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VARIATION OF BINOCULAR CONTRAST SUMMATION WITH INDUCED VERTICAL FIXATION DISPARITY

I, Kristina Louise Aikens, hereby release this paper as described above to Ferris State University with the understanding that it will be accessible to the general public. This release is required under the provisions of the Federal Privacy Act.

Kristina Aikens
Doctoral Candidate

03/19/2019
Date

VARIATION OF BINOCULAR CONTRAST SUMMATION WITH INDUCED VERTICAL FIXATION DISPARITY

by

Kristina Louise Aikens

This paper is submitted in partial fulfillment of the
requirements for the degree of

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Michigan College of Optometry

May, 2019

VARIATION OF BINOCULAR CONTRAST SUMMATION WITH INDUCED VERTICAL FIXATION DISPARITY

by

Kristina Louise Aikens

Has been approved

13 April, 2019

APPROVED:

Faculty Advisor: Dr. Avesh Raghunandan

ACCEPTED:

Faculty Course Supervisor

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ABSTRACT

Background: Previous studies have supported the notion that binocular summation varies with stimulus spatial frequency. In this study we hypothesize that the magnitude of the interocular phase shift induced by a fixation disparity has an indirect relationship with the magnitude of binocular contrast summation. *Methods:* Binocular and monocular contrast detection thresholds were measured in 6 (six) subjects for 3 (three) spatial frequencies (1 (one), 3 (three) and 9 (nine) cpd) and for various magnitudes of vertical fixation disparities induced by 5 (five) magnitudes of vertical prism (0 (zero) PD, 1.5PD BU/BD, 3 (three) PD BU/BD). Detection thresholds were measured using a 2 (two) interval forced choice method with a descending methods of limits. Vertical fixation disparity was measured at the beginning and end of each binocular contrast sensitivity measure for each spatial frequency condition. *Results*: The binocular contrast summation ratio was compared to the average phase shift produced by the vertical prism. The data trends provide suggestive indications that induced period shift due to vertical fixation disparity may influence the magnitude of binocular contrast summation, however there was no significant difference in this relationship. There was significant vergence adaptation to vertical prism during testing. *Discussion:* The current experimental paradigm is not effective at revealing a phase dependence, specifically given the confound of prism induced vergence adaptation. Thus, these results should be interpreted with caution.

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CHAPTER 1

INTRODUCTION

The increased detectability of a visual stimulus under binocular viewing conditions compared to monocular viewing conditions is referred to as binocular summation. Binocular summation occurs with stimulus variables including temporal frequency, spatial frequency, movement, and contrast (Cogan et al., 1982, Read et al., 2016, Alberti, 2018). Contrast detection thresholds under binocular conditions have been shown to be lower than monocular detection thresholds in normal human binocular systems (Campbell and Robson 1967, Rose 1977, Arditi et al. 1980, Cogan et al. 1982, Legge, 1983, Meese et al., 2006). This tendency becomes less pronounced as contrast levels increase. Pirenne (1943) originally attributed the superiority of binocular viewing to the probability summation of each eye as an independent detector. However, evidence of the existence of binocularly driven cortical neurons (Hubel and Weisel, 1968), and reports that detection thresholds under conditions that allow sensory fusion are superior to those predicted by probability summation alone (Matin, 1962, Blake and Rush, 1980) discounted the operation of "binocular" processes that were strictly independent between eyes. Observations of summation magnitudes that exceeded the predictions of probability summation have been taken as evidence for the existence of dedicated neural or physiological mechanisms that merge signals from each eye at a binocular cortical level – specifically when viewing conditions favor sensory fusion. This type of summation has been termed “neural” or “physiological” summation. It is noteworthy that behavior consistent with probability summation has been demonstrated in normal binocular systems when stimulus conditions do not favor sensory fusion (Matin, 1962; Rose, Blake and Halpern, 1988). Hence, the visual system is capable of employing both Probability Summation and Neural summation strategies, depending on the viewing situation.

