Effect of Vertical Interline Spacing on Word Recognition and Reading Speed using the Peripheral Retina

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ABSTRACT

The purpose of this study was to investigate the effect of increasing the spacing between sentences upon word recognition speed and word recognition accuracy when using the peripheral retina. By identifying optimal interline spacing for patients with central field loss, this could determine guidelines for best presentation of written materials in the presence of central scotoma. Seventeen participants with no ocular pathology were recruited and asked to read words with their fovea and peripheral retina (at 6 degrees from the fovea) whilst their fixation was monitored using an infra-red eye tracker. Whilst improvement in reading speed can be gained by increasing interline spacing to 1.5x when reading with the fovea, there is no effect (or detriment) of manipulating interline spacing when reading with the peripheral retina. There is also no effect on word recognition accuracy.

Keywords: reading, low vision, scotoma, crowding phenomenon

INTRODUCTION

The task of reading is carried out by the central retina, specifically the fovea, in individuals with no retinal pathology. Fluent reading is important for maintaining many activities of daily living and the inability to read can be considered a serious handicap.[1] Age-related macular degeneration (AMD) is the most common cause of visual impairment in industrialised countries[2] and is an ocular condition that can cause structural damage to the anatomy of the central retina. Consequently it results in a loss of central vision and impacts upon reading with the fovea.

When a person with central field loss reads, they use a peripheral retinal point termed the *preferred retinal locus* (PRL).[3-5] Whilst the PRL can be useful for reading, a common complaint from people who use it to read is that they are unable to read as fast as they did before the central field loss.[6-8] When print is increased in size to compensate for decreased acuity in the peripheral retina, reading speeds still remain slower compared to reading speeds using the central retina.[1,9] The decreased number of letters read during each forward saccade while reading may account for decreased reading speeds.[6,10,11]

Studies that have used Rapid Serial Visual Presentation (RSVP), a method that eliminates the need for eye movements while reading, report that when acuity and abnormal eye movements are controlled, reading speeds still remain slower when using the peripheral retina.[12,13] As decreased acuity and abnormal saccades cannot fully provide an answer to the poorer reading speeds experienced by those with central field loss it has prompted researchers to concentrate on the psychophysical aspects of reading, particularly the crowding phenomenon. The crowding phenomenon is defined as 'the adverse spatial interaction due to the proximity of adjacent targets'.[7] It is present in the central retina but is increasingly evident in the peripheral retina and is thought to contribute to slower reading.[4,14,15] Studies have investigated the effect of crowding with interletter spacing within words and have found that when interletter spacing is increased above the standard 1x spacing, it does not result in a decrease of the crowding phenomenon within words in the central or peripheral retina.[1,4,14,16,17] Increasing interletter spacing may in fact cause the visual span in the peripheral retina to shrink further. The visual span in reading is defined as the number of letters that are able to be seen at a single glance without having to make an eye movement.[18] It has been reported that the visual span in people without retinal pathology, at the fovea, is 10 letters in size and decreases to 1.7 letters at 15^{o} in the periphery.[19] These results were based on normal participants and may be different in people with a central scotoma. In a study by Cheong,[20] participants without retinal pathology were compared with participants with central field loss resulting from AMD. Findings showed that participants with AMD who fixated eccentrically using various retinal locations, had significantly smaller visual spans than normal participants who were tested at 10

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degrees eccentrically, thereby suggesting that scotoma interference is thought to play a part in the reduced visual span in the peripheral retina of patients with AMD.

Other studies have focused attention on another aspect of crowding in the form of vertical interline spacing between a target word and the flanking words above and below. In a two-phase experiment using the RSVP method and testing the reading speed of participants at the fovea, 5 and 10 degrees in the lower visual field, Chung[7] found a significant impact on reading speed when interline spacing was increased from 1x to 2x the standard interline spacing. Bernard et al[21] utilised a gaze-contingent visual display with an artificially simulated central scotoma at 6 and 10 degrees and found a significant advantage for 1.25x interline spacing on reading speeds. However, the increase in reading rates found by Bernard et al were not as large as the increase in reading rates found by Chung.[7] Studies investigating interline spacing that have used participants with central field loss report different findings. Chung et al[22] found no significant effect on reading speed when interline spacing was increased, whilst Calabrese[3] found that there was an improvement of 7.1 words per minute (w/pm) when interline spacing was increased from 1x to 2x interline spacing.

Studies in the area of vertical interline spacing do not report on whether word accuracy is affected when interline spacing is increased. It raises the question of whether word accuracy in the peripheral retina is decreased when using a smaller interline spacing and there are conflicting findings as to the range of improvement in reading speed when interline spacing is manipulated. The aim of this study was to investigate the effect of interline spacing on both reading speed and word recognition accuracy in the normal peripheral retina.

