocular or binocular. Binocular concordance is essential during daily periods of respite from optical strabismus for the preservation of binocular visual functions including stereopsis. Binocular concordance, however, is not essential for the maintenance of normal monocular spatial vision in monkeys.

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Factors Influencing Static Stereoscopic Vision among Adults with Normal Visual Functions

Tadashi Muraoka1, Toru Konishi1, Hiroya Goto1, Masaru Takeuchi2, 1Department of Ophthalmology, National Defense Medical College, Tokorozawa-City, Japan; 2Department of Ophthalmic and Neurological Surgery, National Defense Medical College, Tokorozawa, Japan.

Purpose: To identify factors that differentiate stereoscopic from non-stereoscopic vision with a small binocular disparity among adults with apparently normal visual functions.

Methods: We studied 395 Japanese males (age 43.8±7.7, range 20-58) certified healthy according to the Japan Air Self Defense Force (JASDF) aeromedical standard, with apparently normal visual functions including static stereoscopic acuity (40 seconds of arc or better by the Titmus Stereo Test) and dynamic stereoscopic function (within 20 mm of deviation by the three bars test). Subjects were divided to 2 groups by their confidence in depth perception at 40 seconds of arc in the Titmus Stereo Test: those who were able to distinguish the optotypes by their three-dimensional appearances (n=213), and those who were able to distinguish the optotypes, but not confident in the stereic differences between the optotypes (n=182). Distant visual acuity (5 m), near visual acuity (30 cm), angle of strabismus, near point of convergence, and dynamic stereoscopic function were analyzed.

Results: No statistically significant differences between the two groups were found in distant and near visual acuity, angle of vertical strabismus, and dynamic stereoscopic function. However, significant differences were observed in age (42.4±8.4 versus 45.4±6.4 years, p<0.05 by Wilcoxon rank sum test), and in near point of convergence (71.5±12.0 versus 74.7±10.3 mm, p<0.05 by Wilcoxon rank sum test). Multivariate analysis suggests that the factors that differentiate static stereoscopic vision from non-stereoscopic visual perception are age (>46, range odds rate 2.20), angle of horizontal strabismus (>2.1 prisms, range odds rate 1.69), and deviation in three bars test (>10 mm, range odds rate 1.82) (p<0.05 by Wald test).

Conclusions: Some subjects who cannot perceive static stereoscopic optotypes three-dimensionally are still able to distinguish between different optotypes. In adults with apparently normal visual functions, perception of depth in static stereoscopic vision may be affected by age, angle of horizontal strabismus and dynamic stereoscopic function.

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degrading BSV on performance of certain fine motor tasks requiring speed/accuracy.

Methods: Binocular functions (Frisby/Preschool Randot (PSR) stereocuity, horizontal phasic prism fusion amplitudes) were measured in participants aged 18-40 years (n = 54), with Frisby stereocuity <300' and logMAR visual acuity (VA) ≤0.30. Participants performed 3 timed motor tasks: water-pouring (450mLs accurately into 5 measuring cylinders at 90mL) and bead-threading on upright needles (30 large, 22 small beads). Task and binocular function measures were then repeated in randomised order while wearing convex spherical lenses of increasing power over one eye, reducing uncorrected VA in 3-line increments up to 12 lines degradation, followed by a convex spherical lens of sufficient power to induce unisocular suppression. Comparisons were made with Kruskal-Wallis tests.

Results: Median Frisby stereocuity levels were 20' arc at baseline, reducing to 30' arc when VA was degraded by 3 lines, 55' arc by 6 lines, 215' arc by 9 lines, and was unmeasurable in most by 12 lines. Some maintained fusion/stereocuity at 12 lines degradation and required an additional lens to induce unisocular suppression, while in others it was unmeasurable at 6 or 9 lines degradation. Task performance times deteriorated for the large bead task (0-20% performance deterioration between lenses, total 43% deterioration from median baseline time of 56.82s, p < 0.001). During the water-pouring task, degrading BSV was significantly associated with altered performance (p = 0.025), and performance times (p < 0.001), while alterations were small (0.20-0.33, 0.5mL) and not markedly associated with level of BSV.