Several studies have proposed computational models that attempt elucidate the process of neural or physiological summation. These include the signal: noise summation theory proposed by Campbell and Green (1965); the quadratic summation model proposed by Legge (1983), and more recent models which incorporate monocular and binocular stages of inhibitory and facilitatory interactions in the form of contrast gain control (Meese et al., 2006; Maehara and Goryo, 2005; Ding and Sperling, 2006, Ding, Klein and Levi, 2013).

While contrast detection threshold varies between monocular and binocular viewing conditions, it also varies with the spatial and temporal properties of a stimulus (Campbell and Robson, 1967, Rose, 1977 and 1980, Kelly, 1979). There is evidence of binocular summation of stationary grating stimuli in psychophysical studies (Campbell and Green, 1965, Blake and Levinson, 1977, Legge, 1983, Levi, Harwerth, Smith, 1980). Previous psychophysical studies have also documented evidence for the effect of spatial frequency on binocular summation. (Rose 1988, Alberti and Bex 2018, Raghunandan and

Cumings 2016). In contrast, Anderson and Movshon (1989) reported that binocular summation results were not affected by spatial frequency (1.5 to 6 cpd). The effects of horizontal (and to some extent vertical) fixation disparity on binocular summation has been assessed by Rose (1988) and Read et al. (2016), who reported that binocular summation occurs over a range of horizontal fixation disparities before binocular performance approaches the level of probability summation. However, a recent study by Raghunandan and Cumings (2016) noted a decrease in the magnitude of binocular summation with increasing spatial frequency. One hypothesis for this trend is that small magnitudes of habitual fixation disparity can induce large interocular phase disparities especially at higher spatial frequencies. It is known that counter-phase gratings display very little to no binocular summation (Green and Blake, 1981). Therefore, it is conceivable that small magnitude of fixation disparities could be transformed into large interocular phase disparities that approach counterphase disparities at high spatial frequencies.

Therefore, the aim of this study was to measure contrast detection thresholds for binocular and monocular grating stimuli for 3 (three) spatial frequencies and for vertical fixation disparities induced by 5 (five) magnitudes of vertical prism. We report no significant effect of vertical fixation disparity on the binocular summation of contrast in grating stimuli. However, we advise caution in interpreting these results using the current paradigm. We noted a significant effect of adaptation of fixation disparity with prolonged use of the inducing vertical prism. This posed as a significant unforeseen confound in elucidating the effect of induced vertical fixation disparities on binocular summation magnitude.

CHAPTER 2

METHODS

All stimuli were generated using Matlab on a MacBook Pro and presented on a gamma corrected Dell Trinitron CRT interfaced with a DataPixx^{TM} hardware system using Psychotoolbox (Brainard, 1997). This allowed 16 Bit grayscale look up table resolution.

STIMULI

The stimulus for contrast detection threshold for each eye was a 2.13 x 2.13 Gabor grating with 1 (one) of 3 (three) cosine carrier spatial frequency gratings (4 (four), 9 (nine), and 18 (eighteen) cpd) and temporally modulated at 2 (two) Hz (Figure 1 (one)).

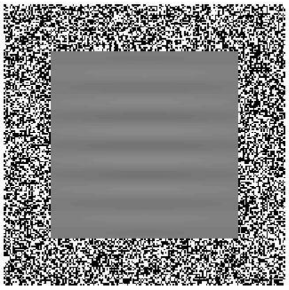

Figure 1. Example of the Gabor grating stimulus with a cosine carrier spatial frequency grating.

The stimulus was viewed through a phoropter with cross polarizing filters over the viewing apertures and the monitor to ensure dichoptic viewing of the stimulus. The polaroid filters were oriented such that the right eye viewed only the left half of the monitor and the left eye viewed only the right half of the monitor. The screen background was dark and the viewing distance was 1.19 m.