MATERIAL AND METHODS

A repeated-measures study design was implemented to determine the effect of interline spacing and retinal eccentricity on word recognition speed and word accuracy. Word recognition speed was measured as the number of words read correctly per minute (w/pm) and word accuracy was recorded as the number of words read correctly. Vertical interline spacing at 1x, 1.5x and 2x were presented to participants at the fovea and 6 degrees in the inferior visual field.

Participants were students of a tertiary institution with good general health, no ocular pathology and able to read a minimum of N8 font using the Bailey-Lovie Word Reading Chart[23] at 40 centimetres (cm) either without correction or with contact lenses. All procedures have been carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans; informed consent was obtained from all participants and the procedures used were approved by the La Trobe University Faculty Health Sciences Human Ethics Committee (Approval number: 10/69).

As the participants had normal vision with no central scotoma but were required to read print with their peripheral retina, their fixation patterns were monitored to ensure that they utilised the correct retinal area for reading. This was done using the Tobii Eye Tracker Series 1750 binocular infrared eye tracker (Tobii Technology, Danderyd, Sweden) (Figure 1). The Tobii 1750 has an integrated 1280 × 1024 pixel 17 inch monitor. Participants viewed the monitor from a distance of approximately 60 cm so that the visual angle of the screen was 30° × 24° (W × H). The Tobii Eye Tracker Series 1750 has accuracy within 0.5 degrees of the visual angle when head movements are kept to a minimum. Eye fixations were defined as an eye position which remained within a 30 pixel area for a duration that was greater than 100 milliseconds (ms). An automatic 9-point (3 × 3) calibration reference grid[24] was used to calibrate each individual participant prior to data acquisition. The configuration of the testing apparatus included a dual computer and dual monitor setup. Computer 1 was a HP Compaq Pentium 4.2.60 GHz with 504 MB RAM and computer 2 was a Dell Pentium D 2.8 GHz with 1 GB RAM, the TET server enabled communication between computers. The dual computer configuration is generally faster than presenting stimuli using one computer alone and is the reason why this setup was chosen.

Figure 1. Tobii Eye Tracker Series 1750.

Stimuli were generated on Microsoft PowerPoint 2007 and slides were converted to a JPEG file and re-sized to 1024 × 768 pixels in Adobe Photoshop Elements 2.0. Each condition consisted of a string of 10 unrelated target words of the most commonly used five-letter words in the English language.[25] Each target word consisted of five letters rendered in lowercase courier new font. To simulate vertical crowding five 'x' were positioned above and below corresponding to the same letter length as the

target words. During study design, the 'x' was replaced with letters comprising five-letter words but this was found to be confusing to participants as to which word to read. Target words at the fovea were of N8 font size and at the 6 degrees eccentric point they were of N50 size. This font size reflected the critical print size (the smallest print that can be seen and read fluently) at the fovea and at 6 degrees. Stimuli were presented as black letters on a white background (Figure 2). The presentation of these stimuli was similar to that described by Chung.[7] When testing was conducted at 6 degrees eccentricity a red fixation cross was positioned 6.3 cm from the centre of the target word to indicate where the participant was to maintain fixation while reading. ClearView 2.7.1 eye gaze analysis software (Tobii Technology, Danderyd, Sweden) was used to organise and present stimuli. Reading speed data was recorded automatically by this software, by recording the amount of time (duration) each slide was displayed to the participant.

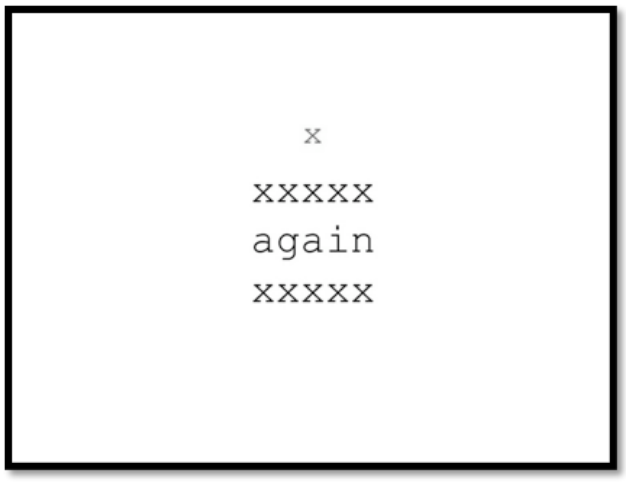

Figure 2. Example of stimuli at 1x spacing.

Participants were seated in front of the Tobii eye tracker and undertook six reading conditions. They were required to read aloud as fast as they normally read and were in control of when the words would appear on the screen by pressing the space bar on the key board to advance to the next word in the trial. When reading with the fovea the participants looked directly at the target word, when reading with the 6 degree eccentric point the participant maintained fixation on a red cross positioned above the target word. The reading trials were reviewed to ensure that participants' fixations did not deviate by more than 1 cm (0.95°) below the middle of the red cross. If a fixation deviated more than 1 cm or the participant made an eye movement to look at the word, the reading trial was discarded and repeated a maximum two times.

