Not All Spacings are Created Equal: The Effect of Text Spacings in On-the-go Reading Using Optical See-Through Head-Mounted Displays

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ABSTRACT

The emergent Optical Head-Mounted Display (OHMD) platform has made mobile reading possible by superimposing digital text onto users' view of the environment. However, mobile reading through OHMD needs to be effectively balanced with the user's environmental awareness. Hence, a series of studies were conducted to explore how text spacing strategies facilitate such balance. Through these studies, it was found that increasing spacing within the text can significantly enhance mobile reading on OHMDs in both simple and complex navigation scenarios and that such benefits mainly come from increasing the inter-line spacing, but not inter-word spacing. Compared with existing positioning strategies, increasing inter-line spacing improves mobile OHMD information reading in terms of reading speed (11.9% faster), walking speed (3.7% faster), and switching between reading and navigation (106.8% more accurate and 33% faster).

CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**.

KEYWORDS

Text Spacing, Inter-line Spacing, Inter-word Spacing, Reading on-the-go, Mobile Reading, Heads-up Computing, OHMD, Smart Glasses

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1 INTRODUCTION

The future world we live in will likely be a blend of physical and virtual realities, creating a seamless and immersive experience [34, 94]. The exact details of how this will manifest are still being explored and debated, but increasing evidence has pointed to an emergent concept called the "metaverse" that blends these two realms. By allowing users to access virtual information while still being aware of their surroundings [53, 87], Optical See-Through Head-Mounted Display (OHMD), due to its heads-up and hands-free capabilities [35, 57], is a promising platform that can help users to more seamlessly explore and live in the metaverse. With OHMDs, users can now adopt a new heads-up interaction paradigm [89], allowing them to receive in-context, just-in-time digital assistance anytime and in any environment.

In order to receive and respond to digital information in real-time while performing daily activities, users need to engage in multitasking (e.g., on-the-go reading). Previous works [53, 64] have demonstrated this trade-off between reading and navigation performance; when OHMD reading performance increases, users' perception of the environment tends to decrease. This imposes higher design requirements on how information should be presented in order to minimize interference with users' primary tasks. Researchers have extensively investigated various aspects of text presentation, such as text colour [40, 41, 67], background colour [54, 87], font type [15, 31, 60], text position and layout [23, 68, 87], as well as the use of animation [54], to improve users' reading experience on OHMDs in multitasking scenarios.

However, whether spaces within the text body can be *further* adjusted to improve the mobile OHMD reading experience is a research area that has been overlooked. We emphasise the word "*further*", as it is typically a typographer's job to determine the optimal spacing within the text. This includes spacing properties between words (inter-word spacing) and lines (inter-line spacing). Well-designed fonts have spacing arrangements that are often considered optimal, thus, rarely adjusted any further by users. Default

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spacing arrangements in typography are typically designed for conventional usage scenarios, while mobile reading on OHMDs is a unique use case with vastly different characteristics. This means that the default spacing arrangement may not be optimal for this new context. With this consideration in mind, we investigated strategies to further adjust inter-word and inter-line spacing within on-screen text blocks, with the goal of finding a presentation style to better support mobile OHMD reading.

Note that one reason spaces with text were previously under-explored is related to the length of the text. Previous studies have mainly explored the reading of small chunks of text (a few words to a sentence) on OHMDs [23, 54, 87] as they are easier to read during mobile multitasking scenarios. With only a small amount of text, there is limited need and room to further adjust spaces within the text. Yet if only small chunks of text were permitted to be displayed on OHMDs, it could be restrictive. While it is easy to display simple instructions or notifications, longer pieces of text (e.g., email, news article, recipe, etc.) need to be broken down into small chunks and displayed piece by piece, which has been shown by previous studies to significantly reduce user comprehension [32, 62, 85].

In our investigation, we first identified design factors (i.e., maximum range, alignment method) that affect text spacing for OHMD mobile reading in Study 1. Then in Study 2, we incorporated the inter-word and inter-line spacings within on-screen text blocks with the goal of finding an optimal presentation style to support reading and physical navigation multitasking. Finally, we compared the optimal text spacing interface (identified in Study 2) with two position-based strategies using navigation tasks of two levels of complexity in Study 3. We found that increasing the default spacing can improve mobile OHMD reading in simple and complex navigational situations. However, the effect differs between inter-word and inter-line spacing. While increasing inter-word spacing brings about negative effects, increasing inter-line spacing can significantly improve mobile OHMD reading and navigation performance (11.9% faster reading; 3.7% faster walking; 33% faster and 106.8% more accurate task switching between reading and navigation) as compared to position-based strategies. Based on the results, we discussed the reasons behind this phenomenon and design implications on how our findings can be used to improve the mobile OHMD reading experience.

In summary, our contribution is: we empirically explored the effects of text spacing on OHMD mobile reading, demonstrated that increased spacings are beneficial and identified the acceptable text spacing range, and investigated the optimal inter-word and inter-line spacing. We also compared our text spacing interface with two state-of-the-art position strategies (bottom-center and middle-right) using navigation tasks of two levels of complexity and demonstrated that the former benefits OHMD mobile reading performance.

2 RELATED WORK

2.1 Multitasking: OHMD Reading while on the go

Recent research revealed that Extended Reality (XR) would become mainstream in everyday life in the coming years [34, 94]. One type of wearable XR device is the emerging smart glasses platform or OHMD. Unlike traditional reading, OHMDs allow users to access digital information while still being aware of their surroundings [53, 87], making them especially useful for on-the-go situations [43, 58, 68, 87]. However, mobile OHMD reading requires users to multitask, dividing their visual attention between the OHMD display and their physical environment. The field of cognitive psychology has established that multitasking involves concurrent utilisation of a person's cognitive resources[71], which according to the Resource Competition Framework [70] can result in the slowing down, postponement, or termination of tasks when one is cognitively overloaded; a phenomenon referred to as the resource depletion penalty. Since real-life environments are often unpredictable and dynamic, physical navigation can impose significant mental and physical demands on users [64]. This may, in turn, compromise the user's ability to focus on the digital information presented on OHMD [53, 99]. In addition, the OHMD's screen is also transparent, which can make the text more difficult to read in dynamically changing environmental conditions such as lighting, background colour, and texture [40, 41]. Furthermore, existing OHMDs typically have a lower screen resolution than average mobile phones. Overall, these characteristics of OHMDs and their unique usage context mean that existing guidelines and practices in the user interface (UI) design may not be directly applicable. This concern motivates our study.

2.2 Text Presentation on OHMDs

To accommodate the specific characteristics of mobile OHMD reading, various properties of text presentation have been studied and redesigned. We discuss three categories that are most relevant to our study.

2.2.1 ***Text Style.*** Typeface, size, and format significantly affect perceptions of legibility, sharpness, and ease of reading in a computer-displayed text [15]. In the mobile OHMD reading context, previous studies [40, 56, 68] have shown that simple green text (#00FF00 in hex) against a black transparent background [54, 87]) is most visible and sans serif typefaces such as Arial are most readable [31, 40, 51]. Furthermore, a minimum size of 30pt at a distance of 2m was recommended for the Microsoft Hololens OHMD [8]. We incorporated these recommended text styles in our studies as control variables.

2.2.2 ***Text Layout.*** Various approaches have also been proposed to optimise text layouts for OHMD mobile reading. Orlosky et al. [68] suggested an intelligent system for automated positioning, such that text is placed in an on-screen position that complements the user's background environment. Similarly, Tanaka et al. [95] determined the optimal screen area for displaying information by using a mounted camera to evaluate the sight image behind the OHMD. While these methods aim to display information in ideal positions, they are responsive to the dynamically changing environment in which the user is present. This may lead to continuous changes in virtual object positions, which adversely affects the user's ability to multitask, especially in mobile situations. More closely linked to mobile OHMD reading scenarios are dual-task applications. Chua et al. [23] investigated the effect of notification positioning on monocular OHMDs and found that middle-right and top-right positions were most suitable for long-duration usage, while central positions were optimal for less urgent scenarios. Rzayev et al.'s [87] study extended these findings by demonstrating that the centre or bottom-centre positions decreased subjective workload and improved text understanding compared to the top-right position. Since mobile OHMD reading is a dual-task application that may be used for prolonged duration, we consider bottom-centre and middle-right positions to be comparable state-of-the-art strategies.

2.2.3 ***Text Quantity.*** The amount of text displayed on a single OHMD screen could affect user perception. According to Chen et al. [22], low-text quantities might include labels with a few words, while high-text quantities might consist of detailed description of objects. Previous studies on OHMD mobile reading have primarily focused on short texts (i.e., low-text quantities), such as presenting only several words [54, 87] or one sentence at a time [43]. While these strategies can help reduce the cognitive load associated with mobile reading, they limit the amount of content that can be shown.

Studies have shown that displaying small chunks of words on the screen can negatively impact users' reading comprehension. Dillon et al. found that splitting sentences between pages often results in a frequent return to the previous page to reread the text [32]. This splitting will likely disrupt the comprehension process by placing an extra burden on the limited capacity of working memory. Additionally, 10-20% of the eye movements made when reading in this condition are regressions to earlier fixated words. Previous research [62, 85] also indicated that larger text sizes are more readable than smaller ones.

In the mobile learning context, Ram et al. [77] suggested that users can comprehend 6-8 chunks of the information displayed on-screen for controlling the information density. They further recommended that the information be persisted on the same screen to ease the temporal load on the working memory. Previous research has also highlighted the importance of data persistence for enhancing the understanding of information presented on OHMDs [66, 76], which suggests the potential value of displaying longer texts on these devices. However, Fukushima et al. [38] investigated presenting 10-line text using default spacing settings on an OHMD while walking on a treadmill and found that the text blocks displayed were challenging to read while walking and felt "overwhelming". Therefore, we investigate how to adjust text spacing so that users can access longer text (e.g., emails or articles) intuitively and efficiently for OHMD mobile reading.

2.3 The Effect of Text Spacing on Reading

Reading is a complex cognitive process involving several mental processes, including visual perception, language comprehension, and memory [82]. Eye movements play a crucial role in reading, as they allow the reader to fixate on individual words and phrases, and to move smoothly from one part of the text to another [78, 79, 82]. The speed and accuracy of these eye movements can impact reading comprehension, and efficiency [55, 82]. The specific patterns of eye movements used during reading (e.g., z-pattern, f-pattern, and zig-zag pattern) can influence reading behaviour and comprehension [45, 46]. These patterns are determined by how people scan and focus on the words and phrases in a text, and can affect the speed and accuracy of the reading.

The z-pattern is a common reading pattern in which the reader's eyes move starting at the top left and moving horizontally to the top right, then diagonal down to the bottom left, and then another horizontal movement to the right. This pattern allows the reader to cover the entire page and fixate on each word [36, 45]. The f-pattern, on the other hand, is a more efficient reading pattern in which the first horizontal movement is similar to z-pattern, but the reader would scan a vertical line down the left side and fixate on keywords and phrases. If they found something interesting, they would read the line, forming the second horizontal line movement, and repeat the process [36, 65]. The zig-zag pattern extends the z-pattern by seeing it more as a series of z-movements instead of one big z-movement [45, 46]. The zig-zag pattern is particularly relevant in our case, as we asked participants to read the entire content and fixate on each word. They will continue to move to the right and then a little down and back to the left before starting another horizontal movement to the right again, which is how readers naturally read large blocks of text.