Conclusions: Based on this sample, degrading BSV significantly affects performance in certain fine motor skill tasks, more so when suppression occurs. Findings agree with other studies showing impairment on bead-threading tasks when stereocuity/motor fusion is impaired. The task battery is limited and further research is required to establish the contribution BSV makes to other fine motor tasks.

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Effect Of Monocularly And Binocularly Induced Astigmatic Blur On Stereocuity Shinichiro Nakano1, Takahiro Hiraoka2, Yumi Hasegawa3, Tetsuro Oshika1.

1Optomathology, Ryugasaki Saniheiki Hospital, Ryugasaki, Japan; 2Optomathology, University of Toksuka, Ryugasaki, Japan.

Purpose: To evaluate the effect of monocularly and binocularly induced astigmatism on stereocuity.

Methods: Twelve normal volunteers (31.2 ± 5.2 (mean ± SD) years) with spherical equivalent refraction between 0 and -6.00 diopeters (D), refractive astigmatism up to 0.75 D were enrolled. After correcting each refractive error by spectacles, against-the-rule (ATR) or with-the-rule (WTR) astigmatism was intentionally produced in both eyes in three steps (+1.0, +2.0 +3.0D) in random order, and stereocuity was evaluated by using 9 circular-quadruple targets (20 ~ 400 arc seconds) of OPTEC Vision Tester 6500 (Stereo Optical Co., Inc.). The cylindrical addition of different powers (+1.0 ~ +3.0D) was compensated with spherical lenses to achieve zero spherical equivalence. These examination was repeated with monocularly astigmatic induction (i.e.: no astigmatism in fellow eye).

Results: The mean stereocuity (log arc seconds) in each condition was 1.59 ± 0.19 for binocular WTR, 1.47 ± 0.16 for monocular WTR, 1.49 ± 0.14 for binocular ATR, and 1.50 ± 0.19 for monocular ATR astigmatism at 1D induction. At 2D induction, it was 2.06 ± 0.35, 1.96 ± 0.31, 1.80 ± 0.29, and 1.84 ± 0.29, respectively. At 3D induction, it was 2.41 ± 0.19, 2.22 ± 0.27, 1.96 ± 0.31, and 2.28 ± 0.29, respectively. When compared between binocular and monocular astigmatic induction, there were no significant differences in stereocuity for ATR astigmatism (p = 0.24 for 1D, p = 0.56 for 2D, and p = 0.28 for 3D, Mann-Whitney U test), and also for WTR astigmatism (p = 0.80, 0.24, 0.14, respectively). When compared between ATR and WTR astigmatism, there were no significant differences in stereocuity for monocular astigmatic induction (p = 0.84 for 1D, p = 0.93 for 2D, and p = 0.71 for 3D). Similarly, there were no significant differences in stereocuity between ATR and WTR astigmatism for binocular astigmatic induction up to 2D (p = 0.32 for 1D and p = 0.13 for 2D) However, at 3D induction, stereocuity in binocular ATR astigmatic defocus was significantly worse than that in binocular WTR astigmatic defocus (p < 0.021). In addition, significant correlations were found between astigmatic power and stereocuity in all conditions (r = 0.81, p < 0.001 in monocular WTR, r = 0.85, p < 0.001 in monocular ATR, r = 0.81, p < 0.001 in monocular ATR and r = 0.80, p < 0.001 in binocular ATR astigmatism, Spearman's rank correlation coefficient).

Conclusions: Both binocular and monocular astigmatic induction degraded stereocuity as astigmatic power increased. There were no apparent differences in stereocuity between binocular and monocular astigmatic induction. However, stereocuity seemed to be affected more severely by ATR than WTR astigmatism in binocular and high power astigmatic induction.
Stereoacuity with Monovision and Small Aperture Approaches to Correct for Presbyopia
Enrique J. Fernandez, Christina Schwarz, Pedro M. Prieto, Silvestre Manzanera, Juan Tabernero, Pablo Arrill. Laboratorio de Optica, Universidad de Murcia, Murcia, Spain.