For monocular contrast detection tasks, the Gabor stimulus was presented in the square region visible by the tested eye, while the non-tested eye viewed a gray square region of the same angular size and mean luminance (2.62 cd.m^{-2} as measured through the polarizing filters). The two square regions were positioned adjacent to each other with a lateral separation of 0.57 degrees. For binocular contrast detection tasks, the Gabor stimulus was presented to each eye simultaneously in both square regions.

To measure vertical fixation disparity a small black square was presented continuously to both eyes in the center of the gray test box as a fusion lock. Two 30 arc minute nonius lines were presented dichoptically on either side of the fusion lock simultaneously for 100 milliseconds (Figures 2 (two) and 3 (three)). The right eye viewed the line to the left of the fusion lock and the left eye viewed the line to the right. The left line was of a fixed location and in alignment with the fusion lock throughout

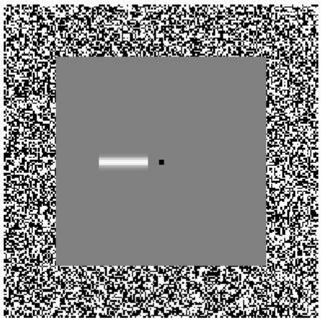

Figure 2. Example of the stimulus presented to the right eye to measure fixation disparity. Note the black square and Randot pattern as fusion locks and the white reference line.

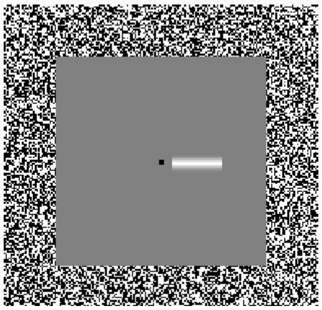

Figure 3. Example of the stimulus presented to the left eye to measure fixation disparity. Note the black square and Randot pattern as fusion locks and the adjustable white measurement line.

testing. The right line was adjustable and presented at randomized starting positions relative to the left line.

PSYCHOPHYSICAL TECHNIQUE

Contrast detection thresholds were measured using a two-interval forced choice method with a two-down-one-up descending staircase method of limits. The stimulus was presented during 1 (one) of 2 (two) temporal intervals which were demarcated by auditory tones. The subject reported whether they detected the stimulus in the first or second interval. The staircase was terminated after 8 (eight) reversals. Detection thresholds were calculated from the average of the last 6 (six) out of 8 (eight) contrast reversals of the staircase data. The stimulus duration of each temporal interval was 1 (one) second, with an inter-stimulus interval of 1 (one) second**.** The peak contrast of the carrier grating was decreased by 0.2 long units for 3 (three) consecutive correct responses and was increased by 0.1 log unit if there was at least one incorrect response. Binocular contrast detection thresholds were determined first, followed by monocular right and monocular left contrast detection thresholds. The monocular right and monocular left contrast detection thresholds were randomly interleaved for each individual trial. Separate blocks of trials were run for each spatial frequency and vertical prism condition.

Vertical fixation disparity was measured at the beginning and end of binocular contrast detection threshold determination for each trial. The subject used a method of adjustment to alter the vertical position of the right line until it appeared in alignment with the left line. This process was repeated five times.

A completed block comprised of 5 (five) repetitions for each of 15 (fifteen) conditions (3 spatial frequencies (4 (four), 9 (nine), and 18 (eighteen) cpd) x 5 magnitudes of vertical prism (0 (zero) PD, 1.5 PD BU/BD, 3 (three) PD BU/BD)).

SUBJECTS

Subjects were screened to ensure normal visual performance and intact binocular vision systems. All six adult subjects had best corrected visual acuity of at least 20/20 in each eye at 10 feet and 40 cm, dissociated phoric posture between 6 prism diopters of exophoria and 3 prism diopters of esophoria at the viewing distance of 1.19 m as measured by alternating cover test, fusion with Worth 4 dot at 10 feet and 40 cm, stereoacuity of at least 40 arc seconds local and 250 arc seconds random dot stereopsis with Randot Stereotest, and normal retinal correspondence as measured with Bagolini lenses. Approval for the use of human subjects was granted by the Ferris State University Institutional Review Board (Appendix A).