Additionally, typography involves various types of text spacing, including characters, words, and lines [7]. These are more suited to readings on conventional devices where users can devote their full attention. In this paper, we focus on two types of spacing that appear to have a greater impact on mobile OHMD reading: inter-word and inter-line spacing, as they guide eye movements and assist in reading speed and comprehension.

2.3.1 ***Inter-word spacing.*** Inter-word spacing refers to the space between words. It is an important factor in the way words are identified, as it helps the reader delineate between the beginning and end of words [75]. Inter-word spacings also guide eye movements and direct the eye towards target reading positions [81]. Previous studies affirm that inter-word spacings are essential, demonstrating a slower reading speed when removed [37, 74, 80, 81, 83].

2.3.2 ***Inter-line spacing.*** Similarly, inter-line spacing, which is defined as the space between vertically adjacent lines, assists in guiding eye movement [75, 81]. Previous studies found a slight increase in reading speed in peripheral vision for normally sighted individuals, but no improvement was found for reading using central vision in desktop reading scenarios [18, 21, 24].

Overall, the default inter-word and inter-line spacing are more optimal for conventional reading scenarios. Yet mobile reading on OHMD is a unique use case with vastly different characteristics. The default spacing arrangement may not be optimal for this new context. It remains inconclusive whether the same insights translate to real-world OHMD reading and physical navigation scenarios. This motivated us to delineate factors influencing mobile OHMD reading performance in a series of full lab studies.

3 RESEARCH OVERVIEW

We proceeded with our investigation in three steps (see Fig1(b)).

(1) **Study 1 - Identifying design factors that affect text spacing on OHMD mobile reading.** We conducted preliminary studies to investigate: 1) What are the benefits, if any, of increasing spacings beyond the default specified by font style? 2) What is the acceptable range for text spacing increments? Since we noticed that additional spacing in the

horizontal direction could utilise two approaches (aligned vs. unaligned), we also conducted a pilot study to find 3) Which approach is more suitable for introducing inter-word spacing?

(2) **Study 2 - Investigating the effects of text spacing on OHMD mobile reading.** With the findings from our previous studies, we proceeded to more systematically investigate how inter-word or inter-line spacings affect mobile OHMD reading. Study 2 identified the optimal text spacing strategy, which we further validated in study 3 with existing approaches.
(3) **Study 3 - Comparing text display method (Spacing vs. Positions) on OHMD mobile reading.** In study 3, we compared the spacing strategy for text displayed in the centre of OHMDs, a display position that is not considered optimal for mobile OHMD reading with different complexities in walking paths. Existing literature suggests bottom-centre and middle-right as ideal positions to achieve a better balance in mobile multitasking scenarios. Thus, we empirically evaluated our proposed text spacing approach (identified in Study 2), with the two recommended approaches to further validate our findings.

4 COMMON SETTINGS

All our studies share a common setting and we provide the summary below.

4.1 Tasks & Materials

Overall, the task is to simulate mobile reading on OHMDs while navigating an indoor environment (via walking). This larger task involves two subtasks: reading text from an OHMD's display and navigating towards a destination, based on pasted signs.

The reading subtask: Asking participants to read silently makes it difficult for experimenters to monitor the reading progress. Thus, we followed Ku's [54] approach in instructing participants to read text aloud, as fast and as accurately as possible while comprehending the content. The reading material presented on OHMD was adopted from the AceReader application [1]. To avoid potential confounding effects, we chose ten English articles under the "fun fact" category since these articles were less familiar to general audiences. AceReader was designed to offer articles of the same difficulty level, each with 8 well-calibrated multiple-choice questions (with 4 answer options each). To ensure the reliability and validity of the selected articles, we conducted a pre-test where we asked seven lab members to complete 160 multiple-choice questions (MCQs) without providing them with the original articles. The articles with the lowest scores were selected for the study. In addition, we conducted a post-test where we asked participants if they were familiar with the reading articles using a 7-point Likert scale to control for any potential effects of prior familiarity on their reading comprehension scores.

Each article has an average of 360 words (SD=11.1), with 14.6 words per sentence (SD=3.5), and a Flesch Score in the 65-70 range, which suggests it can be easily understood by 8th graders [4]. The text was displayed on an iPad and mirrored the OHMD screen. Display settings were chosen according to prior research. The text was green (#00FF00 in hex) against a black background that appears transparent on OHMD [40, 54, 56, 68, 87], with an Arial font of size 30pt [8, 31, 40, 51].

To navigate to the next page of text, participants simply needed to tap on the iPad screen without needing to look at the iPad.

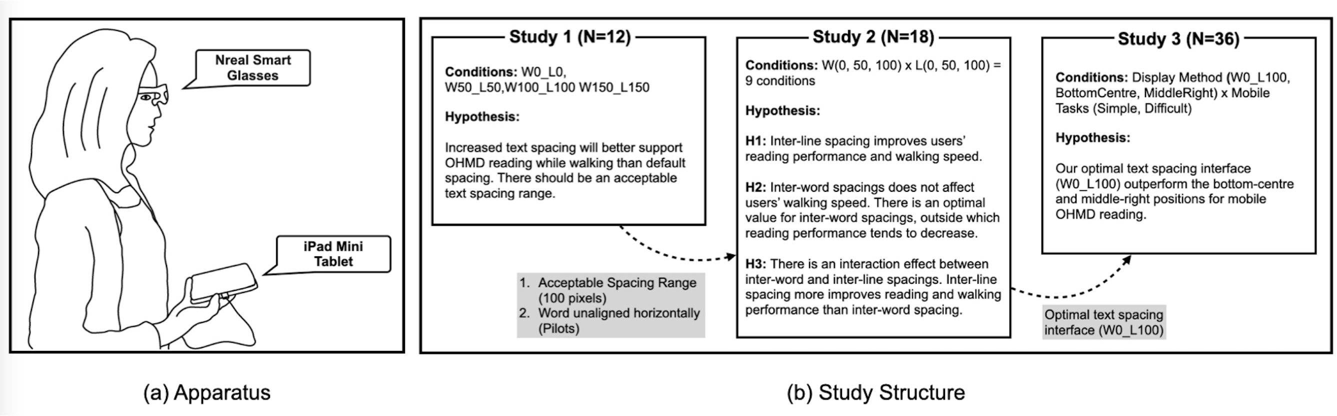
Navigation subtask: In this study, participants were asked to walk along a rectangular path with two levels of complexity: simple and complex. Study 1 and 2 used simple walking path only, while Study 3 used both simple and complex walking paths. Participants circulated the path 2 times per condition (see Fig:2(a) and Fig:2(c)). A sign with 4 locations listed was pasted on each wall along their path. Depending on their current round of circulation (e.g. the second round), they had to read aloud the location listing with the corresponding number (e.g. they had to read out "2. Recording Room at Level 9" from the sign). As recommended [51], the signs showed 160 pseudo location names (21-31 characters, M=24.6, SD=2.09) with white Arial font against a black background.

During the study, we asked participants to read from an OHMD while navigating the assigned path. For the simple path, participants were asked to read and follow navigation signs as they passed by them. For the complex path, there were navigation signs placed to the left and right of the participant, and they were required to follow the direction of the signs to determine which one to read. They were allowed to stop and resume walking as and when necessary. Each trial began when the user read the first word of text on OHMD and ended only when the participant completed all rounds of walking, regardless of whether they finished reading the text on OHMD.

4.2 Devices & Software

One of our key considerations was to select the right OHMD model for our experiments, as we hoped to minimize technical limitations which may affect the OHMD reading experience. After evaluating 4 different OHMDs (Vuzix Blade, Epson BT300, Microsoft Hololens 2, and NReal Light), we picked the Nreal Light glasses [5], as it provided the best viewing experience in mobile walking scenarios. Our decision was based on several factors, including the weight, field of view, display resolution, and user comfort of each device. NReal is lightweight (106 grams) and has higher visual clarity, with a 52-degree diagonal field of view and stereoscopic display resolution of 1920x1080 pixels. In air casting mode, its screen is 115 inches diagonal at 3 metres, such that text can be clearly displayed, and comfortable to read for mobile uses.

Participants wore the Nreal Light glasses which mirrored the screen of a connected iPad Mini tablet [2]. React, Typescript, and Ionic were used to develop the experiment application hosted on the iPad Mini (Apparatus: see Fig1(a)). We compared the use of the iPad mini with alternative devices, such as smartphones and the Nreal smart glasses' own controller. We chose the iPad mini because its screen mirroring was most similar to the Nreal glasses, and offered users better readability and simplicity. The iPad mini's small and light form factor was well-received by users and did not cause any complaints about holding it while walking. However, in situations where the users' hands are occupied, it may be better to replace the iPad mini with a more portable device and use a wearable controller such as a ring mouse to interact with the OHMDs.



Study 1 (N=12)

Conditions: W0_L0, W50_L50,W100_L100 W150_L150

Hypothesis:

Increased text spacing will better support OHMD reading while walking than default spacing. There should be an acceptable text spacing range.

1. Acceptable Spacing Range (100 pixels)
2. Word unaligned horizontally (Pilots)

Study 2 (N=18)

Conditions: W(0, 50, 100) x L(0, 50, 100) = 9 conditions

Hypothesis:

H1: Inter-line spacing improves users' reading performance and walking speed.

H2: Inter-word spacings does not affect users' walking speed. There is an optimal value for inter-word spacings, outside which reading performance tends to decrease.

H3: There is an interaction effect between inter-word and inter-line spacings. Inter-line spacing more improves reading and walking performance than inter-word spacing.

Optimal text spacing interface (W0_L100)

Study 3 (N=36)

Conditions: Display Method (W0_L100, BottomCentre, MiddleRight) x Mobile Tasks (Simple, Difficult)

Hypothesis:

Our optimal text spacing interface (W0_L100) outperform the bottom-centre and middle-right positions for mobile OHMD reading.

Figure 1: (a) The apparatus included the NReal OHMD and iPad Mini tablet, which participants held as they performed the experiment. (b) A structure connecting the summary of our three studies.

Figure 2: The mobile tasks used. For both (a) simple and (c) complex walking tasks, the floors were taped to outline a rectangular path with a perimeter of 30 meters (width of 8m) that participants followed. Signs were pasted 2.5m away from the path, in the participant's line of sight. The sign changed accordingly in each study. For the simple path (a), participants were asked to read and follow navigation signs as they passed by them (b). For the complex walking task (c), there were navigation signs placed to the left and right of the participant, and they were required to follow the direction of the signs to determine which one to read (d). Note that Studies 1 and 2 used simple walking path only, while Study 3 used both simple and complex walking paths.

4.3 Common experimental procedure

All our studies shared similar experimental procedures. Thus, we lay down common steps below and if necessary, elaborate on additional details specific to each study in corresponding sections.

The common procedure starts with participants signing a consent form and completing a questionnaire about their demographic information. Next, we asked them to walk naturally for two rounds along the taped path to determine their normal walking speed. We then provided an example task to familiarise participants with the experiment as part of the training session. Afterwards, they began the actual experimental task. After completing a condition, we tested participants' comprehension using the MCQs of their text article. Before proceeding to the next condition, we asked participants to complete a questionnaire relating to perceived task load, and also provided an optional 2-min break. After completing all formal conditions, we collected their overall preference ranking across all conditions. We asked participants to elaborate on their choices through our semi-structured interview, before concluding the experiment.

