# Text Size Affects Eye Movement during Reading among Young Adults and Adults with Presbyopia

**Noor Halilah Buari, M.H.Sc (Optom)*, Siti Nurnazihah Hamka, B.Optom*, Anis Nur Fazlyana Md-Isa, B.Optom*, Shauqiah Jufri, M.HSc (Optom)****

**Centre of Optometry Studies, Faculty of Health Sciences, Universiti Teknologi MARA Selangor, Kampus Puncak Alam, 42300 Bandar Puncak Alam, Selangor, Malaysia, **Topvision Eye Specialist Center, 55, Jalan Peninsula Utama 1, Peninsula Park, Pasir Penambang, 45000 Kuala Selangor, Selangor, Malaysia.*

## ABSTRACT

**Objective:** Reading is an activity that indirectly informs a person's visual capacity to distinguish letters and words. Reading begins with eye movements, then substantial cognitive processing and synthesis, before becoming voice reading. Therefore, text is a factor that could impact reading quality through its control of eye movements. This study examined the eye movements of young adults and adults with presbyopia using texts of different sizes.

**Materials and Methods:** Twenty-five young adults and twenty-two adults with presbyopia and good vision were included in this study. Six text sizes of a passage were chosen as the reading stimuli. The eye movement of participants in saccades and fixation were captured, tracked, and analyzed using the Dikablis eye tracker glasses.

**Results:** Eye movement of young adults differed significantly ($p<0.05$) when reading texts of different sizes. The eyes moved more and had a wider saccadic angle as the font size increased. An increase in fixations or stopping of the eyes were observed with larger texts. Adults with presbyopia had significantly different eye movement patterns than young adults ($p<0.05$), whereby these participants stopped more frequently at longer periods and had a narrower saccadic angle.

**Conclusion:** Eye movements changed when reading texts of varied sizes and the movements differed between younger and older adults. These translate to altered visual searching and attention strategies with varied text readability, indicating that the oculomotor system adapts to the pattern, shape, and size of the presented reading material. This behavior could imply that cognitive processes have been altered to facilitate comprehension.

**Keywords:** Reading; fixations; saccadic; presbyopia; readers (Siriraj Med J 2022; 74: 650-657)

## INTRODUCTION

Reading is more than just looking at a bunch of words, rather a process of transferring and processing knowledge from a presented reading material. Reading is a process of deciphering the meaning of written symbols and letters. To read, a person must be able to (i) recognize the words they see (word recognition), (ii) comprehend what the words mean (comprehension), and (iii) connect word and meaning so that reading becomes automatic and accurate (fluency).[1,2]

Reading materials come in a variety of sizes and formats. Books are the most common type of reading material. Newspapers, magazines, food labels, brochures, emails, reports, and a variety of other available reading materials that are used by children and adults in their daily reading activities. Given the wide range of reading

*Corresponding author: Noor Halilah Buari*
*E-mail: noorhalilah@uitm.edu.my*
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*ORCID ID:http://orcid.org/0000-0002-7058-1176*
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materials available, they are presented in different ways. Reading materials come in varying font styles, text sizes, color, and layout, which may influence the outcome of reading. Font size, in particular, has been significantly shown to impact reading performance.[3-5] Readers with normal vision increased their reading speed as the font size increased.[5] while individuals with a blurred vision also have a similar affect in reading speed.[3]

The size of text also possibly influences eye movement during reading.[2,6-8] Eye movement is a microprocess of reading that causes changes in eye movement parameters such as fixations and saccades. Increased text size has resulted in altered saccadic eye movements.[7,8] Schoolchildren who read 25pt and 30pt sized texts, had increased amplitude of saccade movement.[8] Additionally, as the text size increased, the number of fixations increased, and the duration of fixations decreased.

