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EVALUATING RESPONSE TIMES IN LETTER STRINGS AS CROWDING MAGNITUDE INCREASES

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Charlotte Love

Doctoral Candidate(s)

3/18/19

Date

EVALUATING RESPONSE TIMES IN LETTER STRINGS AS CROWDING MAGNITUDE INCREASES

by

Charlotte Fern Love

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

Ferris State University

Michigan College of Optometry

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EVALUATING RESPONSE TIMES IN LETTER STRINGS
AS CROWDING MAGNITUDE INCREASES

by

Charlotte Fern Love

Has been approved

13 April 2019

APPROVED:

Faculty Advisor: Avesh Raghunandan

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ABSTRACT

Background: Individuals with severe central vision loss usually adopt eccentric viewing for tasks such as reading. While crowding has been implicated as a dominant cause for slower reading speeds with eccentric viewing by reducing letter recognition accuracy, it is possible that crowding could also impose pre-lexical processing delays, which may also contribute to slower reading speeds with increasing viewing eccentricity. Therefore, the purpose of this study is to measure the response times to letter strings with increasing crowding magnitude at different eccentricities to explore pre-lexical processing delays. *Methods:* Letter recognition accuracy and response times were measured in 11 subjects with normal vision for the central letter presented within a trigram. The trigrams were presented for 100ms at a fixation distance of 57 (114) cm. The trigrams were presented at three different locations; the central letter centered at fixation as well as 3 degrees to the left and right of fixation with varying degrees of crowding. All letters were presented with high contrast (0.84) lowercase Courier font. Stimulus eccentricity and inter-letter spacing were presented randomly within a single block of trials. *Results:* Letter recognition accuracy for central and peripheral presentations decreased with decreasing separation of flanking targets. Response times increased proportionally with decreasing inter-letter separation for all 3 viewing separations. In the case of isolated letters, response times were generally slower in the left hemifield compared to the right hemifield despite equivalent response accuracy. *Conclusions:* Visual crowding does indeed induce delays in perceptual processing time for the extraction of letter elements embedded in letter strings. Furthermore, this study demonstrates that perceptual processing delays induced by crowding occurs at pre-lexical processing stages, especially given that the letter strings employed in the current study lacked lexical information.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the support, time, and effort of those who made this study possible; Dr. Avesh Raghunandan, Nathan Traxler, and those subjects who volunteered their time and efforts for this endeavor. This study was funded by a Ferris Faculty Research Grant.

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INTRODUCTION

It is estimated that 1.3 billion people in the world live with some form of vision impairment.[1] The World Health Organization estimates that 80% of the blindness worldwide is preventable; the three leading causes of vision impairment worldwide are uncorrected refractive error, cataracts and macular degeneration. In the industrialized world, Age Related Macular Degeneration (AMD) is the leading cause of vision impairment.[1] As the Baby Boomer generation ages, the number of Americans at risk for age-related eye diseases is predicted to increase.[2] It is estimated that in 2016 nearly 11 million people in the United States were affected with AMD and this number is anticipated to increase to 22 million by the year 2050.[2]

Macular degeneration is a disease of the central retinal tissue causing central vision loss and distortion, while the peripheral retina is left undamaged with normal function. Individuals with severe central vision loss tend to adopt a technique called eccentric viewing. These individual's use their peripheral vision for daily life tasks such as cooking and reading.[2]

It has been shown that when people fixate eccentrically, reading speeds decrease despite adequate magnification.[3] It has been suggested that the decrease in reading speed is due to a narrowed visual span caused primarily by visual crowding interactions in the peripheral retina.[4,5] A 2007 study concluded that 'In all conditions tested--all sizes and spacings, central and peripheral, ordered and scrambled--reading is limited by crowding'.[4]

While crowding has been implicated as a dominant cause for slower reading speeds with eccentric viewing by reducing letter recognition accuracy, it is possible that crowding could also impose pre-lexical processing delays, which could impact reading speed. Pre-lexical processing, refers to processes extracting letter elements in meaningless letter strings that have no equivalence to words comprising a readers lexicon (or word bank). That is, it is conceivable that pre-lexical processing delays induced by visual crowding could also contribute to slower reading speeds, especially with increasing viewing eccentricity.

The purpose of this study is to investigate the effect of crowding on perceptual processing time required for the accurate recognition of letter elements embedded within letter strings. An increase in response times with crowding magnitude will support the hypothesis that crowded letter elements are associated with delays in accurate letter recognition at pre-lexical levels of processing.