4.4 Measures

Measures can be categorised into four groups: 1) primary OHMD reading task performance, 2) secondary navigation (reading while walking) task performance, 3) overall task-switching performance, and 4) subjective measures in terms of task workload and overall preference ranking.

4.4.1 ***Primary reading task performance.*** This was measured using the reading goodput and comprehension. Similar to Ku et al. [54], we calculated reading goodput by dividing the total number of words correctly read out by the total time spent in each text spacing condition. Its units are words-per-minute (WPM). For comprehension, we measured the percentage of questions answered correctly [72, 86].

4.4.2 ***Secondary navigation tasks.*** This was measured using the Percentage of Preferred Walking Speed (PPWS) and reading task accuracy [43, 77]. For PPWS, we measured the walking speed of each text spacing condition and calculated the percentage based on the normal walking speed (measured at the beginning of the study procedure). For accuracy, we measured the percentage of locations correctly read out.

4.4.3 ***The task-switching performance.*** This was evaluated via:

(1) **Switch-back Duration (SBD)**. This measures the average switching time between primary (OHMD reading) and secondary (navigation) tasks [70]. Specifically, we started measuring the duration at the completion of a secondary task and ended at the beginning of a primary task.
(2) **Switch-back Error Rate (SBER)**. We measured the percentage of words repeated, skipped, or incorrectly read aloud while the participant resumed the primary task from the secondary task [13, 91].

4.4.4 ***Subjective measures.***

(1) **NASA-TLX**. This procedure computes participants' perceived task load [44].
(2) **Overall preference ranking across all conditions**.

5 STUDY 1 - IDENTIFY THE POSSIBILITY OF APPLYING TEXT SPACING TO OHMD MOBILE READING SCENARIOS.

We began our design exploration by conducting two preliminary studies. Study 1 answers the following research questions:

RQ1: Does increased text spacing better support OHMD reading while walking than default spacing?

RQ2: If increased text spacing is beneficial, what is the acceptable spacing range?

We assumed in this preliminary stage that spacings include inter-word and inter-line dimensions and that both equally influence OHMD reading while walking. We tested 4 spacing arrangements in 50-pixel increments applied equally in both directions: 0 (i.e. default or no additional spacing), 50, 100 and 150 pixels. A pilot study was conducted to test different spacing increments, and it was found that increasing the spacing by 50 pixels improved participants' ability to distinguish between the different spacing conditions. We excluded 200 pixels as it severely limits the number of words that can be displayed on the OHMD screen (about 8 words) and adversely affects the reading experience [20].

5.1 Participants

We recruited 12 participants (6 females) between 19-28 years old (M=21.8, SD=2.42) from the university community. All participants had normal or corrected-to-normal vision with no colour deficiency and were fluent in English at the university level. None of them had prior experience using OHMDs. They were compensated at the standard rate of US$7.30 per hour.

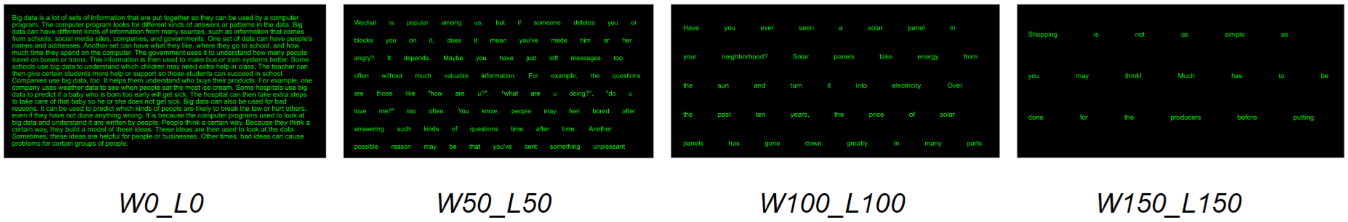
5.2 Design

A repeated measures within-subject design was used. The independent variable was Text Spacing (see Fig. 3: *W0_L0*, *W50_L50*, *W100_L100*, *W150_L150*) and counterbalanced using a balanced Latin square to avoid potential ordering effects.

5.3 Results

5.3.1 Primary Task Performance. This was evaluated by Reading Goodput (number of correct words read per minute) and Reading Comprehension Scores. In summary, uniformly increasing inter-word and inter-line spacing improves the mobile OHMD reading performance, but its benefits diminish as the spacing increases to 150 pixels, suggesting that while increasing text space can potentially be beneficial, there is an optimal range. Text spacings that go below or above this range may adversely affect performance. A detailed analysis is provided below.

Comparing the Reading Goodput (wpm), we found a main effect of Text Spacing ($F_{3,33} = 6.86$, $p < .05$, $\eta^2_G = 0.06$) on Reading Goodput. Pairwise comparisons revealed that 50 pixels ($M = 119.12$ wpm) had a higher Reading Goodput than both 0 pixels ($M = 103.46$ wpm, $p < .05$) and 150 pixels ($M = 104.26.26$ wpm, $p < .05$) (see Fig.4). 100 pixels ($M = 116.56$ wpm) also had a higher Reading Goodput than 0 pixels ($M = 103.46$ wpm, $p < .05$). However, no significant difference between 50 pixels ($M = 119.12$ wpm) and



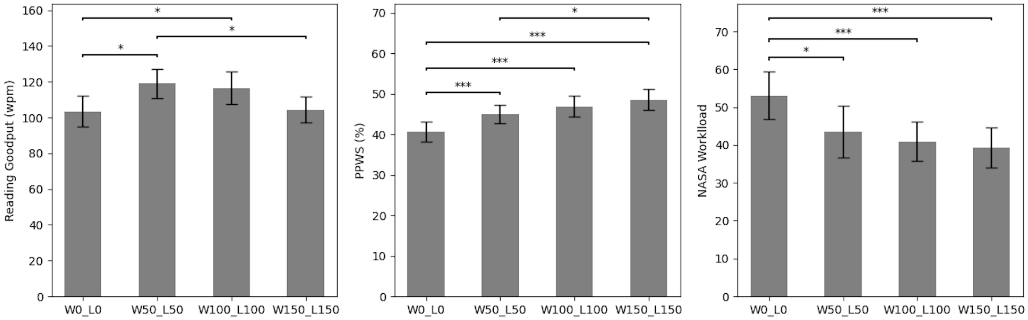
Big data is a lot of sets of information that are put together so they can be used by a computer program. The computer program looks for different kinds of answers or patterns in the data. Big data can have different kinds of information from many sources, such as information that comes from schools, social media sites, companies, and governments. One set of data can have people's names and addresses. Another set can have what they like, where they go to school, and how much time they spend on the computer. The government uses it to understand how many people travel on buses or trains. This information is then used to make bus or train systems better. Some schools use big data to understand which children may need extra help in class. The teacher can then give certain students more help or support so those students can succeed in school. Companies use big data, too. It helps them understand who buys their products. For example, one company uses weather data to see when people eat the most ice cream. Some hospitals use big data to predict if a baby who is born too early will get sick. The hospital can then take extra steps to take care of that baby so he or she does not get sick. Big data can also be used for bad reasons. It can be used to predict which kinds of people are likely to break the law or hurt others, even if they have not done anything wrong. It is because the computer programs used to look at big data and understand it are written by people. People think a certain way. Because they think a certain way, they build a model of those ideas. These ideas are then used to look at the data. Sometimes, these ideas are helpful for people or businesses. Other times, bad ideas can cause problems for certain groups of people.

Wechat is popular among us, but if someone deletes you or
blocks you on it, does it mean you've made him or her
angry? It depends. Maybe you have just left messages too
often without much valuable information. For example, the questions
are those like "how are u?", "what are u doing?", "do u
love me?" too often. You know, people may feel bored after
answering such kinds of questions time after time. Another
possible reason may be that you've sent something unpleasant

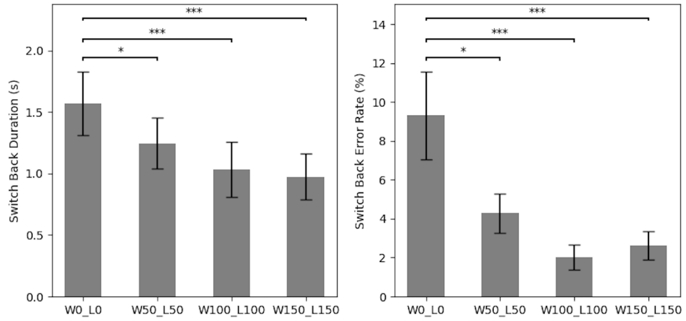
Have you ever seen a solar panel in
your neighborhood? Solar panels take energy from
the sun and turn it into electricity. Over
the past ten years, the price of solar
panels has gone down greatly. In many parts

Shopping is not as simple as
you may think! Much has to be
done for the producers before putting

Figure 3: The four conditions compared in Study 1: inter-word (*W*) and inter-line (*L*) spacing vary by 0 pixels in (*W0_L0*), 50 pixels in (*W50_L50*), 100 pixels in (*W100_L100*), and 150 pixels in (*W150_L150*).



(a) Reading Goodput (b) PPWS (c) NASA Workload



(d) Switch Back Duration (e) Switch Back Error Rate

Figure 4: Study 1 Results: Means and standard deviations (SD) of (a) Reading goodput, (b) Percentage of Preferred Walking Speed, (c) NASA-TLX workload, (d) Switch-back Duration, (e) Switch-back Error Rate for text spacings arrangements of 0 pixels in (*W0_L0*), 50 pixels (*W50_L50*), 100 pixels (*W100_L100*), and 150 pixels (*W150_L150*).

100 pixels ($M = 116.56$ wpm) was found. This shows that text spacings are more suitable for mobile OHMD reading than the default spacing (0 pixels). However, text spacings should not exceed 100 pixels because an increase from 50 to 100 pixels resulted in only a 2.1% decline in reading performance, but increasing it from 50 to 150 pixels led to a 14.3% performance drop. In addition, there was no significant effect of Text Spacing on Reading Comprehension Scores, suggesting that although text spacings can affect Reading Goodput, it does not significantly affect comprehension.

5.3.2 Secondary Task Performance. This was measured using reading Task Accuracy and Percentage of Preferred Walking Speed (PPWS). In summary, we found a positive correlation between the amount of text spacing and navigation performance. In other words, the larger the text spacings, the faster and easier the navigation. Details are provided below.

There was no main effect of Text Spacing ($p > .05$) on Task Accuracy, indicating that participants were similarly accurate with spaced texts as well as without. Also, we found a main effect of Text Spacing ($F_{3,33} = 29.59$, $p < .001$, $\eta^2_G = 0.12$) on PPWS (see Fig.4). Pairwise comparisons revealed that text spaced with 150 pixels ($M = 48.5\%$), 100 pixels ($M = 46.9\%$), and 50 pixels ($M = 45\%$) all resulted in a higher PPWS than 0 pixels ($M = 40.7\%$) (all $p < .001$). In addition, 150 pixels ($M = 48.5\%$) also incurred a higher PPWS than 50 pixels ($M = 45\%$) ($p < .05$). The relationship between text spacing and walking performance is positively correlated (i.e. improvements in walking performance taper as text spacings increase), though not linearly proportional (i.e. increasing from 0 to 50 pixels led to a 10.6%

improvement, while increasing from 100 to 150 pixels only yielded a 3.4% improvement). These findings are in line with the Resource competition framework (RCF) [70]; greater spaces between words provide visual gaps for readers to look at their physical environment. Thus participants were better able to navigate the environment, which explains the faster walking pace.