When text was displayed on an LCD screen, the visual angle measured by saccade length, changed as the text size increased.[7] Here, saccadic eye movement remained consistent at smaller print sizes of up to 32pt text size. When eight different text sizes were compared, readers had the most prolonged fixation duration with a text size of 20pt.[7] Beymer *et al.*[6] studied online reading and discovered that participants read faster with larger fonts. When reading an online text, smaller text (10pt) retained the reader's attention for a more extended time than larger text (12pt).[6] Fixation also occurs more frequently with larger print sizes (32 pixels) than with smaller print sizes (24 pixels).[9]

Normal aging in late adulthood was likely associated with ocular and neural changes resulting in subtle deterioration of visual functions.[10,11] Changing optical features that occurs in older adults significantly reduces sensitivity towards contrast. Due to pupillary miosis, illuminance of the retina in aged eyes is diminished. The aging eye also has increased intraocular light dispersion and optical aberrations, impairing the contrasting appearance of an image.[12] These physiological changes indirectly affect vision performance, such as reading. Characters that are either too small or too huge impede reading speed in the aged population.[13] As a result, adults with reduced contrast sensitivity in low and high spatial frequency have difficulty reading and thus, additional lens with increased dioptric power are required to view standard size prints.[14] Healthy older adults with decreased visual processing speed on the other hand, have deficits in visual attention, associative learning, and executive function.[10,15,16] Thus, it was established that a generalized slowdown of information processing is likely caused by many aging-related cognitive impairments.

There is also a substantial change of the reading process in different age groups.[13,17-19] In preschoolers and elementary school children, reading speed improved with age.[19] Reading speed was fairly constant between teenagers and young adults, indicating that the reading skills had fully developed.[17,18] As people aged, their reading speed slowed. Adults read at approximately 9% slower than teenagers.[17,18] Slower reading could be due to some vision deficits in the healthy but aging eyes. After the age of 45, significant vision losses occur, and most notably in the middle and high spatial frequencies.[17]

Studies had established that changes in the size of texts caused eye movements to change as well. To investigate the cognitive processes of reading, the movement of the eyes were extensively investigated. However, studies in the past were conducted with a limited range of font size or reading materials were from electronic devices, such as online reading or reading from a digital screen (tablets, smartphones and laptops). Moreover, discrepancies exist regarding eye movements and there is limited research which compared reading using various font size on printed materials or among varied age groups. Data on these parameters are key as reading also occurs with printed or hard copy reading materials such as books, newspapers, food labels, brochures and medication labels on a daily basis, apart from reading through electronic displays. Given the age-related variation in reading ability, it is worthwhile to investigate eye movement patterns among young adults and adults with presbyopia. In this current study, the effect of text size and age on reading eye movement was examined between these two groups of readers.

## MATERIALS AND METHODS

### *Participants*

The eye movement behavior in reading different text sizes was conducted using a cross-sectional experiment of young adults (mean age: 22.28±1.46 years) and adults with presbyopia (mean age: age 49±6.65 years). The sample size was estimated using the formula $n=(Z\sigma/\Delta)^2$ computed using the G-power sample size software. The precision ($\sigma$) was set at 1. The standard deviation ($\Delta$) was 2.3, and the Z for the 95 percent confidence interval was 1.96. As a result, each group needed a total of 25 participants.

This study included twenty-five young adults and twenty-two adults with presbyopia. Corruption of data led to, three (3) participants with presbyopia to be eliminated. The inclusion criteria were short-sightedness and long-sightedness with a low to moderate habitual refractive error (sphere correction between +2.00DS and -3.00DS;

astigmatism up to -2.00DC; and addition for near up to +3.00DS). The best-corrected distance and near visual acuity were 6/9 and N6 or better. Participants with any form of binocular vision impairments and ocular illnesses and eye diseases were excluded.