SUBJECT SETUP

Each subject's dissociated horizontal phoria was measured under dichoptic viewing in a method similar to Von Graefe at a test distance of 1.19 m. The prism value of the phoria was divided evenly between each eye and placed in front of each subject using Risley prisms in the phoropter prior to data collection. Each subject wore habitual contact lenses or had their habitual spectacle prescription in the phoropter for data collection.

Each subject trained for 3 (three) trials before beginning data collection. Then each subject completed 5 (five) trials with 0 (zero) PD vertical prism before introducing vertical prism in reversible glasses. The 1.5 PD reversible vertical prism glasses were created with 0.5 PD BU over one eye and 1.0 PD BD over the other. The 3.0 PD reversible vertical prism glasses were created with 2.0 PD BU and 1.0 PD BD. The base direction of the prism alternated between each experimental session and the special frequency was also randomized between each experimental session. The subject was required to fuse the stimulus before the trial could begin. There was a break of at least 8 (eight) minutes between tests to limit the effects of adaptation to the previous prism glasses. One subject elected to forgo testing for all spatial frequencies with 1.5 PD BU/BD.

CHAPTER 3

RESULTS

The outcome variables were: binocular contrast threshold, right and left eye monocular contrast threshold, initial vertical fixation disparity, and final vertical fixation disparity. Binocular contrast summation ratios were determined by dividing the lesser monocular contrast threshold into the binocular contrast threshold for each trial. Average vertical fixation disparity in arcminutes was determined by averaging the 10 (ten) values for each trial, 5 (five) determined prior to binocular contrast threshold and 5 (five) determined after the binocular contrast threshold. The induced period shift was calculated based on the spatial frequency of the target and the average fixation disparity for the trial. This can be determined mathematically by the following equation:

$$Period\ Shift = \frac{(SF * VFD)}{60}$$

SF = spatial frequency of the target (cpd)

VFD = average vertical fixation disparity

The resultant data was binned according to each 0.1 period shift to account for variation between subjects. The average binocular summation for each binned period shift data point was then compared for each spatial frequency, as shown in Figures 4 (four), 5 (five), and 6 (six). Each datum represents the mean (+/- 1 SE) binocular summation ratio of the binned data across all 6 (six) subjects for each magnitude of period shift.