Twenty tertiary students aged from 19 to 48 years (Mean = 24 years, SD = 6.58) were recruited for this study. There were 14 females and three participants required contact lens correction. After a review of the reading trials, three participants were excluded from the analysis as they had poor fixation throughout all reading trials at the 6 degree eccentric point. Data presented here is for the remaining 17 participants. Word recognition speed results were not normally distributed, therefore were analysed using non-parametric tests including the Wilcoxon signed-ranks test or Friedman test. Where data were normally distributed the one-way repeated-measures ANOVA or t-test was used.

RESULTS

WORD RECOGNITION SPEED

As expected, participants read significantly slower with their peripheral retina (Mean = 37.62 w/pm, SD = 7.56) compared to the fovea (Mean = 60.63 w/pm, SD = 10.29) when text was presented with 1x interline spacing [$t(16) = 9.22$, $p<0.0005$]. Foveal word recognition speed significantly improved when interline spacing was increased above the standard 1x and is shown in Figure 3 [Wilks' $\lambda = 0.43$, $F(2,15) = 10.07$, $p<0.0005$, multivariate eta squared = 0.57]. The greatest improvement was at 1.5x spacing, improving from a mean of 60.03 (SD = 10.29) to 67.43 w/pm (SD = 11.20) [$t(16) = -4.463$, $p<0.0005$]. There was no statistically significant difference in speed between 1.5x spacing (Mean = 67.43 w/pm, SD = 11.20) and 2x spacing (Mean = 68.5 w/pm 0, SD = 13.31) [$t(16) = -0.769$, $p>0.05$].

There was no significant effect for interline spacing on word recognition speed when reading with the peripheral retina at 6 degrees (Figure 4) [Wilks' $\lambda = 0.86$, $F(2,15) = 1.22$, $p>0.05$].

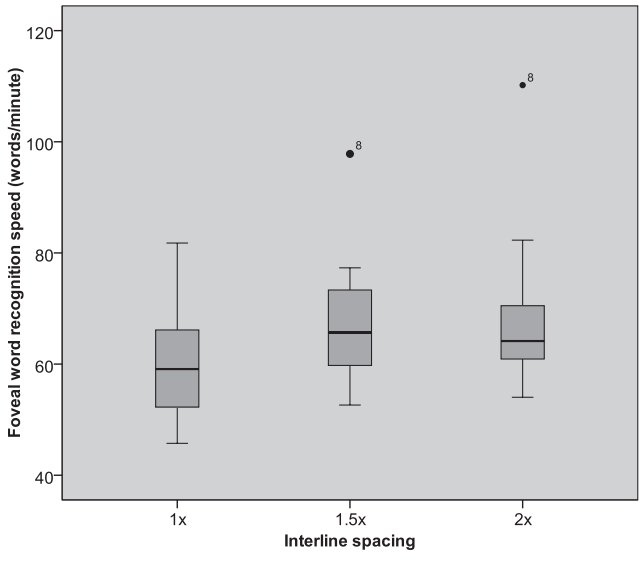

Figure 3. Foveal word recognition speed at 1x, 1.5x and 2x vertical interline spacing.

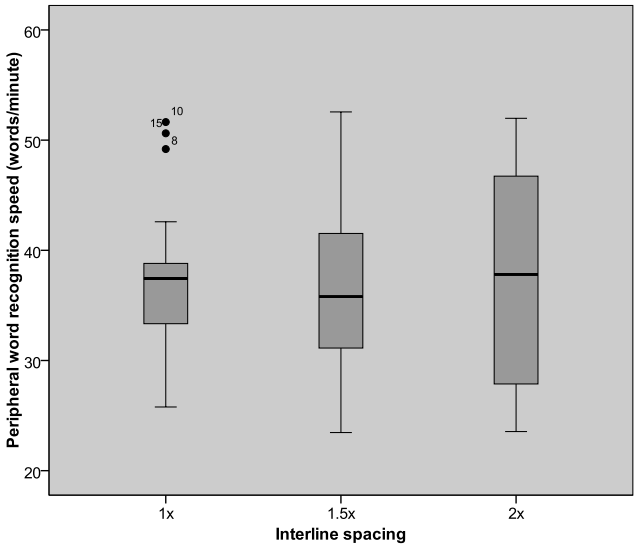

Figure 4 period Peripheral word recognition speed at 1x, 1.5x and 2x vertical interline spacing.