### *Reading stimuli*

Reading passages in the Malay language from the Shauqiah-Ai Hong-Halilah Reading Passage Compendium (SAHRPC) were used as a reading stimuli.[20] The SAHRPC consisted of 42 passages divided into three sets of 13 each. Each set had 13 different Arial font text sizes, ranging from 1.2logMAR to 0.0logMAR. The passages were organized on a 0.1-step logarithmic scale in decreasing order. Each set of eight-page flip designs contained 13 printed passages in landscape format on a matte type A3 sized paper. A paragraph of four to five lines consisting of 50 words were arranged in each passage. Passages were taken from the Malaysian Ministry of Education's Malay language textbook, which is used in primary schools. This study used six Malay excerpts from the SAHRPC. The text sizes were 5pt, 8pt, 14pt, 20pt, 30pt, and 52pt, which were equivalent to 0.2logMAR, 0.4logMAR, 0.6logMAR, 0.8logMAR, 1.0logMAR, and 1.2logMAR text legibility, respectively. The six text sizes were chosen to resemble actual reading materials, with the text size of 52pt representing conventional newspaper headlines. Text of 30pt is similar to newspaper sub-headlines and children's books, 20pt is the same size as books for children aged seven to eight years old, 14pt is the equivalent to grade one to three children's textbooks, 8pt is the same size as tiny column newsprints, and 5pt is comparable to the small print found in The Bible or footnotes.

### *Eye Tracker*

The Dikablis Eye Tracking Glasses Professional (Ergoneer, Germany) is a wireless, head-based eye-tracking device that fits as a glasses-like frame. It includes two small cameras in front of the eyes that record and detect eye movement. The camera captures a 384 × 288-pixel black-and-white video of the eye. The scene camera, positioned on the nose portion of the spectacles, is another small camera. The scene camera records the participant's viewing scene at a resolution of 1,920 × 1,080 pixels during data recording. The scene camera can be tilted up to 12 degrees upward and 81 degrees downward. The eye cameras may be adjusted to meet the wearer's interpupillary distance. The head unit can also be easily adjusted to fit the size of the head using the cord stopper on the drawstring. The head unit can be worn over polarized glasses or spectacles. The D-Lab software version 3.0, installed on a computer, was used to send and analyze the collected data. The Dikablis Eye Tracking Glasses Professional has various data visualization tools, including an eye tracker, heat maps, and a glance flow diagram.

### *Experimental procedures*

The experiment was conducted in a room with ambient lighting and installed with a light booth and the reading stimuli. All participants provided a written informed consent before the experiment was commenced. The study was approved by the university's research ethics committee, in accordance with the Helsinki Declaration (Approval No: REC/426/17). The participants sat facing the reading stimuli (The Malay passage) placed on a reading stand at a working distance of 40 cm after passing the screening procedures. The passages were covered to prevent the participant from reading ahead of time. Along with their spectacle (if any), the participant wore the Dikablis eye tracker. The eye tracker was calibrated and the participant was asked to read aloud at a regular reading speed. The Dikablis eye tracker recorded the eye movement simultaneously during the reading process. The experiment was carried out individually for each text size.

### *Statistical analysis*

Eye movement data consisting of frequency of saccades, saccade angles, number of fixations, and fixation durations were recorded and sent to the D-Lab program. The SPSS version 21.0 software was used for statistical analysis. The median, quartile, mean, and standard deviation were derived as descriptive data from the eye movements. The Kolmogorov-Smirnov test showed that young adults' eye movement data were normally distributed ($p>0.05$). Hence, eye movements with different text sizes among the participants were compared using the One-way ANOVA test. Scheffe post-hoc test was selected for further analysis. A comparison of eye movement behavior between young adults and adults with presbyopia was conducted using an independent t-test. The statistical significance was set at $p<0.05$.