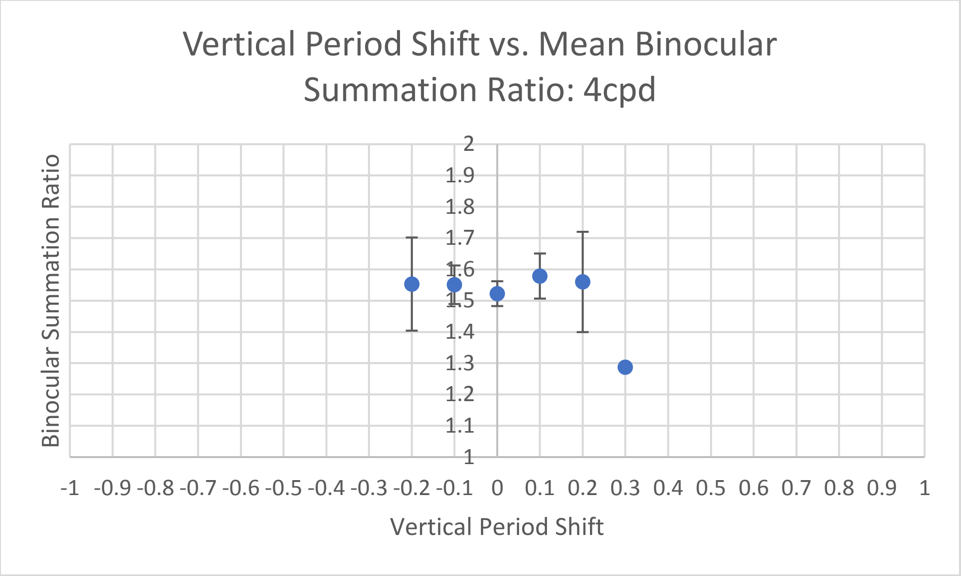

Figure 4. Mean of the binned vertical period shift of the combined data (+/-1 StdErr) vs. mean binocular summation ratio for the 4 cpd spatial frequency.

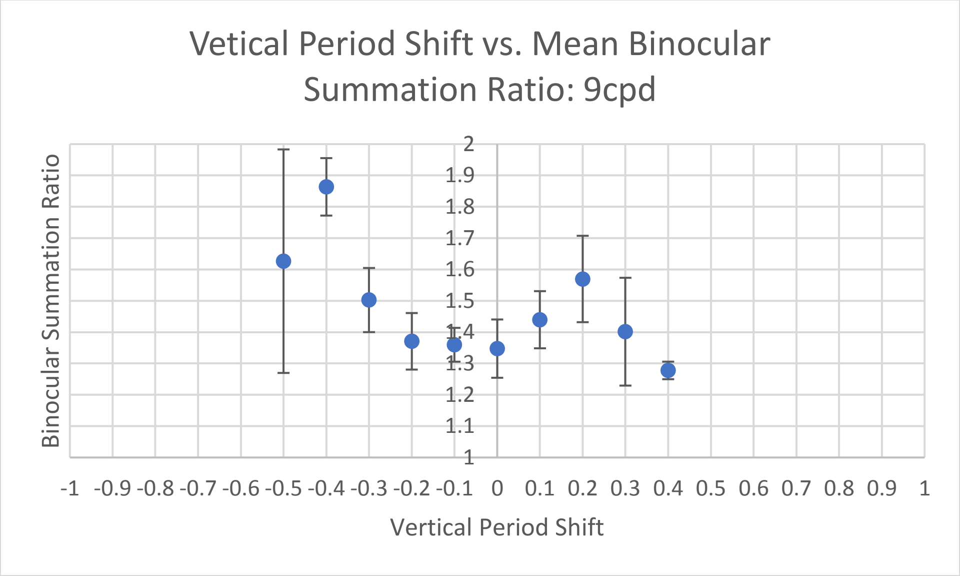

Figure 5. Mean of the binned vertical period shift of the combined data (+/-1 SEM) vs. mean binocular summation ratio for the 9 cpd spatial frequency.