5.3.3 Overall Task-Switching Performance. This was evaluated using Switch-Back Duration (SBD) and Switch-Back Error Rate (SBER: Percentage of words repeated, skipped, or incorrectly read). In summary, we found that increasing text space improves task switching, but its improvement rate roughly followed a power curve (see Fig.4) instead of being linear. In other words, the improvement is much greater with initial space increments but slowly approaches maximum benefit as the increment increases. Note that with a limited range, it is difficult to judge whether further increments of text spacing will approach a theoretical limit or reverse the trend.

The results of SBD and SBER exhibit similar trends. We found a significant main effect of Text Spacing on both SBD ($F_{3,33} = 14.43$, $p < .001$, $\eta_G^2 = 0.09$) and SBER ($F_{3,33} = 10.34$, $p < .05$, $\eta_G^2 = 0.30$). Pairwise comparisons revealed that text spaced with 50 pixels ($M_{SBD} = 1.25s$, $M_{SBER} = 4.3\%$), 100 pixels ($M_{SBD} = 1.03s$, $M_{SBER} = 2\%$) and 150 pixels ($M_{SBD} = 0.97s$, $M_{SBER} = 2.6\%$) incurred less SBD and SBER than 0 pixels ($M_{SBD} = 1.57s$, $M_{SBER} = 9.3\%$) (all $p < .05$). These results suggest that adding text spacings improves OHMD multitasking. Text with 100 or 150 pixels could save participants around 38.2% of task switch-back time and improve task switch-back accuracy by 76.3-78.5% as compared with default spacing (0 pixels).

5.3.4 Subjective measures: The NASA TLX results formed a pattern similar to task-switching performance. Its improvement rate roughly followed a power curve (Fig.4) with much greater gains during initial space increment and slowly approaches maximum benefit as the increment further increases. A detailed analysis is provided below.

We observed a main effect of Text Spacing ($F_{3,33} = 9.99, p < .001$, $\eta_G^2 = 0.07$) on perceived Task Workload. Pairwise comparisons revealed that 50 pixels ($M = 43.45$), 100 pixels ($M = 40.92$) and 150 pixels ($M = 39.28$) had significantly lower task workloads than 0 pixels ($M = 53.14$) (all $p < .05$). This suggests that greater text spacings can reduce task workload (i.e. 50, 100, and 150 pixels outperformed 0 pixels). These findings also show similar trends to PPWS, SBD and SBER results.

In addition, participants were asked to provide feedback on two aspects, i.e. the most preferred and the maximum acceptable condition (upper bound of text spacings). All participants preferred having text spacings over default spacing. Of all spacing configurations, seven participants preferred 100 pixels as their first choice, while the remaining five preferred 50 pixels. Eight participants felt 150 pixels were their upper bound, while four chose 100 pixels.

5.4 Discussion

We draw the following conclusions based on our findings.

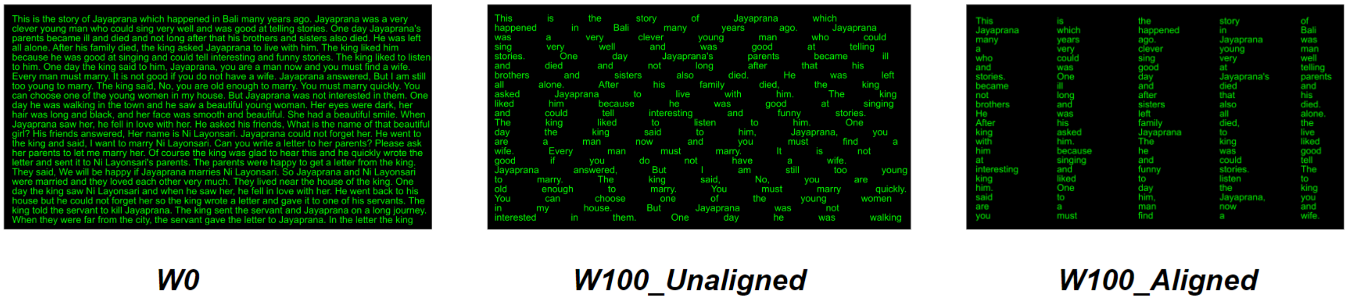
5.4.1 ***Increased text spacings outperform the default spacing arrangement, and improve OHMD multitasking performance.*** We found that greater text spacings (100 and 150 pixels) considerably outperformed default spacing in terms of reducing participants' task workload, resulting in a significantly higher PPWS, and lower SBD and SBER measures of multitasking. This suggests that text spacing could positively influence the way in which participants shifted their attention between the digital display and the physical environment. Participants' feedback showed that with increased text spacings, they could more easily view digital information while simultaneously locating their physical environment through the gaps between words. Besides, these spaces seemed to help participants detect task-switching boundaries, which caused less disruption and reduced the overall multitasking workload.

As a result, all participants preferred having some text spacing over default spacing. Participants found that default spacing made it "difficult to see the surrounding environment through the text" (P8, P9). Also, spacings between words "facilitate[d] smooth reading and switching between the primary and secondary tasks" (P1, P12).

5.4.2 ***There is an acceptable range for text spacings.*** Although different measures provided different conclusions, considered together, we conclude that the benefit of spacing increment lies within a certain range. Beyond its range, the overall benefits either plateaued or diminished. For example, as the spacing increased beyond 100 pixels, the reading performance decreased. While deciding whether to pick 100 or 150 as the suitable range, we looked at the data as well as consulted our participants. Based on the subjective feedback, eight participants found 150 pixels to be "too spacious" (P2, P9), and as it supported much fewer words per screen, content had to be spread "across multiple pages/screens" (P8). The downside of this is that participants had to click and scroll more frequently, which "[added to] more mental and physical demand" (P1). Taking into account objective results and subjective feedback, we chose 100 pixels as the upper limit for our follow-up studies.

5.5 Pilot Study

The logical next step is to investigate potential differences in inter-word and inter-line spacings for OHMD mobile reading. However, while inter-line spacing is straightforwardly defined, inter-word spacing can either be unaligned (the space between the last letter of a word and the first letter of the next word) or aligned (the space between the first letters of consecutive words is the same as the previous word that adopted from previous study [92], see Fig.5). We further conducted a pilot study with 9 participants between the ages of 20-27 (Mean=23, SD=2.55) to understand if words should or should not be aligned horizontally for effective OHMD reading and walking. Results show that the unaligned arrangement (*W100*) was more suitable for inter-word spacings, as it significantly outperformed the aligned arrangement in terms of task-switching performance (61.64% improvement) and task workload (15.28% reduction). Further examination of the literature revealed that when all columns and rows are visually aligned, variable word lengths cause word boundaries to become less obvious to readers, thereby adversely affecting their reading performance [75, 80]. Additionally, our results revealed that text without inter-word spacing (*W0*) outperformed text with 100-pixel (*W100*) inter-word spacing in reading performance. This contradicts Study 1 results, which showed that equal inter-word and inter-line spacings could improve reading



W0

This is the story of Jayaprana which happened in Bali many years ago. Jayaprana was a very
clever young man who could sing very well and was good at telling stories. One day Jayaprana's
parents became ill and died and not long after that his brothers and sisters also died. He was left
all alone. After his family died, the king asked Jayaprana to live with him. The king liked him
because he was good at singing and could tell interesting and funny stories. The king liked to listen
to him. One day the king said to him, Jayaprana, you are a man now and you must find a wife.
Every man must marry. It is not good if you do not have a wife. Jayaprana answered, But I am still
too young to marry. The king said, No, you are old enough to marry. You must marry quickly. You
can choose one of the young women in my house. But Jayaprana was not interested in them. One
day he was walking in the town and he saw a beautiful young woman. Her eyes were dark, her
hair was long and black, and her face was smooth and beautiful. She had a beautiful smile. When
Jayaprana saw her, he fell in love with her. He asked his friends, What is the name of that beautiful
girl? His friends answered, Her name is Ni Layonsari. Jayaprana could not forget her. He went to
the king and said, I want to marry Ni Layonsari. Can you write a letter to her parents? Please ask
her parents to let me marry her. Of course the king was glad to hear this and he quickly wrote the
letter and sent it to Ni Layonsari's parents. The parents were happy to get a letter from the king.
They said, We will be happy if Jayaprana marries Ni Layonsari. So Jayaprana and Ni Layonsari
were married and they loved each other very much. They lived near the house of the king. One
day the king saw Ni Layonsari and when he saw her, he fell in love with her. He went back to his
house but he could not forget her so the king wrote a letter and gave it to one of his servants. The
king told the servant to kill Jayaprana. The king sent the servant and Jayaprana on a long journey.
When they were far from the city, the servant gave the letter to Jayaprana. In the letter the king

W100_Unaligned

This is the story of Jayaprana which
happened in Bali many years ago. Jayaprana
was a very clever young man who could
sing very well and was good at telling
stories. One day Jayaprana's parents became ill
and died and not long after that his
brothers and sisters also died. He was left
all alone. After his family died, the king
asked Jayaprana to live with him. The king
liked him because he was good at singing
and could tell interesting and funny stories.
The king liked to listen to him. One
day the king said to him, Jayaprana, you
are a man now and you must find a
wife. Every man must marry. It is not
good if you do not have a wife.
Jayaprana answered, But I am still too young
to marry. The king said, No, you are
old enough to marry. You must marry quickly.
You can choose one of the young women
in my house. But Jayaprana was not
interested in them. One day he was walking

W100_Aligned

This is the story of
Jayaprana which happened in Bali
many years ago. Jayaprana was
a very clever young man
who could sing very well
and was good at telling
stories. One day Jayaprana's parents
became ill and died and
not long after that his
brothers and sisters also died.
He was left all alone.
After his family died, the
king asked Jayaprana to live
with him. The king liked
him because he was good
at singing and could tell
interesting and funny stories. The
king liked to listen to
him. One day the king
said to him, Jayaprana, you
are a man now and
you must find a wife.

Figure 5: Three types of text display format were evaluated in the Pilot study: (i) *W0*; (ii) *W100* Unaligned; (iii) *W100* Aligned with 5 columns per screen.

performance. An interaction effect between inter-word and inter-line spacings could be a plausible reason for this. This also suggests that inter-line spacing (applied to Study 1 conditions but absent in Pilot) could have a greater positive effect on reading performance than inter-word spacing. We investigated these possibilities in our Study 2.

6 STUDY 2 - INVESTIGATING THE EFFECTS OF TEXT SPACING ON OHMD MULTITASKING

Our previous studies' results revealed two preliminary insights. Firstly, we found the desirable range for inter-word and inter-line spacings to be 0 to 100 pixels. Secondly, we found that the unaligned text was more suitable for inter-word spacings, yielding a lower task workload and improved multitasking performance compared to its aligned text counterpart. In addition, results and participant feedback suggest that the effects of inter-word and inter-line spacings are possibly not equal. To investigate potential interactions, we conducted a follow-up study with the following research questions.