## RESULTS

This study compares the eye movement among young adults for texts in different font sizes. The number of saccades was found to be significantly increased ($F(5, 144) = 96.6$, $P<0.001$) when reading different text sizes. More saccadic movements were made when the text size increased, starting from 0.8logMAR to 1.2logMAR. Fig 1

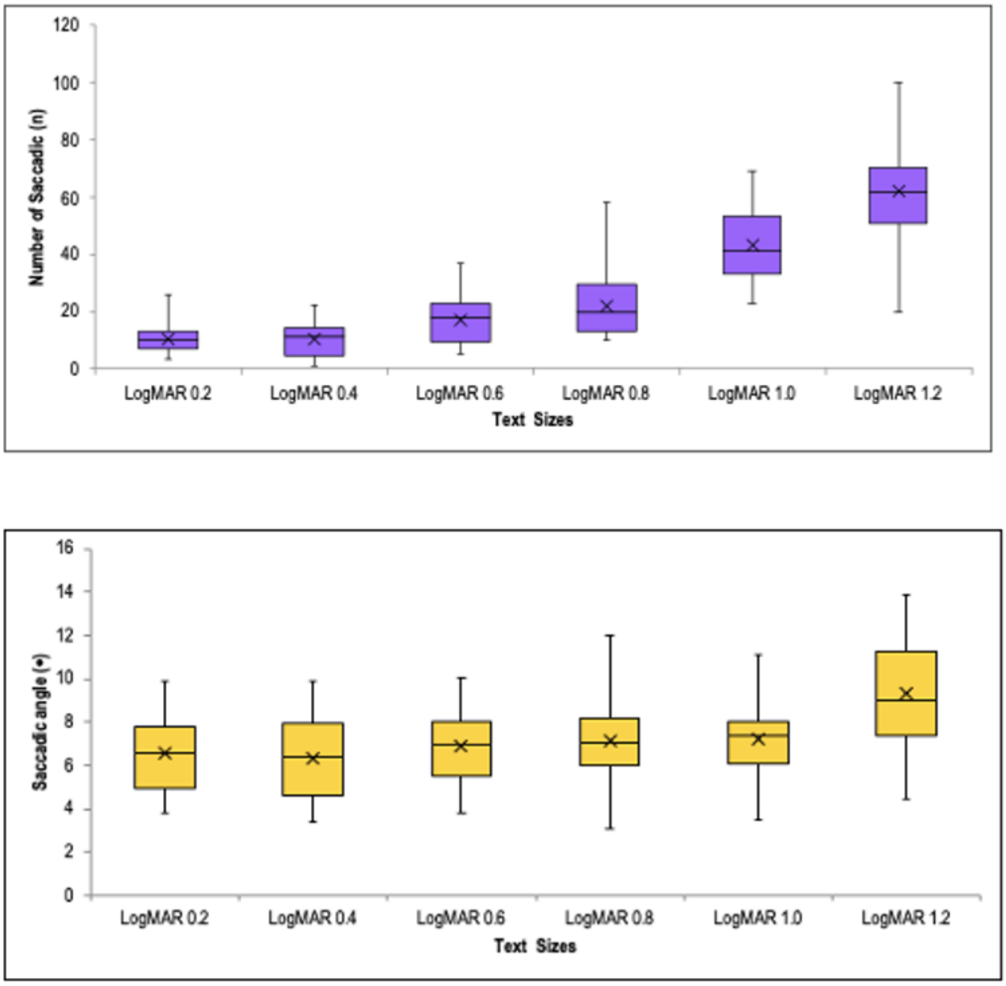



**Fig 1.** The saccadic eye movement behavior for different text sizes is shown in box plots. (a) Number of saccadic and (b) saccadic angles are shown above. The median is the horizontal line at the center of the box, and 'X' represents the mean value.

depicts the trend of the number saccadic movement. The saccadic angle became wider and more substantial as the text size increased, F (5, 144) = 7.03, p<0.001. When young adults read 1.2logMAR text size, which was comparable to 52pt, there were substantial changes in the saccadic angle data.