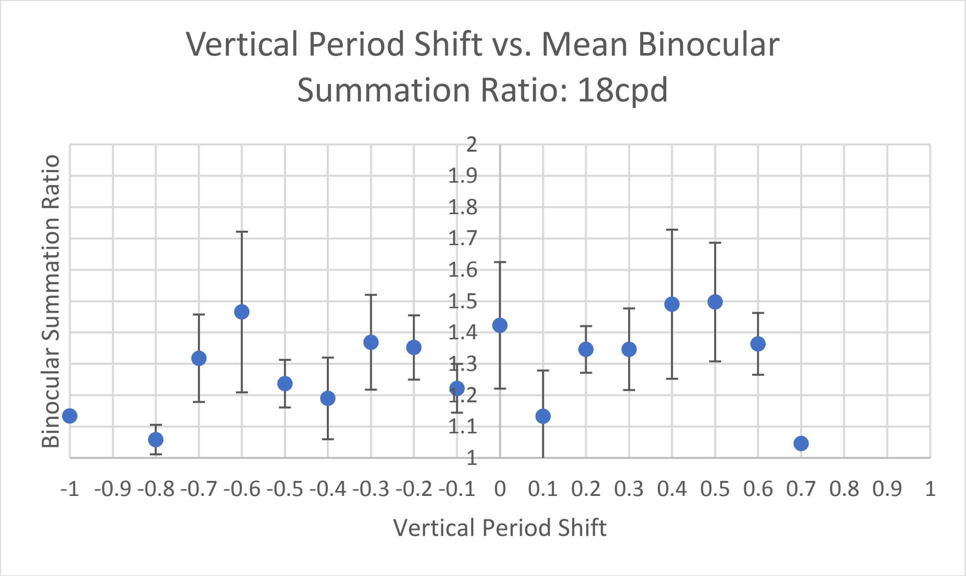

Figure 6. Mean of the binned vertical period shift of the combined data (+/-1 SEM) vs. mean binocular summation ratio for the 18 cpd spatial frequency.

The data trends depicted in Figures 4 (four) to 6 (six) provide suggestive indications that induced period shift due to vertical fixation disparity may influence the magnitude of binocular contrast summation. However, results of a two-way (SF x period shift) ANOVA indicate that the differences in the mean values are not great enough to exclude the possibility that the difference is due to random sampling variability; there is not a statistically significant effect of vertical fixation disparity on binocular contrast summation for any of the 3 (three) spatial frequencies (4 cpd: (F(4,136) = 0.147, P = 0.964); 9 cpd: (F(9,133) = 0.830, P = 0.590); 18 cpd: (F(14,135) = 0.514, P = 0.921).

A second analysis compares the mean initial vertical fixation disparity (+/- 1 SEM) to the mean final vertical fixation disparity (+/- 1 SEM) for each magnitude of vertical prism for every subject (Figure 7 (seven)).

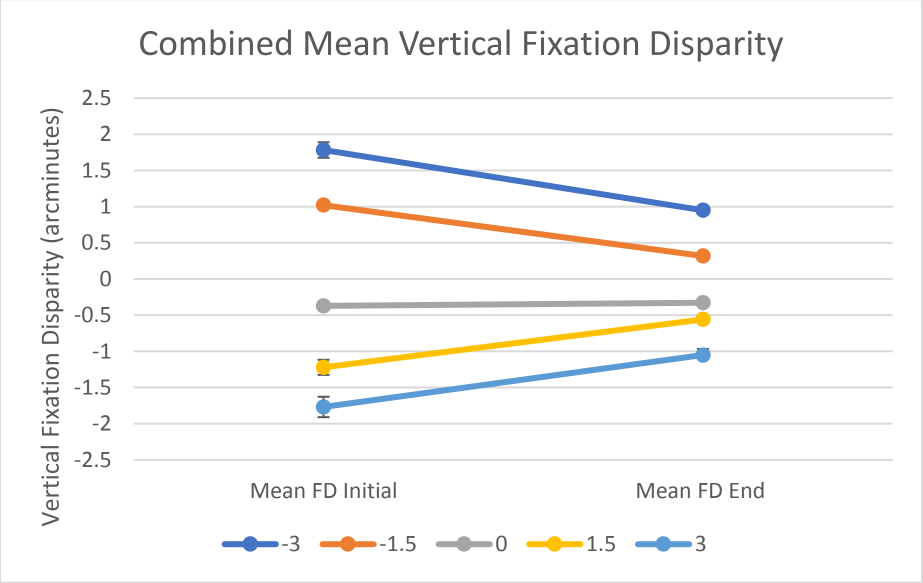

Figure 7. Mean (+/-1 SEM) of the initial and end vertical fixation disparity data of all subjects for each of 5 (five) magnitudes of vertical prism.