CHAPTER 2

METHODS

Letter recognition accuracy and response times were measured in 11 college-level adult subjects with normal vision for the central letter presented within a trigram. All Subjects possessed at least 20/20 visual acuity OD and OS at distance and near (40cm) and at least 30” of contour stereopsis and 250” of random dot stereopsis. All subjects performed above a 12 GLE in the 4 sub-tests comprising the *WJ III Diagnostic Reading Battery*™ test. The trigrams were presented for 100ms at a fixation distance of 57 (114) cm. All letters were presented with high contrast (0.84) lowercase, standard boldness Courier font. Letter size was selected as the font size that produced approximately 80% correct recognition accuracy when the target letters were presented in isolation (i.e. un-flanked by adjacent letters) at 3 viewing eccentricities. The critical font sizes were determined in a separate study.

The trigrams were presented at three different eccentricities; the central letter centered at fixation as well as 3 degrees to the left and right of fixation. Each trigram comprised a target lowercase middle letter (a, c, z or x), flanked on either side by a lowercase ‘x’. Crowding magnitude was manipulated by varying the flank separation relative to the target letter. The following inter-letter separations were used: Central targets were flanked by a ‘x’ separated by 0, 1, 2 and 4 arc minutes and the +/- 3 degree viewing eccentricity targets were flanked by a ‘x’ separated by 0, 10, 20 and 40 arc minutes. Stimulus eccentricity and inter-letter spacing were presented randomly within a single block of trials. An isolated letter condition was also included and interleaved randomly with the crowded trigrams at each of 3 viewing eccentricities.

Response time was recorded as the time elapsed for accurately reported letters from stimulus offset to the subject's selection from a list of all 4 target letters presented on the monitor immediately following stimulus offset. Once the stimulus offset, a square arrangement of four boxes (2X2) with the 4 target letters appeared below fixation. Subjects selected their responses using a mouse. The cursor appeared initially central within the arrangement of target letters and equidistant from all four answers.

The program was written using *Matlab*© software; recording of response times and accuracy of the response were also reported by this program. Results were later analyzed using *Microsoft Excel*© spreadsheets. Data analyses of response times were restricted to trials in which letter recognition was reported accurately.

CHAPTER 3

RESULTS

Letter recognition accuracy for central and peripheral presentations decreased with decreasing separation of flanking targets (Figure 1 bottom row). A Two-Way Repeated Measures ANOVA (Inter-letter Separation x Eccentricity) conducted on recognition accuracy, indicated a significant main effect of inter-letter separation ($F(4,109) = 60.973$, $p < 0.001$). However, there was no significant effect of eccentricity, nor a significant interaction effect between inter-letter separation and eccentricity.

Response times in general increased with decreasing separation of flanking targets for both central and peripheral targets. A Two-Way Repeated Measures ANOVA (Inter-letter Separation x Eccentricity) was conducted on the Mean Response times for the target letters presented at eccentricities of 3 degrees to the left and right of fixation. In the case of response time, there was a significant main effect of inter-letter separation ($F(4,109) = 10.043$, $p < 0.001$), a significant main effect of eccentricity ($F(1,109) = 6.164$, $p = 0.032$) and a significant interaction effect between inter-letter separation and eccentricity ($F(4,109) = 3.963$, $p = 0.008$). See figure 1 top row.

While response times varied significantly with inter-letter spacing for the right viewing eccentricity (+3), interestingly, response times did not vary significantly with inter-letter spacing for the left viewing eccentricity (-3). Response times were significantly ($p < 0.05$) higher for the 20 arc minute inter-letter separation and isolated letter conditions in the left viewing eccentricity compared to the right viewing eccentricity, even though response accuracy for each inter-letter separation did not vary significantly with viewing eccentricity.

One way Repeated Measures ANOVA revealed a significant effect of viewing eccentricity on response times ($F(2,32) = 17.772$, $p < 0.001$) and response accuracy ($F(2,32) = 6.442$, $p = 0.007$) for isolated targets (Figure 2). A Pairwise Multiple Comparison (Holm-Sidak method) revealed no significant effect of -3 and 3 degree viewing eccentricity on response accuracy ($p = 0.121$) but a significant effect on response time ($p < 0.001$). This latter result seems to suggest that response times appear relatively delayed in the left hemifield for comparable levels of response accuracy, specifically in the case of uncrowded letter targets. See Figure 2.