Fig 2 shows the frequency of fixations and fixation time. When font size increased, young adults made more stops during reading, F (5,144) =95.6, p<0.001. The number of fixations gradually rose with increasing text size, while fixation changed at text sizes 1.0logMAR and 1.2logMAR in young adults. The time the eye takes to stop during reading is called fixation duration. Fig 2 shows the fixation duration for different text sizes. Fixation duration was significantly longer for smaller text sizes, F (5,144)=7.04, p<0.001. At 0.2logMAR, 0.4logMAR, and 0.8logMAR, the eyes made more prolonged duration of stopping during reading.

Fig 3 shows the comparison of the number of saccadic movements and saccadic angles between adults with presbyopia and young adults. It was found that the number of saccadic movements were significantly different for different text sizes at 0.2logMAR (t(45)=-2.43, p=0.019), 0.6logMAR (t(45)=-2.77, p=0.008) and 0.8logMAR (t(45)=-2.32, p=0.025). Presbyopia readers made more saccadic movements compared to young adults.

The saccadic angle was significantly different at 0.2logMAR (t(45)=2.5, p=0.016) and 0.6logMAR (t(45)=2.5, p=0.015) between both groups of adults. Adults with presbyopia produced smaller and narrow saccadic angles when they moved from one fixation to another, especially with smaller text sizes.

Fig 4 shows the comparison of the number of fixation and fixation duration between young adults and adults with presbyopia. Adults with presbyopia made significantly (p<0.05) more pauses during a reading at all text sizes than young adults except at 1.2logMAR. Both adults with presbyopia and young adults had more fixation at larger text size than smaller text size. The