The data trend in Figure 4 show that the magnitude of induced fixation disparity did not remain constant throughout testing. The induced fixation disparity tends to decrease toward zero fixation disparity regardless of the direction and magnitude of the induced fixation disparity for all 6 (six) subjects. Results of a one-way ANOVA indicate that the difference in the mean values is great enough to exclude the possibility that the difference is due to random sampling variability; there is a statistically significant difference between initial and final vertical fixation disparity (F(10,839) = 171.359, P = <0.001). This trend was significant for most magnitudes of vertical prism based on AD-HOC testing via the Holm-Sidak method ((1.5 PD BU: P = <0.001); (3 PD BU: P = <0.001); (1.5 PD BD: P = <0.001); (3 PD BD: P = <0.001)), but was not significant under conditions with 0 (zero) vertical prism (0 PD: P = 0.716).

CHAPTER 4

DISCUSSION

The current results suggest that binocular contrast summation failed to vary systematically with interocular phase shifts due to vertical fixation disparities induced with vertical prisms. This result appears at odds with the data reported by Rose, Blake and Halpern (1988) who reported significant changes in binocular contrast summation with experimentally induced pedestal fixation disparities. The authors speculate that the lack of an interaction between the induced phase shift and binocular summation noted in the current study is related to the significant vergence adaptation that occurred with the use of vertical prism. This speculation is supported by the results depicted in Figure 4 (four), which shows a significant reduction in induced fixation disparity between the initial and final binocular contrast detection measures. This speculation is further supported by previously documented adaptation to vertical prism occurring at variable rates in periods as short as 3 (three) to 10 (ten) minutes to over 3 (three) hours (Ogle and Prangen 1953, Rustein and Eskridge 1986, Eskridge 1988). In addition, the authors do not dispute the notion that fixation disparity can be reliably measured under dichoptic viewing conditions using nonius lines and a fusion lock consisting of both a central and peripheral fusion lock (Schroth et al. 2015, Ukwade 2000).

Furthermore, given that the measures were only conducted at two-time intervals (which were idiosyncratic given that the psychophysical procedure was self-paced for both the fixation disparity measures and the binocular contrast detection measures), therefore, there is no way to determine the true fixation disparity at the precise time of a given binocular contrast threshold measure.

Thus, the authors suggest any interpretation derived from this study pertaining to the lack of an effect between vertical fixation disparity, spatial frequency and binocular summation, be treated with caution. Instead, the authors proclaim that the current experimental paradigm is not effective at revealing a phase dependence, specifically given the confound of prism induced vergence adaptation. The authors have since employed a more effective experimental paradigm to elucidate these interactions.