Purpose: Different bilateral approaches are currently applied to correct for presbyopia. While they provide reasonable visual acuity over an extended range of object vergences, inter-ocular image quality difference tends to reduce stereo vision. We compared stereo-acuity (SA) with monovision and a small aperture inlay measured by using a binocular adaptive optics instrument.

Methods: For performing the experiment a prototype of a binocular adaptive optics visual analyzer was employed. The experimental system allowed the simultaneous measurement and manipulation of optics in the two eyes of a subject. The apparatus incorporated two programmable modulators using liquid crystal on silicon technology for wavefront shaping and to produce the artificial pupils. The prototype was also equipped with a stimulus generator based on a pair of high luminance micro-displays in order to perform visual testing through the modified optics. Each display was independently projected over its corresponding eye, still simultaneously, creating retinal disparity. For characterizing stereopsis, a three-needle test was programmed. Subjects underwent a forced choice test, discriminating if the stimulus, the central wire, was in front or behind the reference two other wires for different disparities. The following cases were tested for the stimulus placed at distance: a) normal (4 mm pupils); b) micro-monovision (0.75D in one eye); c) monovision (-1.5D in one eye); d) small aperture (1.6 mm pupil in one eye). SA was measured in three subjects with normal stereovision, with paralyzed accommodation. In the experiment 15 runs for each disparity value were completed.

Results: The average results showed a SA around 10 arcsec in the normal case for the tested conditions. The small aperture barely affected stereopsis, with a small average increase to 15 arcsec, although not significantly different from the normal case. Micro-monovision reduced SA by a factor of 4 (to around 45 arcsec). In the 3 subjects tested monovision produced a near random response within our disparity range, revealing a SA larger than 80 arcsec. A simple model based on the measured retinal images for each case were predicted the SA we found experimental findings.

Conclusions: A new adaptive optics instrument permits the investigation of the impact of different optical solutions to correct presbyopia, including stereo vision. The small aperture approach does not modify SA due to a moderate retinal disparity. On the contrary, monovision severely degraded stereo vision as a result of largely different image quality in both eyes.

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Surprising Speed Jitter Invariance Of Pattern Matching In Random Dot Stereopsis
Frank Schaeffel, Arne Ohlendorf, Matthias Bethge. 3Section Neurobiology of Eye, Ophthalmic Research Institute, Tuebingen, Germany; 4Bernstein Center for Computational Neurosciences, Tuebingen, Germany.

Purpose: During fixation, retinal images jitter around the fixation point, partly independently in both eyes. Since we are not aware of the jitter (despite that the amplitudes should be large enough to be seen), it is assumed that the image is stabilized by neural processing. We have tested how sensitive random dot stereopsis is against independent random spatial jitter of the two patterns to be fused, to learn about the performance of the “image stabilizer”.

Methods: Two random square random dot patterns with 4 deg angular extend in the visual field were alternately presented on top of each other at 30 Hz on a computer screen. A pink/green spectacle was used to make only one pattern visible for each eye. The two patterns contained a 2 deg squared random dot field in the middle that could be displaced with mirror symmetry in horizontal direction (Julesz 1964) by 4 min of arc, causing a strong impression that the square was in front or behind the surrounding pattern. The patterns for each eye could be independently and randomly jittered with different angular amplitudes. Furthermore, 5 different patterns pairs could be shown in rapid sequence at 30 Hz for each eye.

Results: Thirteen adult subjects could reliably tell whether the central square was in front or behind the reference plane, even with independent random spatial jitter of the patterns shown to either eye. At 0.53 deg average jitter amplitude, 77% of the response were still correct, even though the disparities were 8 times smaller than the jitter amplitudes and 16 times smaller than the dots in the patterns. This result could be explained by a post-receptor image stabilization in both eyes that operates at least at 30 Hz before the information from both eyes is combined in the cortex. A less likely explanation is that pattern matching occurs in fact at 30 Hz (even though their positions in the left and right eye were variable). To test this hypothesis, 5 different pattern pairs were exchanged at 30 Hz, and jittered in addition. Surprisingly, depth perception was still functional and not different from the results with a single pattern.