CHAPTER 4

DISCUSSION

From this study we can make multiple inferences. First, the decrease in response accuracy (Figure 1, bottom row) of the central letter comprising the trigram noted with decreasing inter-letter spacing is consistent with the observations of visual crowding. This supports the research proposed by Pelli [4] and Legge [5] and supports Bouma's law of crowding[6]. As such, it validates that the current experimental paradigm was effective in tapping into visual crowding mechanisms.

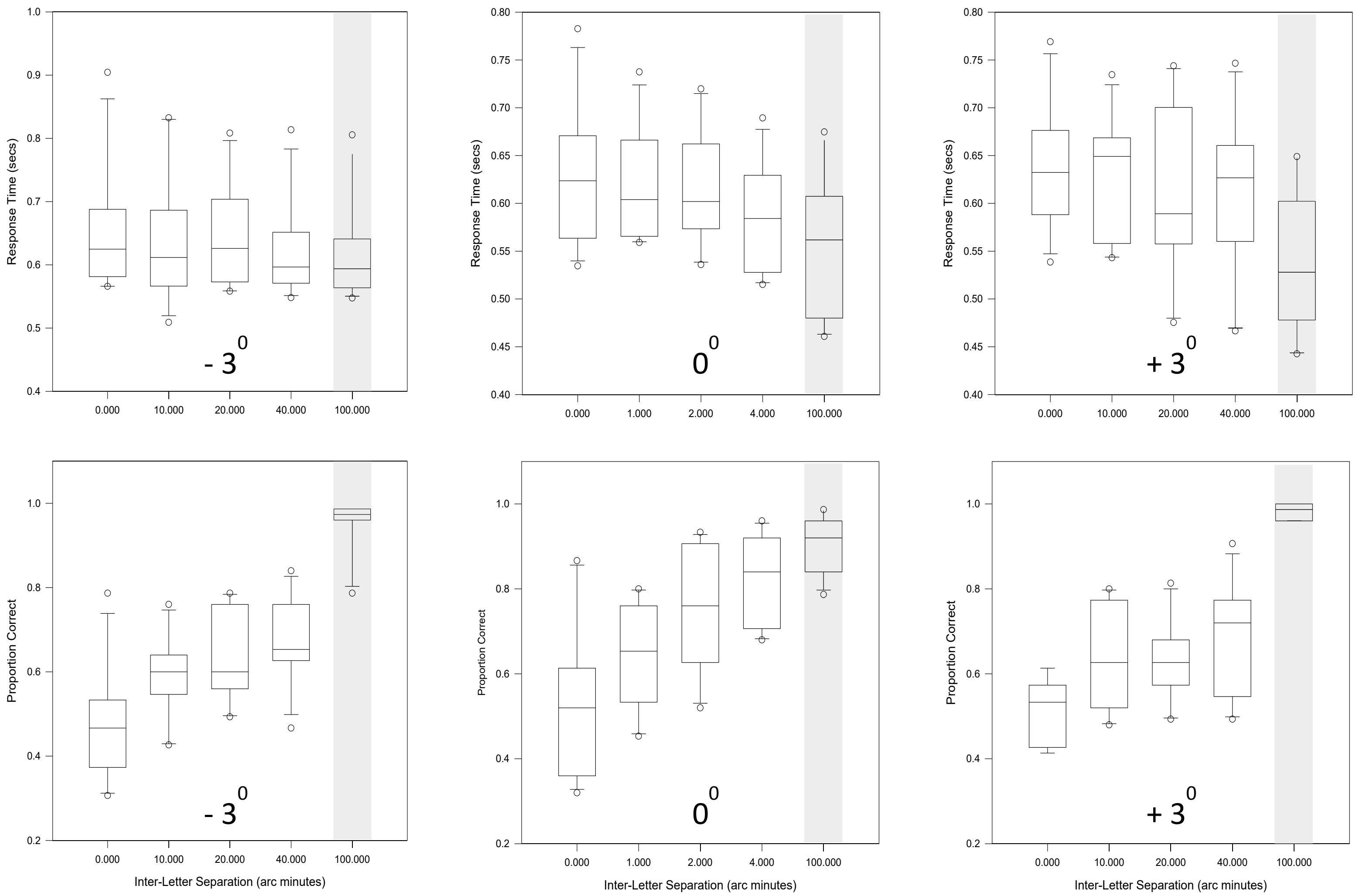
The increase in response times is consistent with the suggestion that the perceptual processing time required by subjects to make correct responses of the central target increases with increasing magnitudes of visual crowding (Figure 1, top row) . Hence, visual crowding does indeed induce delays in perceptual processing time for the extraction of letter elements embedded in letter strings. Furthermore, this study demonstrates that perceptual processing delays induced by crowding do occur at pre-lexical processing stages, especially given that the letter strings employed in the current study lacked lexical information.