RQ1: How do inter-line spacings affect OHMD reading and walking performance? Results from previous studies suggest that inter-line spacings have a positive effect on reading and walking performance. Thus, we hypothesise that:

H1.1: Inter-line spacing improves users' reading performance.

H1.2: Inter-line spacing increases users' walking speed.

RQ2: How do inter-word spacings affect OHMD reading and walking performance?

Study 1's results indicate that inter-word spacings should not exceed 100 pixels, after which reading performance declines. This may be reflective of natural reading techniques, for which words are segmented into meaningful phrases as we read. Excessive increases in inter-word spacing necessitate more eye movements in this process. For walking speed, however, our pilot study (see section 5.5) suggests that inter-word spacings do not affect walking speed. Hence, we hypothesise that:

H2.1: There is an optimal value for inter-word spacings, outside which reading performance tends to decrease.

H2.2: Inter-word spacing does not affect users' walking speed.

RQ3: Is there an interaction effect between inter-word and inter-line spacing for mobile OHMD reading scenarios?

Study 1 and pilot study (see section 5.5) suggest possible interaction effects between inter-word and inter-line spacing. Hence, we hypothesise that

H3.1: There is an interaction effect between inter-word and inter-line spacings.

H3.2: Inter-line spacing improves reading and walking performance more than inter-word spacing.

6.1 Participants

We recruited 18 participants (8 males) between the ages of 19 and 25 (Mean=21.5, S= 2.28) from the university community. None of them participated in previous studies and had prior experience using OHMDs. All other participant details follow that of previous studies.

6.2 Design

We used a within-subject design with 3 inter-word spacing levels (*W0*, *W50*, *W100*) x 3 inter-line spacing levels (*L0*, *L50*, *L100*), which resulted in 9 conditions per participant as shown in Fig. 6. The order of inter-word and inter-line spacing variables were counterbalanced using a balanced Latin square to avoid potential ordering effects. The same measures from previous studies were used.

6.3 Results

The Switch-Back Error Rate (SBER) did not meet the normality assumption of ANOVA (Shapiro-Wilk tests, $p > .05$); thus, we applied the aligned rank transformation [98].

There was no significant interaction effect of inter-word spacing x inter-line spacing ($p > .05$) on all measurements.

6.3.1 *Primary reading performance:*

For inter-word spacing, we only found a main effect on Reading Goodput ($F_{2,34} = 17.27$, $p < .001$, $\eta^2_G = 0.06$) (see Fig 7). Pairwise comparisons revealed that *W0* ($M = 113.08$ wpm) resulted in the highest Goodput (all $p < .001$), followed by *W50* ($M = 106.9$ wpm) and finally *W100* ($M = 99.26$ wpm). Also, *W50* was significantly higher than *W100* ($p < .05$). This suggests that inter-word spacing reduces reading speed, which is in line with previous studies findings. For inter-line spacing, there was a main effect on Reading Goodput ($F_{2,34} = 49.97$, $p < .001$, $\eta^2_G = 0.15$). Pairwise comparisons revealed that *L0* ($M = 93.09$ wpm) resulted in the lowest Reading Goodput (all $p < .001$), but *L50* ($M = 111.1$ wpm) and *L100* ($M = 115.05$ wpm) were comparable ($p >$

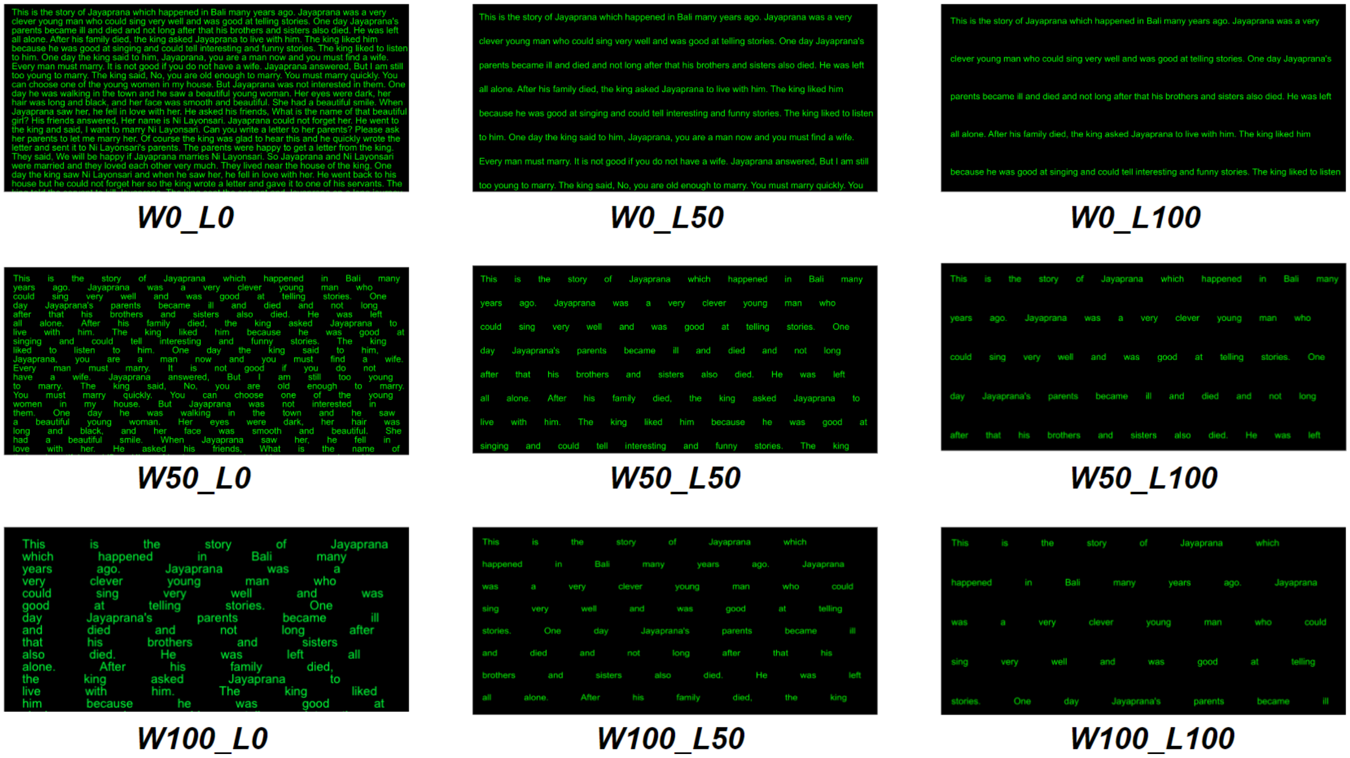


Figure 6: 3x3 combinations of text spacing conditions were used in Study 2, including 3 inter-word spacings (*W0, W50, W100*) by 3 inter-line spacings (*L0, L50, L100*).

.05). These results suggest that while additional inter-word spacing reduces reading goodput, additional inter-line spacing increases it, but only for the first 50 pixels.

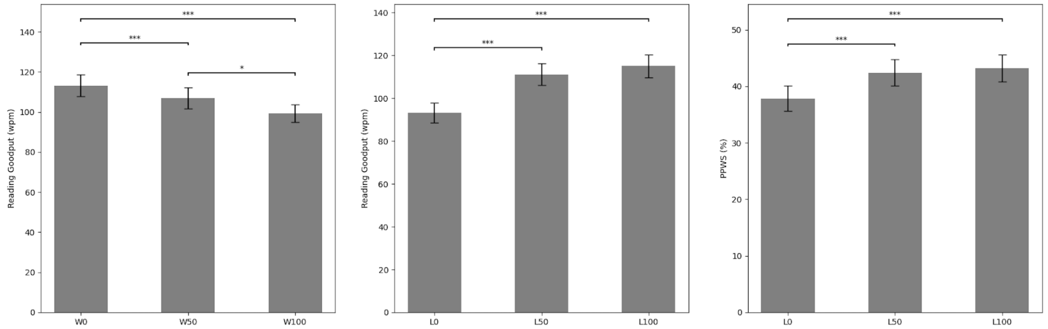
6.3.2 Secondary Task Performance: There was no main effect of inter-word spacing on Task Accuracy and PPWS, while we found a significant main effect of inter-line spacing on PPWS ($F_{2,34} = 71.16$, $p < .001$, $\eta^2_G = 0.05$) but no effect on Task Accuracy (see Fig 7). Pairwise comparisons show that *L100* (M = 43.33%) and *L50* (M = 42.43%) had higher PPWS than *L0* (M = 37.87%) (all $p < .001$, see Fig 7). This suggests that greater inter-line spacing could generate higher walking speeds.

6.3.3 Overall Task Switching Performance: There was no main effect of inter-word spacing on SBD and SBER. We found significant main effects of inter-line spacing on SBD ($F_{2,34} = 60.94$, $p < .001$, $\eta^2_G = 0.27$) and SBER ($F_{2,34} = 8.54$, $p < .001$, $\eta^2_G = 0.12$). Pairwise comparisons showed similar trends between both measures, which revealed that *L100* ($M_{SBD} = 0.81s$, $M_{SBER} = 1\%$) and *L50* ($M_{SBD} = 1s$, $M_{SBER} = 2.5\%$) had lower SBD and SBER measures of multitasking than *L0* ($M_{SBD} = 1.55s$, $M_{SBER} = 5.13\%$) (all $p < .001$) (see Fig 7). In addition, *L100* ($M_{SBD} = 0.81s$, $M_{SBER} = 1\%$) had a lower SBER than *L50* ($M_{SBD} = 1s$, $M_{SBER} = 2.5\%$) ($p < .001$), which suggests that greater inter-line spacing can generate task switching speeds and accuracy in multitasking scenarios.

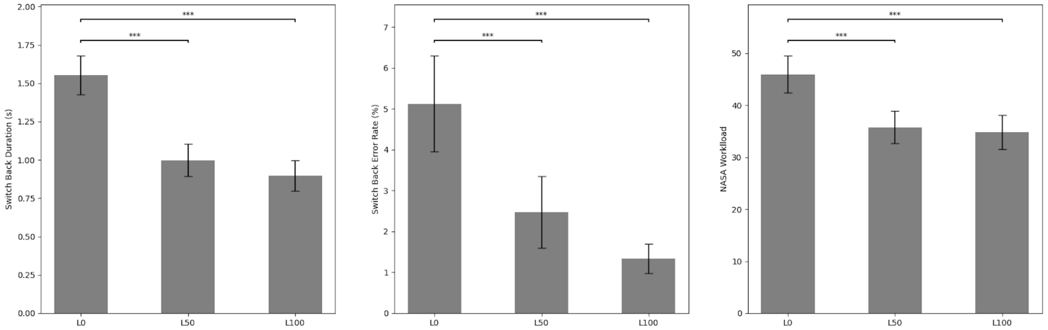
6.3.4 Subjective measures: The NASA TLX assessment revealed one main effect of inter-line spacing ($F_{2,34} = 26.39$, $p < .001$, $\eta^2_G = 0.10$) (see Fig 7). Pairwise comparisons revealed that *L100* (M = 34.83) and *L50* (M = 35.75) both had a lower task workload than *L0* (M = 45.9) ($p < .001$, each). This suggests that increasing inter-line spacing may help participants lower task workloads in multitasking scenarios. Participants' preferences also showed a similar trend. Eleven participants preferred having only inter-line spacing (without inter-word spacing) between words: nine preferred *W0_L100* while two preferred *W0_L50*. Yet, only six participants preferred combining both spacings: Five preferred *W50_L100* (i.e. inter-line spacing larger than inter-word spacing) and one preferred *W100_L100*. Only one participant preferred *W100_L0* (inter-word spacing without inter-line spacing) because excessive inter-line spacing made it difficult for her to move from one line to the next as she read.