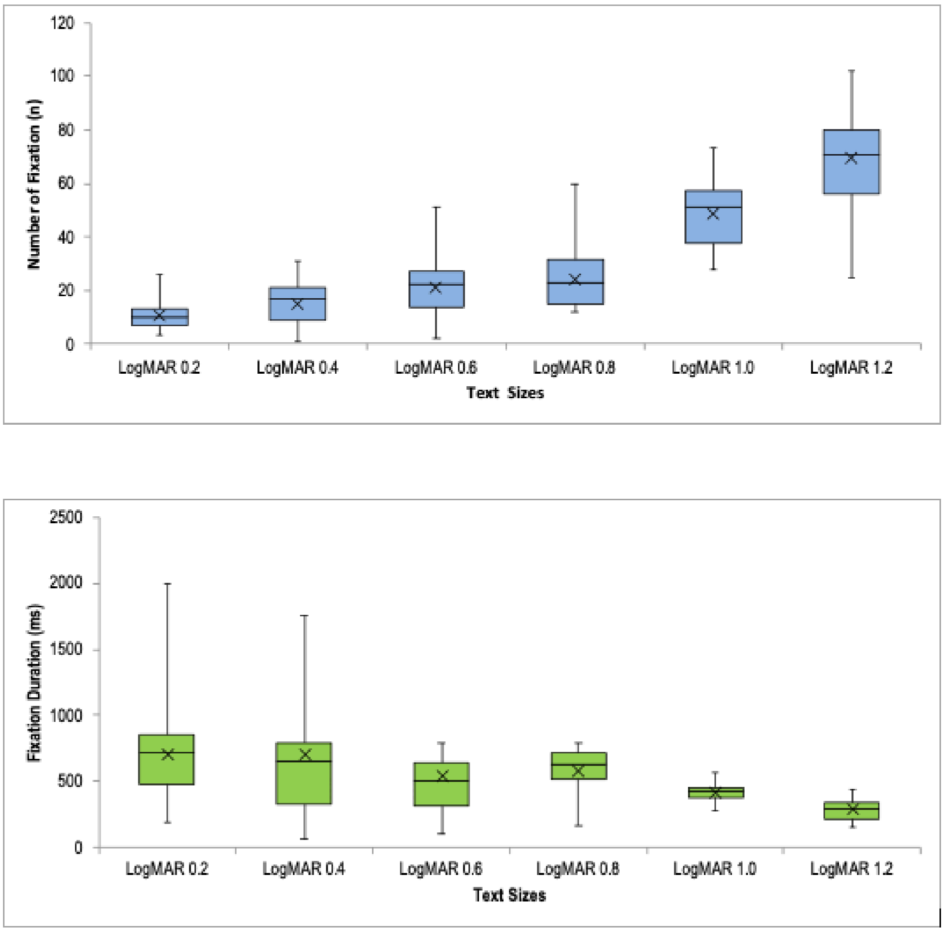



**Fig 2.** The fixation eye movement behavior for different text sizes is charted in box plots. The median value represents a middle horizontal line in the box, and the mean value is represented by the 'X' symbol within the box.

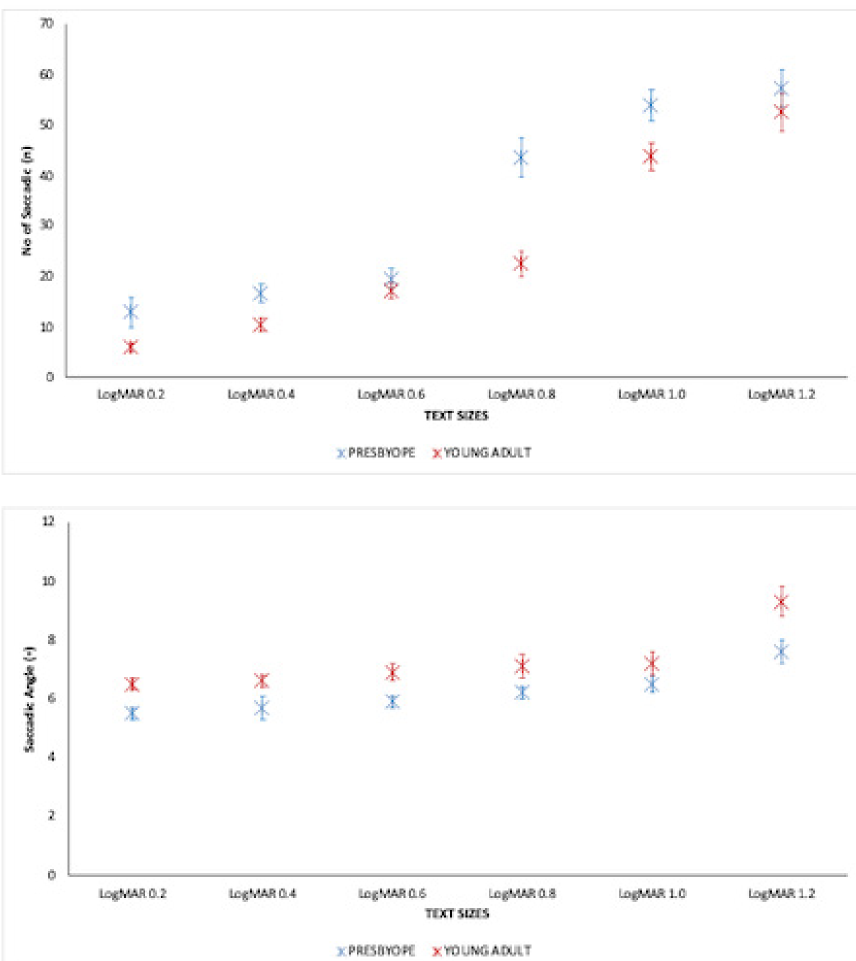
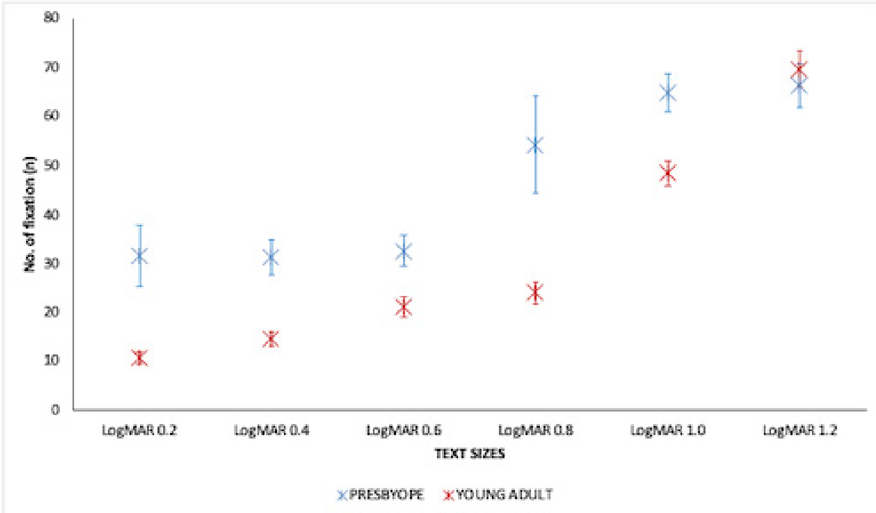