In the absence of visual crowding, perceptual processing delays appear higher in the left hemifield compared to the right hemifield and central fixation despite comparable response accuracy (Figure 2). This is an interesting point and would be a curious avenue for further research comparing the left and right hemifield perceptual processing times. It would be interesting to compare left and right hemifield amongst different populations or even languages.

English is typically written from left-to-right, Persian, Arabic and Hebrew are written right-to-left, while Chinese and Japanese can be written in vertical columns; would there be a difference among processing times between different styles of writing or languages? A recent study investigated the perceptual span between Arabic and English readers; it showed asymmetry between left and right perceptual span between the two languages.[7] This study provides evidence that perceptual span is modified by the overall direction of reading.[7]

It has been proposed that there is slower temporal processing in the peripheral vision and contributes to slow reading performance. [8] Processing delays endemic to crowded letter elements reported in this study may represent an additional factor contributing to slower reading speeds when using the peripheral retina.

FIGURE 1.

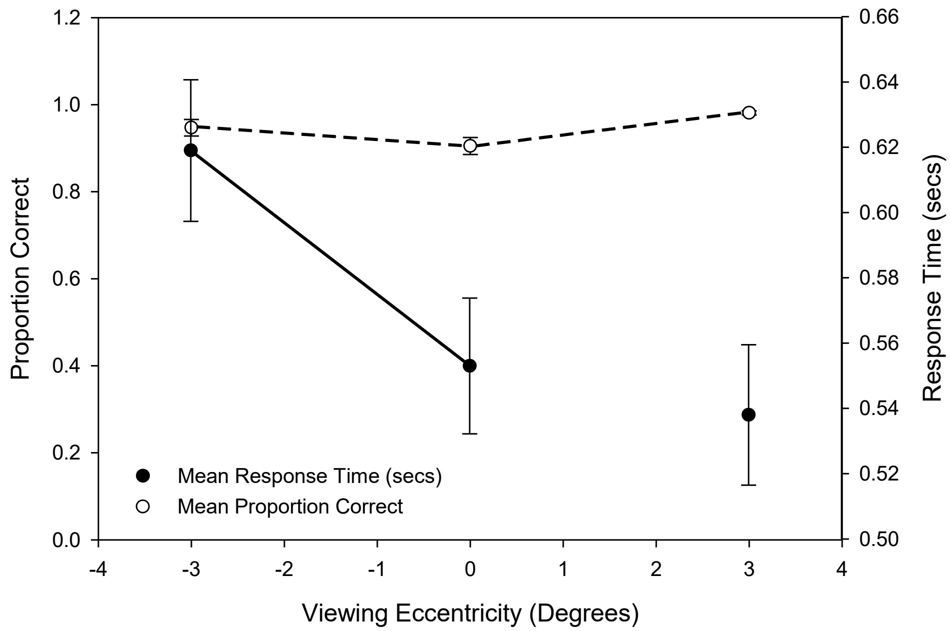


Top Row: Box plots of response times (secs) with increasing inter-letter separation for targets presented 3 degrees to the left (-3^0) and right ($+3^0$) of fixation (0^0).

Bottom Row: Box plots of proportion correct letter recognition with increasing inter-letter separation for targets presented 3 degrees to the left (-3) and right (+3) of fixation (0).

Data for isolated letter presentations are indicated along the x-value = 100 (gray shaded region). Data pooled across 11 observers. The lower boundary of the box indicates the 25th percentile, the line within the box marks the median, and upper boundary of the box indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles, respectively. Unfilled data points represent outliers.

FIGURE 2.



Mean Response time (+/- 1SEM) (filled circles right ordinate axis) and mean proportion correct (+/- 1SEM) (unfilled circles and left ordinate axis) are plotted for the isolated letter condition when presented at viewing eccentricities of 3 degrees to the left (-3), right (+3) & at fixation (0).

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APPENDIX A

IRB APPROVAL LETTER

FERRIS STATE UNIVERSITY

Institutional Review Board for Human Subjects in Research

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

Date: April 17, 2018

To: Avesh Raghunandan

From: Dr. Gregory Wellman, IRB Chair

Re: IRB Application #150504, *Processing Speed Differences of Word Discrimination between Central and Peripheral Retinal Regions*

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, *Processing Speed Differences of Word Discrimination between Central and Peripheral Retinal Regions,* #150504 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 May 18, 2019.**

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