WORD RECOGNITION ACCURACY

Using the peripheral retina to read negatively affected word recognition accuracy ($Z = -3.13$, $p=0.002$). Word accuracy at the fovea was 100% correct for every participant regardless of the interline spacings used for reading. When participants used their peripheral retina, there was great variability in their word recognition accuracy and no significant effect of increased interline spacing was found ($\chi^2 = 3.79$, $p>0.05$), as shown in Figure 5.

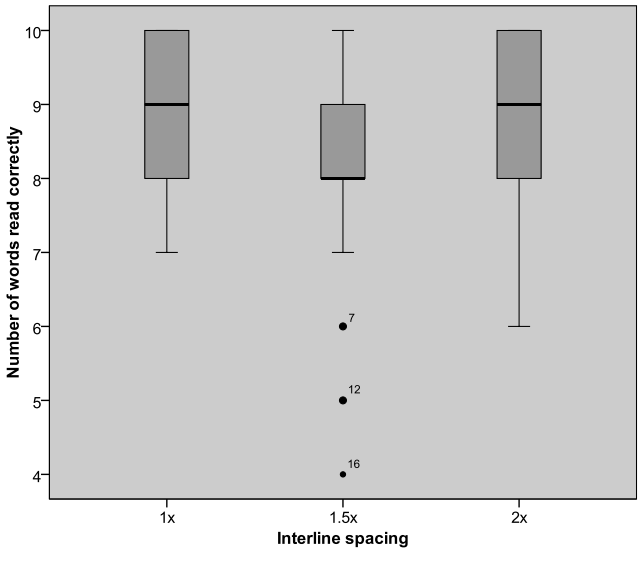

Figure 5 period Peripheral word recognition accuracy at 1x, 1.5x and 2x vertical interline spacing.

DISCUSSION

Slower reading rates using the peripheral retina are caused by multiple factors such as decreased acuity,[1,9,26] abnormal saccadic eye movements[6,10-13] and a decreased visual span.[19,20] The methodological design of this study intended to isolate the effect of interline spacing on word recognition speed from other factors by controlling known aspects that contribute to slower reading. Therefore font was increased in size when participants read with the 6 degree eccentric point to compensate for decreased acuity, a red fixation cross and single words were used to eliminate saccadic eye movements, and word length was restricted to five letters to account for the decreased visual span in the peripheral retina.

Normally-sighted participants were chosen for two reasons. One was to determine whether reading speeds can be increased in the normal peripheral retina. Secondly it has been shown that the visual span can be reduced in the presence of central field loss as the most viable PRL can be located near the border of the scotoma, which can interfere with letter identification of the target word.[20] This would therefore not be a factor with normal retinas.

The finding that reading using the fovea is significantly faster than using a peripheral eccentric point is in agreement with previous research.[1,7,9,13,14] At the fovea participants read an average of 60.63 w/pm compared with 37.62 w/pm in the periphery, an average decrease of 23.01 ($p<0.0005$). Whilst there is much variability in foveal reading speed reported in the literature, the foveal reading speed measured in the current study was found to be slower overall than the speeds reported in several other studies.[7,9,12,13] Large variations in reading speed with the peripheral retina are also reported in the literature[3,9,13] and the reading speeds reported in the current study are slower than most other reports. However, the reading speed reported by Calabrese et al[3] is similar to that found in the current study.

The difference between the method of determining reading speed could account for the higher speeds measured in other studies, especially those in which the RSVP paradigm was used where reading speed is pre-programmed, that is, participants read at the rate determined by the program rather than at their natural pace. We therefore attempted to maintain a natural reading situation by allowing the participant to control when words would appear on the monitor and to read as fast as they normally would. This methodology most likely accounts for the slower reading speeds measured.

The statistically significant improvement in foveal word recognition speed when interline spacing was increased to 1.5x spacing, but no further improvement at 2x spacing, is in agreement with the study by Chung.[7] The findings of the current study suggest that reading with the peripheral retina does not significantly benefit from an increase in

interline spacing, however there is also no disadvantage to providing text at a larger spacing if the preference is to read with 1.5x or 2x spacing.

We also sought to determine if a participant could identify words more accurately when interline spacing was increased. As expected, word accuracy was not dependant on interline spacing when reading with the fovea and this is in agreement with some other studies.[27,28] There was no effect on ability to accurately recognise words using the peripheral retina when interline spacing was increased. Some participants reported that they were "able to make out the first and last letter of the word, but the letters in the middle were harder to see" and this inability to identify the middle letter could account for lack of improvement in accuracy. This finding was also reported by Sommerhalder et al.[27]

CONCLUSION

The findings of this study suggest that there is no particular benefit to increasing interline spacing for patients with a macular scotoma, however there is also no detriment. Thus patients can read print with the interline spacing for which they have a personal preference. The greatest limitation of this study was that participants did not have a central scotoma and further research is planned to study the effect of interline spacing on reading speed and word accuracy in the presence of a central scotoma.

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