**Fig 3.** Comparison of saccadic eye movement for different text sizes between adults with presbyopia and young adults. (a) Number of saccadic and (b) saccadic angles is shown above.



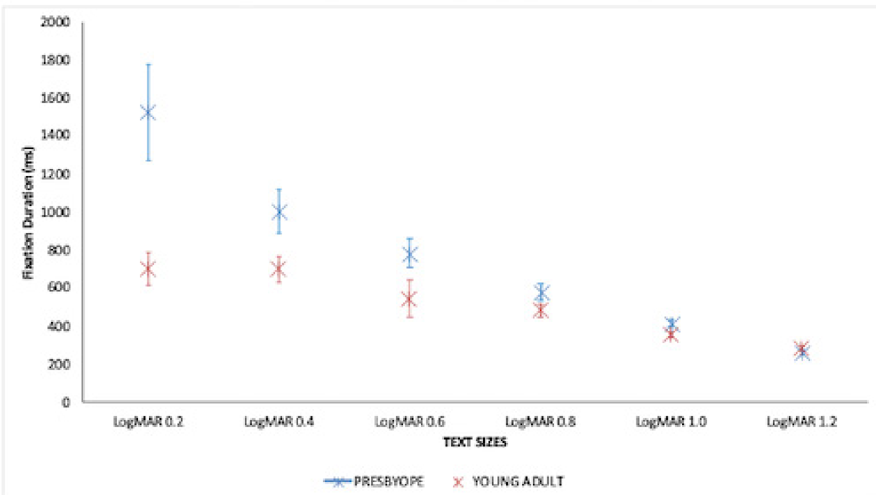




**Fig 4.** Comparison of fixation eye movement for different text sizes between adults with presbyopia and young adults. (a) Number of fixation and (b) fixation duration is shown above.

current data also demonstrates that fixation duration in adults with presbyopia was significantly slower at 0.2logMAR (mean:1523±254ms, $t(45)=-3.83$, $p<0.001$) and at 0.4logMAR (mean:1003±115ms, $t(45)=-2.23$, $p=0.025$) compared to the young adults readers. Fixation duration was longer at smaller text sizes than larger text sizes.