6.4 Discussion

6.4.1 ***Inter-line spacings increase OHMD reading and walking speed, as well as overall multitasking performance.*** Our results show that text with inter-line spacings (of 50 and 100 pixels) considerably outperformed those without additional inter-line spacings (*L0*) in terms of task workload, reading speed, walking speed, as well as multitasking speed and accuracy. These benefits were also evident from participant comments. With increased inter-line spacing, they could "easily track where [they] stopped when switching back to the primary reading task" (P9 and P4). With small or no inter-line spacing, they "felt confused about where to



(a) Interword Spacing - Reading Goodput (b) Interline Spacing - Reading Goodput (c) Interline Spacing - PPWS



(d) Interline Spacing - Switch Back Duration (e) Interline Spacing - Switch Back Error Rate (f) Interline Spacing - NASA Workload

Figure 7: Study 2 Results: Means and standard deviations (SD) of significant measures: (a) Reading goodput for inter-word spacings, (b) Reading goodput for inter-line spacings, (c) Percentage of Preferred Walking Speed for inter-line spacings, (d) Switch-back Duration for inter-line spacings, (e) Switch-back Error Rate for inter-line spacings, (f) NASA-TLX workload for inter-line spacings.

locate the next line that should read” (P11 and P10). Overall, we find support for hypotheses H1.1 (inter-line spacing improves reading performance) and H1.2 (inter-line spacing increases walking speed).

6.4.2 *Inter-word spacings reduce reading speed while walking.*

While almost all objective measures show no effect for inter-word spacing, participants produced the highest goodput with *W0* conditions. In fact, adding 50 pixels and 100 pixels of inter-word space reduces goodput by 5.5% and 12.22% respectively. This undesirable effect is consistent with our qualitative results, where almost all participants (17/18) disliked *W100_L0*. As hypothesised, participants felt that the additional 50 pixels result in the eyes having “to move rapidly and [is] thus very distracting” [P9]. Distracted participants could, as a result, accidentally read from the wrong line. Therefore, we find no support for H2.1, which hypothesises that there is an optimal inter-word spacing. We consider the possibility that spacings between *W0* and *W50* (e.g. W10, W20, W30, W40) may influence outcomes and suggest this as a direction for future exploration. In addition, our results support H2.2, which hypothesises that inter-word spacing does not affect walking speed.

6.4.3 *Inter-line spacing is more beneficial than inter-word spacing in OHMD multitasking scenarios.*

Inter-word spacing is more important than inter-line spacing in stationary reading contexts [18, 42], and our previous studies also hint towards the fact that this translates to the mobile OHMD reading situation. Despite this, our results do not support H3.1, revealing no interaction effect between inter-word and inter-line spacings on all measurements. In fact, our results reveal that inter-line spacings have significant positive effects on reading goodput, PPWS, task switching performance and task workload. On the other hand, inter-word spacings negatively affect reading goodput and have no effect on all other measurements. Hence, we find support for H3.2, that inter-line spacings are more advantageous than inter-word spacings.

From our studies so far, we have gained two main insights. Firstly, the mechanism by which inter-word spacings affect reading speed differs from that of inter-line spacings; while inter-word spacing influences the reading of consecutive words, inter-line spacing affects the reading of successive lines. Since the frequency of word-to-word reading is higher than that of line-to-line reading, “undesirable inter-word spacing could [more] easily have a negative effect on reading speed” (P11). Participants also found it challenging to locate words when switching between secondary and primary tasks (P7 and P15). Despite the negative effects of inter-word spacing on reading goodput, Study 1 showed that equal inter-word and inter-line spacings improved reading performance. This suggests that inter-line spacings can function to compensate for the negative impacts of increased inter-word spacings. Secondly, results demonstrated that inter-line spacings positively affect task-switching performance (between primary to secondary tasks). Taken together, we recommend *W0_L100* as the optimal spacing, as it facilitates reading and walking performance. We formally evaluate *W0_L100* in the following study.

7 STUDY 3 - COMPARING TEXT DISPLAY METHODS (SPACING VS. POSITIONS) ON OHMD MULTITASKING WITH DIFFERENT COMPLEXITIES IN WALKING PATHS

The information displayed on OHMD should not occupy the entire screen [96, 97]. Previous research has suggested strategies for localising text content to a particular area on the screen, so as to balance the needs of reading and environmental awareness. Nine locations (top, middle, bottom X left, centre, right) were tested; middle-right [23], and bottom-centre [87] locations were found to be most suitable for text displays on OHMD in multitasking scenarios. In this study, we aim to find out how our text spacing approach compares with recommendations from previous research with different complexities in walking paths. Our research question is: Can the optimal text spacing interface from Study 2 outperform the middle-right and bottom-centre positions for mobile OHMD reading in walking paths with varying complexities?

7.1 Participants

We recruited 36 participants (17 males) between the ages of 19 and 34 (Mean = 23, SD = 3.00) from the university community. None of them participated in previous studies and had prior experience using OHMDs. All other participant details follow that of previous studies.

7.2 Design

The experiment used a two-factor, mixed factorial design. A between-subject factor Mobile Tasks has 2 levels (Simple, Complex) (see Fig.2), and a within-subject factor Display Method has 3 levels as shown in Fig 8 (*W0_L100*, Bottom Center, Middle Right). We ensured that the number of words on screen was similar across all three levels (average of 96 words). Hence, the full design resulted in 3 conditions (3 display methods) per participant, counterbalanced using a balanced square design to avoid potential ordering effects. The same measures from previous studies were used.

7.3 Results

There was no significant interaction effect of Display Method x Mobile Tasks ($p > 0.05$) on all measurements. Also, there was no significant between-subject effect of Mobile Tasks ($p > 0.05$) on all measurements.

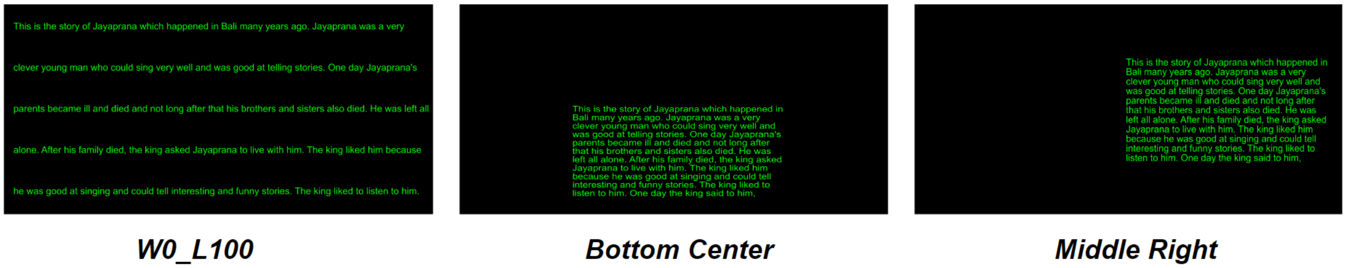
7.3.1 Primary reading performance: There was a significant effect of the Display Method ($F_{2,68} = 16.76, p < .01, \eta^2_G = 0.04$) on Reading Goodput (see Fig. 9). Pairwise comparisons revealed that *W0_L100* ($M = 105.4$ wpm) had a significantly higher Reading Goodput than both the bottom centre ($M = 100.32$ wpm, $p < .05$) and middle right ($M = 94.19$ wpm, $p < .001$). Also, there was a significant difference between the bottom centre and the middle right ($p < .05$). This suggests that participants read faster and more accurately with our text spacing interface than with positioning strategies. There was no significant effect of the Display Method ($p > .05$) on Reading Comprehension. This suggests that participants could comprehend the passages well with text spacing as well as the positioning strategies.

7.3.2 Secondary Task performance: There was no significant effect of the Display Method ($p > 0.05$) on Task Accuracy (see Fig. 9), suggesting that participants were similarly accurate when completing the secondary tasks with text spacing and positioning strategies. There was a significant effect of Display Method ($F_{2,68} = 3.97, p < .05, \eta^2_G = 0.003$) on PPWS. Pairwise comparisons revealed that *W0_L100* ($M = 39.1\%$) had a significantly higher PPWS than the middle right ($M = 37.69\%, p < .001$). But no significant difference was found between *W0_L100* and bottom centre ($M = 38.67\%$). This suggests that participants walked faster with the text spacing interface than the middle right position.

7.3.3 Overall Task switching performance: There was a significant effect of Display Method on both Switch-Back Duration ($F_{2,68} = 12.97, p < .001, \eta^2_G = 0.06$) and Switch-Back Error Rate ($F_{2,68} = 3.87, p < .05, \eta^2_G = 0.05$) (see Fig. 9). Pairwise comparisons revealed that *W0_L100* ($M_{SBD} = 1.15s$, $M_{SBER} = 3.71\%$) had a significantly lower switch-back duration and reading error rate than the middle right ($M_{SBD} = 1.53s$, $M_{SBER} = 7.52\%$) (all $p < .001$) and bottom centre ($M_{SBD} = 1.52s$, $M_{SBER} = 7.66\%$) (all $p =< .001$) positions. However, no significant difference between the bottom centre and the middle right was found. This suggests that participants could switch back quickly with the text spacing interface to their primary task, and they could read more accurately with our text spacing interface upon resuming their primary task.

7.3.4 Subjective measures: There was a significant effect of Display Method ($F_{2,68} = 6.90, p < .05, \eta^2_G = 0.05$) on perceived task workload (see Fig. 9). Pairwise comparisons revealed that *W0_L100* ($M = 50.8$) had a significantly lower subject workload than the middle right ($M = 57.13, p < .05$). But no significant difference was found between *W0_L100* and the bottom centre ($M = 53.43$), as well as the bottom centre and middle right. While Rzayev et al.'s study suggested that text read from the OHMD's bottom centre position can impose a lower subjective workload compared with other positions (i.e., middle right), this may be due to differences in task complexity; while Rzayev et al. utilised a simple walking scenario, our navigation task simulated real-world complex situations that naturally resulted in a higher workload.

For the simple walking path, eight participants preferred our text spacing interface over the two text positioning methods. Six participants preferred the bottom centre, while the remaining four preferred the middle right position. For the complex walking path, twelve participants preferred our text spacing interface over the two text positioning methods. Three participants preferred the bottom centre, while the remaining three preferred the middle right position. Between the bottom centre and middle right, eight participants preferred the former. This suggests that our text spacing strategy becomes more advantageous as the difficulty of the navigation path increases.



This is the story of Jayaprana which happened in Bali many years ago. Jayaprana was a very
clever young man who could sing very well and was good at telling stories. One day Jayaprana's
parents became ill and died and not long after that his brothers and sisters also died. He was left all
alone. After his family died, the king asked Jayaprana to live with him. The king liked him because
he was good at singing and could tell interesting and funny stories. The king liked to listen to him.