Conclusions: Random dot stereopsis operates extremely fast (30 Hz at least per pattern, nearly to be matched robust against jitter (retinal positions randomly vary much more than the disparity to be decoded). This finding challenges the standard model of neural disparity coding where the neurons are assumed to have a fixed preferred disparity that originates from their binocular receptive fields. It confronts us with the intriguing question how invariance against random variations in the offset between the left and right image can be achieved by the neural circuitry and involves a close analysis of all dots since one dioptr of defocus blocks random dot stereopsis.

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Vergence Adaptation And Convergence Accommodation In Convergence Insufficiency
Vidhyaapriya Sreenivasan1, Preethi Thiagarajan2, William R. Bohler1. 1Optometry, University of Waterloo, Waterloo, ON, Canada; 2State College of Optometry, State University of New York at New York, NY.

Purpose: Our group previously showed that the capacity to tolerate steady increases in base out (BO) prism (positive fusional vergence; PFV) correlated with an increased rate and magnitude of vergence adaptation1 in binocular normal adults. We concluded that vergence adaptation increased blur tolerance by reducing the excessive convergence accommodation resulting from the base-out prism. Reduced levels of PFV is a common finding in convergence insufficiency (CI) as is reduced vergence adaptation2. Here we examine whether the reduced vergence adaptation in these individuals is accompanied by a reduced ability to control convergence accommodation output compared to normals.

Methods: Ten participants (mean age = 17.4±2.3 yrs) with convergence insufficiency (CI) were examined. Participants showed reduced PFV at 40 cm or inadequate levels to compensate for their high exophoria (Sheard’s criteria) at near (mean BO to blur in group=12±0.9Δ). Testing followed our previous experimental design for (n=11) binocularly normal adults1. Patterns of vergence adaptation to a 12 Δ BO while viewing a difference of Gaussian target were measured at 3 min intervals over a 15 min period using brief phoria measures (Thorington technique).

Concurrent measures of convergence accommodation were also taken using a PowerRefractor (Multichannel system,Germany) for 5 sec at each 3 min interval. The magnitude of change in vergence adaptation and convergence accommodation was quantified in each CI participant using an exponential decay function and then compared to normal data. As tonic changes in accommodation could confound the CA measures, this was assessed in each participant following testing.

Results: The data of two participants who were unable to fuse through the 12 Δ BO could not be included in the averaged results. When exponential decay patterns of vergence adaptation and CA were compared to our binocularly normal participants, patients with CI showed significantly reduced amplitude of decay of vergence adaptation (CI=2.9±0.8Δ; Normals=6.6±0.4Δ, p<0.01) and convergence accommodation (CI=0.23±0.1D; Normals=0.51±0.02D; p<0.03). Tonic accommodation did not show any significant difference (p>0.72) before and after sustained prism viewing in the CI group (Changes=0.05±0.1D), similar to binocular normals (Changes=0.01±0.2D; p=0.8).

Conclusions: The reduced capacity of vergence adaptation found in patients with convergence insufficiency results in higher levels of convergence accommodation which may correspond to the reduced base-out to blur response observed during clinical positive vergence testing in the group.


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The Relationship Between Accommodation and Vergence in Binocular Viewing During Early Infancy
T R. Candy, Erin Babitsky, Tawna Roberts, Eric Seemiller, Vivian Wong. Ophthalmology, Indiana University, Bloomington, IN.

Purpose: Classical models of accommodation and vergence incorporate a number of components either in the context of the Maddox/Heath classifications (blur-driven, disparity-driven, tonic, coupled, proximal and voluntary) or Controls Theory models (phasic, tonic, coupling and plant). In either vocabulary, these components may combine with different weights to generate relatively coupled or independent responses when all cues are available. Previous studies have reached inconsistent conclusions regarding the relative maturation of accommodation and vergence, but have implied that the final motor responses are not tightly coupled in copyright 2012 by the Association for Research in Vision and Ophthalmology, Inc., all rights reserved. For permission to reproduce any abstract, contact the ARVO Office at pubs@arvo.org.
early infancy. This study asked whether this relative independence only becomes apparent across individuals or exists within an individual.