## DISCUSSION

Two elements of eye movement behaviours investigated in this study were saccadic movement and fixation. Reading at a size of 20pt displayed a significant change in eye movement behaviour. The findings revealed that saccadic angle became broader as the text size increased, which was also demonstrated in a previous study.[7,8] The amplitude of the saccade movement was also increased in 7- to 12-year-old children as they read 25pt and 30pt texts.[8]

Investigation of the shape and size of text on an LCD screen discovered that saccade lengths in degrees of visual angle widened with large texts.[7] The findings of Franken *et al.*[7] mirrored the current study that also showed saccade movement changed at a larger text. Other studies however, found no significant differences in saccadic movement, both length and the number of saccades between different print sizes.[6,9] Considering the major difference, Baymer *et al.*[6] used reading stimuli with texts with the font sizes of 10pt, 12pt, and 14pt, while this study used a wider range of size. In the current study, saccades and saccadic lengths were similar at smaller text size, but, increased with increasing text size due to more jumping eye movements between the lines of the whole passage, which were laid out to fit the page layout. The participant's shifting visual searching strategies could account for the different outcome gained in this study compared to the literature from the past.

As text size increased, the number of fixations increased and fixation duration reduced. For example, a 30-point text size had a significant increase in fixation, whereby, smaller text size led to less frequent stops but more time processing visual information. Studies have revealed a similar pattern whereby the eye made fewer and longer fixations with smaller text sizes.[6-9] Decreasing text size (10-pt or 24 pixels) resulted in significantly longer fixation durations.[6-9] At a text size of 2-pt, the fixation duration changed substantially.[7]

Atypical fixation behaviour was also revealed with reading materials of various text sizes. For smaller texts, the eye may spend more time fixating due to the crowding effect,[8,21] as longer stops were necessary for the eye to focus and extract visual information. Another possibility for longer stops is that letters or words printed closer to each other may interfere with the visual extraction process. Reading texts presented with larger spaces between the words did not seem to promote enhanced concentration.[22] However, readers found it difficult to read the smaller texts, which could explain how fixation behaviour diminishes with smaller texts. Changes in fixation behaviour also suggested that the eye employs visual attentional strategies to adapt to changes in different reading stimuli.

Compared to young adults, adults with presbyopia made more saccadic movements across different text sizes when eye movement data was analyzed. In terms of the size of the saccadic movement, adults with presbyopia made smaller and narrower angles between one fixation to another, especially with smaller text size. Furthermore, as the age increased, more stopping or pauses were made during reading for all text sizes. Fixations were also longer with smaller texts among adults with presbyopia compared to young adults.

Apart from a few other plausible explanations, this finding relates to reading performance, which has been shown to gradually decrease with age, even among individuals with good vision.[13,23] Contrast sensitivity have been demonstrated to decrease with age.[12,24-26] Physiological changes in the crystalline lens causes increment in light dispersion and aberration of sensitivity that reduces contrast.[12] Reduced contrast sensitivity also influenced visual-based cognitive abilities and visual speed processing.[12,26] Longer latencies in low contrast text affect information processing speed.[24] Previous research found that older adults have slower cognitive visual processing than younger adults.[10,27]

Decreased speed in reading could also be caused by deterioration in the transient system in an older adult.[10,27] The reduced spatial frequency may directly affect reading speed and change eye movements. Cognitive deficits in the elderly, such as visual attention and associative learning have been linked to changes in oculomotor function.[16,26,27] Age-related decline in motor function and ocular disease also affect eye movement.[27-30] Furthermore, older adults make more pronounced eye movement transitions compared to younger adults.[29] Young adults also had the quickest saccadic reaction compared to the aged participants. These findings demonstrate extremely strong age-related effects, corresponding to the various stages of normal nervous system development and degeneration.[31]

## CONCLUSION

In conclusion, eye movement changes when young adults and presbyopia readers read passages with varying text sizes. Changes in saccade eye movements proposed that visual searching strategy had shifted and changes in fixation behavior suggested a shift in visual attentional strategy. Age also affects eye movement behavior during reading, as adults with presbyopia demonstrated significantly different saccadic eye movements and fixation compared to young adults. These changes, however, reveal that the eye movement behavior is adaptable to changes in the pattern, shape, and size of the reading materials. Trend of these eye movement parameters may provide some insight that cognitive and brain processing during reading are altered to facilitate understanding a variety of reading materials.

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