W0_L100

This is the story of Jayaprana which happened in
Bali many years ago. Jayaprana was a very
clever young man who could sing very well and
was good at telling stories. One day Jayaprana's
parents became ill and died and not long after
that his brothers and sisters also died. He was
left all alone. After his family died, the king asked
Jayaprana to live with him. The king liked him
because he was good at singing and could tell
interesting and funny stories. The king liked to
listen to him. One day the king said to him,

Bottom Center

This is the story of Jayaprana which happened in
Bali many years ago. Jayaprana was a very
clever young man who could sing very well and
was good at telling stories. One day Jayaprana's
parents became ill and died and not long after
that his brothers and sisters also died. He was
left all alone. After his family died, the king asked
Jayaprana to live with him. The king liked him
because he was good at singing and could tell
interesting and funny stories. The king liked to
listen to him. One day the king said to him,

Middle Right

Figure 8: Three types of text display method were evaluated in Study 3: (i) *W0_L100*) (ii) Bottom Center, (iii) Middle Right.

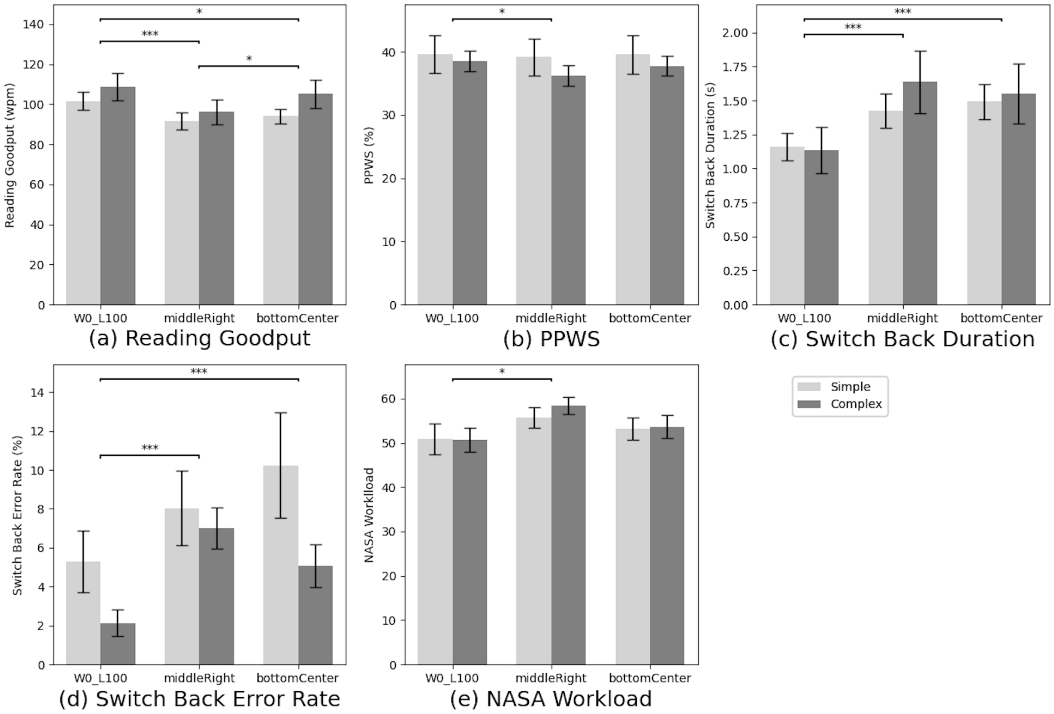


Figure 9: Study 3 Results: Means and standard deviations (SD) of significant measures: (a) Reading Goodput, (b) Percentage of Preferred Walking Speed, (c) Switch-back Duration, (d) Switch-back Error Rate, (e) NASA-TLX workload for both simple and complex walking paths.

7.4 Discussion

7.4.1 ***Is the optimal text spacing interface identified from Study 2 better than the middle right and bottom centre positioning strategies for mobile OHMD reading?*** In this study, a mixed design method was used, in which the same experiment was conducted on two groups with different walking path difficulties. The results obtained from both groups demonstrated a consistent pattern, providing strong evidence for the generalizability of the findings to a broader population and to varying levels of walking path difficulty. In previous studies [23, 87], positional approaches were not tested in scenarios displaying large amounts of text. While we do not claim to surpass these approaches, we were inspired by them in developing our own methods for displaying large chunks of text. We have identified three strategies for displaying such text, each of which maintains a similar total number of words to leave the same space for users to maintain their awareness of their surroundings. Although we kept the same remaining spaces on OHMD across the three Display Methods, the results revealed that our text spacing interface yields notably higher reading and walking performance over the two recommended position methods in both the simpler and the more complex walking paths. Participants' preferences supported these because increasing inter-line space (*W0_L100*) "allow[ed] greater readability" (P5, P21). The spacing between lines also facilitated greater temporal awareness (P10, P25). P6 and P27 felt it was "easy [to continue] after switching between tasks". Compared to the two positioning methods, participants felt that the text spacing strategy made it easy for them to locate where they had last stopped, requiring them to only "read a couple of words instead of glancing through sentences" (P7, P23). Additionally, participants' preferences also suggested that our text spacing strategy becomes more beneficial as the navigation path's difficulty increases. Overall, results demonstrated that the spacing strategy identified in Study 2 could bring more benefits to the activity of mobile OHMD reading, perhaps more so than existing position-based layout strategies.

8 OVERALL DISCUSSION

This study revealed two key insights: First, increasing spacings beyond the default spacings can significantly improve the mobile OHMD reading experience, especially during more complex navigation scenarios. Second, the effects of inter-word text spacings can differ significantly from inter-line spacings. In particular, Pearson's correlation test showed that **inter-word spacings negatively correlate to reading performance** while bearing no correlation to navigation and task-switching performance. In contrast, **inter-line spacings positively correlate to reading performance, navigation, and task-switching performance**.

In the next sections, we explore hypotheses and reasons for differences between inter-word and inter-line spacing. Our investigations involve three subtasks that determine mobile OHMD reading performance: 1) the reading task; 2) the navigation task, and 3) switching between the reading and navigation tasks.

8.1 The effect of spacing on reading performance.

Reading is a complex skill in which humans move their eyes three to four times every second as a result of visual and cognitive processing [16]. The EMMA eye-movement model [88] provides a theoretical foundation that relates eye movement with shifts in visual attention, and predicts that readers tend to take a longer time to encode individual visual objects when reading widely spaced text. Conversely, narrowly spaced text expedites the encoding and eye movement process, allowing for a more efficient reading experience. While this explains why increased overall spacing causes reading performance degradation, it does not explain the more nuanced varying effects between inter-word and inter-line spacing.

A possible explanation for this relates to the manner in which English text is generally read in a zigzag fashion [46]. While other reading styles have been studied (e.g., F-Pattern reading), we assume the general consensus that English is read in a Z-shape, from left to right and top to bottom (see Fig.10). Considering this, inter-word spacing affects the reading of the words within the same line, while inter-line spacing affects the reading from the end of one line to the beginning of the next line. Since there are always fewer lines than the number of words, increasing inter-word space costs more overall eye movement in the overall reading experience than inter-line space. Fig. 10 illustrates a quantified example of this argument and explains why increasing inter-word spacing can have a significantly higher negative impact on users' reading performance as compared to inter-line spacing.

8.2 The effect of spacing on navigation performance (or facilitating environmental awareness)

The fundamental advantage of OHMD-based reading lies in the direct augmentation of displayed information over the view of the physical environment [17, 43]. As the OHMD glass is transparent and see-through, participants are able to view the external environment via blank areas on the screen, i.e. areas that are not covered by text. This is a plausible explanation for why increased text spacing facilitated higher levels of environmental awareness in our participants, as indicated by their higher walking speed (PPWS) and lower mental workload.

However, this does not explain why only inter-line spacings improved navigation performance, while inter-word spacings failed to do so. We may consider the fact that each unit of inter-line spacing opens up a larger area of blank space than each unit of inter-word spacing (Fig. 10 (b) and Fig. 10 (c)) demonstrates this very point). Moreover, while line spacings open up an entire "row" of blank space, word spacings are more scattered and irregular across the screen, thus attenuating any positive effect word spacings may bring to navigation performance. These findings are supported by Pearson's correlation test, which showed that walking speed negatively correlates to mental workload, also consistent with previous studies [12, 49, 87].

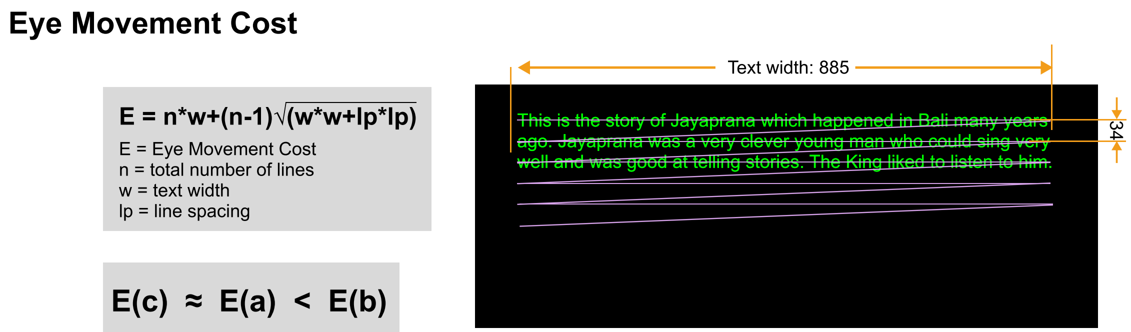
8.3 The effect of spacing on facilitating task switching between reading and navigation

Spacings improved the task switching performance between reading and navigation, though inter-line spacing was much more effective than inter-word spacing in this regard. We flesh out possible reasons for this based on reading and visual search processes.

Firstly, task switching in our use case involves constant shifts in focus from text on-screen to the background environment, and vice-versa. When returning to text on-screen, participants undergo a visual search process in order to accurately and efficiently locate the last word they read (i.e. the visual target). All other words in the text function as non-target distractors. Previous research on crowding had suggested that visual targets become less visible when adjacent targets (i.e. distractors) are in close proximity[25, 27], which ultimately slows reading [33, 59, 73]. While the default spacing is not considered to be crowded during focused reading, it becomes "crowded" when both viewing clarity and cognitive resources are reduced in mobile multitasking scenarios, thus it results in suboptimal performance.