Methods: Accommodation and vergence responses were recorded simultaneously from 74 3-4 month-old infants using an eccentric photorefractor (Multi Channel Systems, 25Hz). The infants were presented with an animated movie (a broadband spatial amplitude spectrum) moving repeatedly in a ramp fashion between dioptric distances of 1.1 and 2.85D. The subjects viewed the movie in full-cue binocular viewing conditions. The correlation between the accommodation and vergence responses to this stimulus was determined and the responses were simulated using Hung and Semmlow’s static model (1980) and Schor’s dynamic model (1992).

Results: 66 infants gave usable data and 37 of them had a correlation between their accommodation and vergence data of greater than 0.6. The vergence responses were more repeatable within individuals than accommodation and relative drift of the accommodation response was not uncommon at deep levels (the order of 1-2 D) beyond the depth of focus predicted by their expected acuity. While the average responses could be simulated well using the models, the deterministic structure of the models prevented simulation of the drift.

Conclusions: While the accommodation and vergence systems demonstrate coupled open-loop responses during early infancy, the effective coupling in full-cue conditions is not tight in many 3-4 month-olds. While this may lead to inaccurate responses at times, it could also permit young infants to maintain both focused and aligned visual experience during early development and reduce the potential for cue conflict and strabismus.
seconds (\(^{\circ}\)). In each iteration one disk is randomly shown to be in front of the others by a certain disparity difference. The subject has to identify the front disk by pointing on it using our gesture control (see figure). The time to detect the correct disk was measured. In five iterations we showed the disparity differences 300\(^{\circ}\), 225\(^{\circ}\), 150\(^{\circ}\), 75\(^{\circ}\), and 15\(^{\circ}\). This enables the evaluation of perception time as a function of decreasing disparity. We tested 10 healthy subjects (17-36 years) at a distance of six meters. We classified a given disparity to be perceptible by the subject, if the subject was able to identify the front disk at least four out of five times.

**Results:** The average perception times for correct decisions varied from 1234 ms to 2951 ms in the range of 75\(^{\circ}\)-300\(^{\circ}\) disparity and from 2358 ms to 3877 ms with the disparity of 15\(^{\circ}\) (see diagram). In average the perception times decreased with increasing disparity and seemed to saturate in the range of 75\(^{\circ}\)-300\(^{\circ}\). A clear gain of perception time is observable at 15\(^{\circ}\). Two subjects were not able to detect the correct disk and were removed from the statistics.

**Conclusions:** The presented test is a novel tool to analyze stereo vision in far distances by measuring perception time as a function of disparity using a virtual environment.

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**Purpose:** A wearable-head-mounted system that shows information about the proximity of objects by color and thickness of the depicted contour has been developed and tested.

**Methods:** In this work, a Trivisio ARvision-3D HMD (Head mounted display) has been used. This HMD has integrated two cameras with 752x480 pixels and projects in two 800x600 LCD displays. A proprietary algorithm has been developed to perform a contour map of the scenario. The algorithm is based in the following sequence: contour detection, depth algorithm computation, and assignation of color or thickness to the plotted contours according to distance from the HMD to the objects detected. Contour detection is performed first because in order to accelerate the depth computation this is only processed in the vicinity of contour regions. Disparity maps are generated with the stereoscopic correlation between both images. A laptop with Intel Core i5 processor, 2GB RAM memory and three USBs and VGA video output, necessary to connect to ARvision-3D HMD, is used to implement the aid.

**Results:** Processing times of 11 to 15 frames per second are achieved. A graphic interface is also implemented for the Visual Rehabilitation Professional to control the different parameters to apply in the algorithm, such as color, thickness and their related calibrated distances to objects.

**Conclusions:** The system demonstrates that two cameras and a HMD can be used to achieve a wearable vision aid, in such a way that the obstacles could be detected easily on real time. The application also shows information about the proximity of objects by color and thickness of the depicted contour. Future trials include clinical tests.

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