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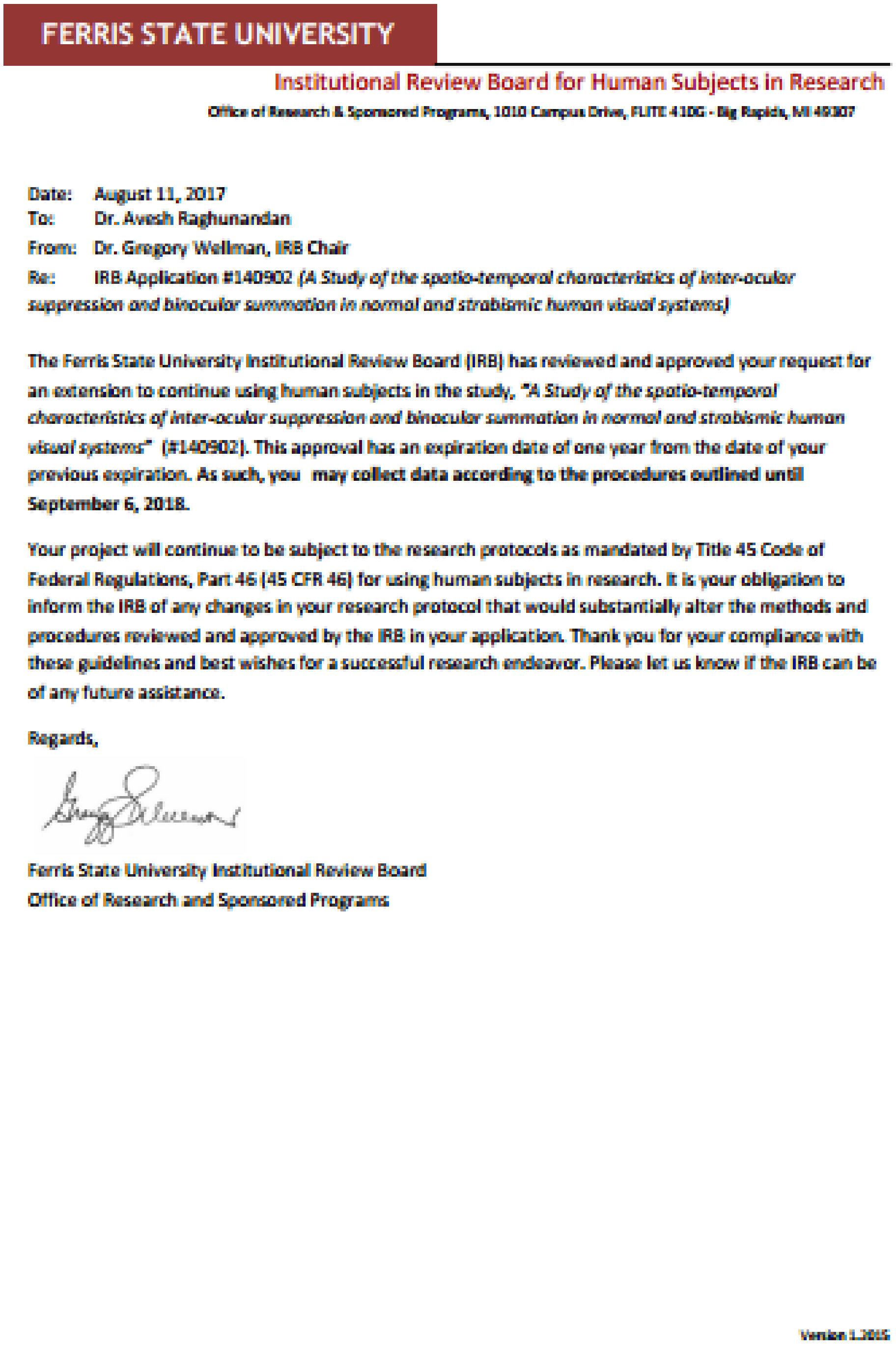
APPENDIX A

IRB APPROVAL FORM



FERRIS STATE UNIVERSITY

Institutional Review Board for Human Subjects in Research

Office of Research & Sponsored Programs, 1010 Campus Drive, FLITE 410G - Big Rapids, MI 49307

Date: August 11, 2017
To: Dr. Avesh Raghunandan
From: Dr. Gregory Wellman, IRB Chair
Re: IRB Application #140902 *(A Study of the spatio-temporal characteristics of inter-ocular suppression and binocular summation in normal and strabismic human visual systems)*

The Ferris State University Institutional Review Board (IRB) has reviewed and approved your request for an extension to continue using human subjects in the study, *"A Study of the spatio-temporal characteristics of inter-ocular suppression and binocular summation in normal and strabismic human visual systems"* (#140902). This approval has an expiration date of one year from the date of your previous expiration. As such, you **may collect data according to the procedures outlined until September 6, 2018.**

Your project will continue to be subject to the research protocols as mandated by Title 45 Code of Federal Regulations, Part 46 (45 CFR 46) for using human subjects in research. It is your obligation to inform the IRB of any changes in your research protocol that would substantially alter the methods and procedures reviewed and approved by the IRB in your application. Thank you for your compliance with these guidelines and best wishes for a successful research endeavor. Please let us know if the IRB can be of any future assistance.

Regards,

Ferris State University Institutional Review Board
Office of Research and Sponsored Programs

Version 1.2015