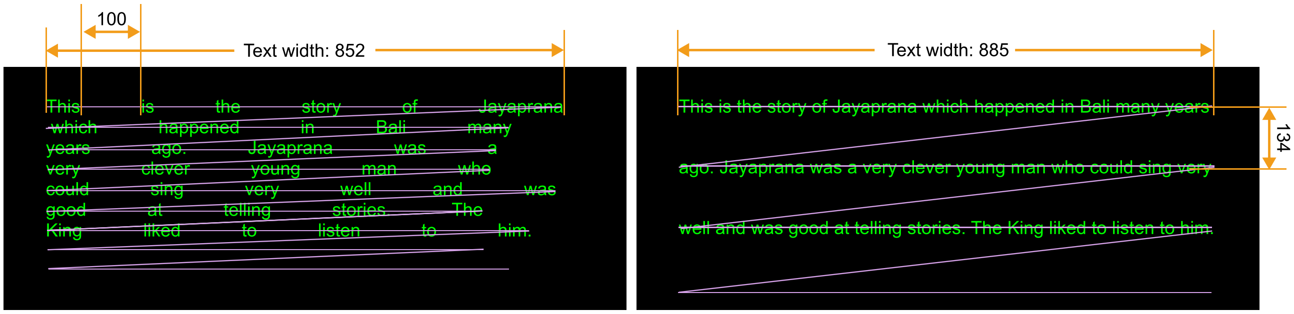
In the inter-word spacing case, while the number of distractors has been largely reduced, the organization of the information is less regular. This also increases the visual search difficulty.

As shown in Fig.10, inter-line and inter-word spacings greatly reduce the number of distractors, though the former appears more visually organised (and less cluttered) than the latter. It is possible then, that inter-line spacing leads to faster and more accurate visual searching. In Study 2, the target-to-distractor visual search time and error rate for default spacing were 1.58s and 4.5% respectively. With inter-line spacing (100 pixels), visual search time was faster (0.74s), and the error rate was lower (1.4%). Previous research [84] demonstrated that by decreasing the target-to-distractor ratio, the



(a) Default Spacing

$E(a) = 3 * 885 + 2\sqrt{885 * 885 + 34 * 34} = \mathbf{4426.3}$



(b) Inter-word Spacing by 100 pixels

$E(b) = 7 * 852 + 6\sqrt{852 * 852 + 34 * 34} = 11080$

(c) Inter-line Spacing by 100 pixels

$E(c) = 3 * 885 + 2\sqrt{885 * 885 + 134 * 134} = \mathbf{4445.2}$

Figure 10: Eye Movement Cost Examples and Zig-Zag Pattern. The reader's eye traces a Zig-Zag route when they read. As they scan from the top left to right, they form an imaginary horizontal line. As they continue from the top right to the next line, they create an imaginary diagonal line. This repeats until they arrive at the last word on the screen. (a) A text message with 38 words arranged in 3 lines within 1024x768 screen size. We assume the text width is 885 pixels and the default spacing is 4 pixels between lines with the font height to be 30 pixels. Increasing its (b) inter-word spacing and (c) inter-line spacing by 100 pixels increases the eye-movement cost by 150% and 0.4% respectively. This shows why the cost of increasing inter-word spacing is much more than that of increasing inter-line spacing for reading performance.

visual search performance could be improved by 50%, which is close to what was observed in our experiment (53%-68%).

Our reasoning is also aligned with previous studies on multitasking which demonstrated that task-switching performance improves when the mental workload is lowered [9, 12, 29, 30, 49, 50, 61, 90, 93].

8.4 Applying our results to other OHMDs

The results obtained in this study apply to the NReal glasses in a specific font. Specifically, our study found that increasing the inter-line spacing to about 3 times the font height works well for the NReal light smart glasses, using a 30 pt font size. This can be used as a rough guideline, though caution should be exercised when applying the results to other contexts.

While we believe in the validity of the high-level conclusion: increasing inter-line spacing can significantly enhance the mobile reading experience on OHMDs, the exact amount of space to be allocated between the lines to achieve the optimal result can depend on many different factors, including the task, environment, device, and properties of the user. While our initial investigation has shown the advantages of inter-line spacing, it does not tell us how to determine the optimal spacing strategy across scenarios and contexts. To do so, we can either conduct many additional empirical studies involving all possible factors so that a more generalizable prediction model can be derived. Alternatively, we can train human agents using human modelling theories [63, 100] to test the results using computational simulations. The human's visual and oculomotor behaviour could be characterized and encoded as features for the smart agents in the reinforcement learning environment. We could place the agents in a finely-modulated environment, which simulates the visual inputs of a smart glass wearer. The agents could be regulated to have the same perception ability as real humans. Then we can run simulations to testify to the proposed method's validity with extended scenarios. The latter approach has the potential to more quickly and efficiently derive a generalizable prediction model which can be a promising avenue for future work.

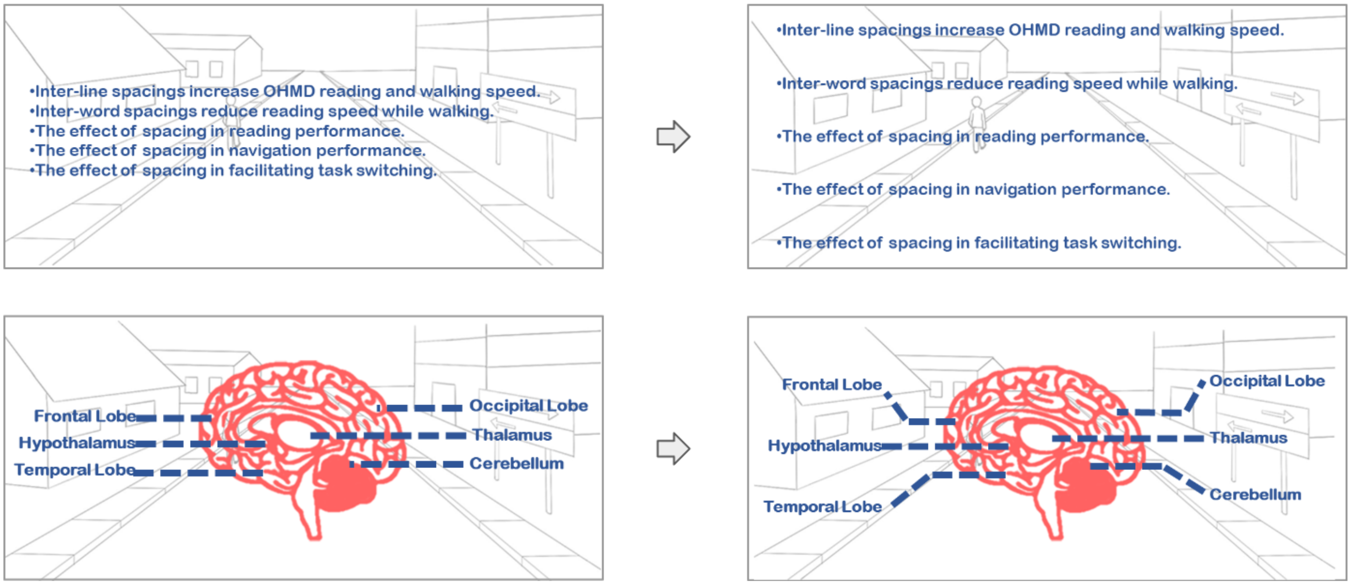


Figure 11: Examples for Design Implication. The inter-line spacing between the labels needs to be adjusted for a better viewing experience on OHMDs.

Nevertheless, we believe our general finding remains sound, that inter-line spacing increased to a certain extent will significantly help mobile OHMD reading in more complex navigational scenarios, though exact spacing distances needed for each OHMD model and font size should be further tested and determined.

9 DESIGN IMPLICATIONS

We explore the implications of our research and recommend methods for displaying text on OHMDs according to various design considerations.

Short text. : Our results do not apply to short text as our research assumes a substantial vertical dimension to the text body. Thus, text that can be displayed in 1 single line should use default spacings specified by previous research.

Text that involves multiple lines: Previous research has suggested breaking paragraphs into multiple lines and displaying them one by one. While this is effective, it affects the users' ability to compare and review content on the screen. For example, in the case of learning, Ram et al. [77] suggested using a data persistence strategy so that information is retained on the screen for easy reviewing. In such cases, how information is properly laid out is an important design issue. One can imagine displaying a bullet list on OHMDs and, based on this research, leaving sufficient inter-line spacing to achieve a better on-the-go reading experience.

This result can also be applied to diagrams. In Fig.11, the inter-line spacing between the labels needs to be adjusted for a better viewing experience on OHMDs.

10 LIMITATION & FUTURE WORK

Our research focuses on reading materials in English; however, text spacing strategies may apply differently to languages of different written scripts. Future work may explore how text spacing strategies can be generalised or translated to other languages for OHMD mobile reading scenarios.

In addition, while our mobile tasks were designed to reflect real-life navigation scenarios, our studies were conducted in the indoor environment instead of the outdoors. This design choice was intended to prevent visibility issues due to natural lighting as it potentially confounds OHMD reading performance [40]. Therefore, extending the proposed text spacing approach to outdoor scenarios will increase its ecological validity.

Furthermore, accurate eye-tracking on OHMD presents a challenge for researchers and developers [52]. Mobile eye-tracking should be able to account for environmental shaking and luminous variations, as well as determine the location on the OHMD where the user is looking [19, 69]. One potential solution is using a pupil core eye-tracker [6] as an add-on unit to OHMDs. While this approach has been effective in stationary environments, its accuracy decreases significantly during walking. Tobii's mobile eye-tracker [48] is another option, but it does not support the integration of OHMDs. Other companies, such as EyeTech Digital Systems [3], specialize in eye-tracking technology and offer a range of products and solutions, including mobile eye-trackers. However, it is worth noting that these solutions currently do not support the integration of OHMDs sufficiently well. In the context of our study on mobile reading with OHMDs, measuring the performance of task switching is important. However, the lack of eye-tracking data can be mitigated by having the user read the text aloud. Previous research has shown that reading aloud results in slower reading speeds than silent reading [26, 28], but this reduction is consistent across all conditions and does not significantly impact the final result.

Additionally, in the context of mobile reading on OHMDs, focal accommodation can be an important factor to consider. When using an OHMD, the display is positioned close to the eye, making it challenging for the eye to shift focus between the display and the surrounding environment. This can cause fatigue and discomfort for the user, as well as hinder their ability to read effectively [14, 39, 47]. Since the text we use is presented in 2D, the accommodation-vergence reflex [14], which is primarily associated with viewing 3D objects, less applies in our case. Yet our study design took these factors into account. We instructed participants to ensure that they could see the text clearly during the training and also trained them to adjust the focus of the OHMD. Additionally, we controlled other factors that may affect focal accommodation, such as the font size and contrast of the text, and the lighting in the environment [10, 11]. Considering these factors, we ensure participants can read comfortably and effectively after training.

Lastly, although our investigations focus on the spacing between words and lines in text. In reality, spacing is applied to not only text but also graphical objects. Thus, more research is needed to explore how text spacing can be optimised for a more effective OHMD mobile reading. These findings could inform the design of future intelligent adaptive text spacing systems for OHMD mobile reading scenarios.

11 CONCLUSION

In this work, we systematically investigated the possibilities and benefits of text spacing as applied to the OHMD mobile reading context. It is easy to assume that text should be shown on OHMD as text displayed on mobile or desktop screens, but our research shows that this is not the case, especially during more complex navigation scenarios. We have developed a text spacing strategy that was proven to work for OHMD mobile reading. Our paper takes a significant step forward in understanding how to design text presentations for OHMD mobile reading and we highlight that text spacings are, in fact, important. We further break down the idea of "text spacings" into important variables, such as dimensionality (inter-word or inter-line) and distance (50 pixels, 100 pixels, etc). These are key factors that influence the outcome of mobile reading. Finally, insights gained from this study can be extended to other explorations in the information acquisition of OHMD in multitasking scenarios.

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