NotiFade: Minimizing OHMD Notification Distractions Using Fading

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ABSTRACT

While animations can minimize attention costs for desktop notifications, their application for Optical see-through Head-Mounted Display (OHMD) notifications is underexplored. To investigate the effectiveness of animation on OHMD notifications in minimizing attention costs, we conducted a study comparing fade-in, blast, and scrolling notification animations. Results showed that fade-in animation minimizes notification interference with the primary task, unlike blast and scrolling animations. Its effectiveness depends on multiple factors, including *fade-duration* and location of the primary task. Finally, we discuss how fade-in animation can improve OHMD notifications and its associated trade-offs.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in ubiquitous and mobile computing**; **Empirical studies in HCI**; **Ubiquitous and mobile devices**.

KEYWORDS

notification, smart glasses, OHMD, OST HMD, fading, interruption, distraction, animation, fade, scroll

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1 INTRODUCTION AND RELATED WORK

Despite the great convenience offered by ubiquitous information access [46], too much information can distract and overwhelm users [2, 25, 36]. With the increasing use of notifications on mobile platforms [12, 32, 51], minimizing the attention costs of these notifications becomes a necessity [3, 40–42].

For Optical see-through Head-Mounted Displays (a.k.a., Augmented Reality smart glasses, OST-HMDs, OHMDs) [26], an emergent mobile platform, notifications often attract users' attention and can interrupt and distract their ongoing tasks [27, 28, 33, 37, 47, 50]. To minimize such attention costs of notifications [35], multiple strategies including, *mediating* strategies (i.e., defer notifications until the user is more receptive to them), *indicating* strategies (i.e., indicate the availability of the receiving party to the sending party), and *mitigating* strategies (i.e., change the device or presentation (modality) of the notifications to make them less distracting), have been proposed [3]. Among them, *mitigating* strategies allow notification in a timely manner which can be particularly useful if prompt attention is required.

One such strategy is using animations to control the information presentation timing. Timing affects the interruption of notifications [1, 13, 44, 56]. For example, in the desktop context, fade animations could reduce the interruption from notifications [35, 38, 39, 57]. A recent study [18] showed that OHMD notifications with fade animation were the least distracting compared to moving and flashing animations according to descriptive and qualitative results. However, their study used a combination of different animations, colors, and sizes, which might have collectively influenced the reduced distraction observed. Moreover, most previous studies explored fade animation in coarse level [18, 34, 35, 38, 39, 55], and they lacked on understanding the factors (e.g., fade duration) affecting the effective use of fade animations in notifications.

Hence, this paper focused on fade-in OHMD animations, and the main research question was *"What factors affect the effective use of fade-in animations in reducing interruption from OHMD notifications?"*. Given the prevalence of scrolling animations in notifications [4, 35], we conducted a controlled study comparing fade-in notifications with the *blast* (i.e., no fade-in) and *scrolling* notifications in two stationary settings; the first, when the user is engaged in a *primary task on OHMD* and attends to OHMD notifications, and the second, when the user is engaged in a *primary task that is NOT on OHMD* and attends to OHMD notifications. Our results show that OHMD notifications with fade-in animations significantly reduce the interference to the ongoing tasks compared to *blast* and *scrolling*. Furthermore, a fade-in duration of two to four seconds was deduced to be the optimal duration. As such, the contributions of this paper are twofold: 1) identifying the factors affecting the effectiveness of fade-in animations for OHMD notifications; 2) empirically evaluating the fade-in animation with commonly used animations in task performance, noticeability, and perceived interruption.

2 STUDY

2.1 Study Goals

This study was conducted to investigate the interruptions caused by notifications with *fade-in*, *blast*, and *scrolling* animations; hence, two sub-questions were assessed in this study.

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Q1. How does the fade-in animation compare to blast and scrolling animations in terms of task performance and perceived interruption when multitasking?

Although it is hypothesized that fade-in animation can reduce interruption to primary tasks, it remains unclear what is the optimal duration of fade-in notifications. To identify suitable *fade-durations* (= time taken by notification to become fully visible), a pilot study with four participants was conducted where participants attended notifications with different *fade-durations* (0s-8s, with 1s gap) while reading passages on an OHMD, similar to the formal study described below (sec 2.5). The study revealed three findings: first, participants were unable to distinguish between shorter *fade-durations* that are less than 1-second; second, participants could clearly distinguish between *fade-durations* that are 2-seconds apart (e.g., 0s, 2s, 4s); and third, *fade-durations* that are more than four seconds were too distracting as participants had to wait for "too long" before the notifications became readable. Thus, blast (*Blast*, *fade-duration=0s*), fast fade-in (*Fast-Fade*, *fade-duration=2s*), slow fade-in (*Slow-Fade*, *fade-duration=4s*), and vertical discrete scrolling (*Scroll*) were selected as the OHMD notification animation for the controlled study to compare fade-in with existing animations and get an initial understanding of the potential range of optimal *fade-duration*.

Q2. Does the effect of fade-in animations depend on the primary task's location?

In a realistic setting, OHMD users will receive notifications during different multitasking situations, particularly when primary tasks are in the virtual world (i.e., on OHMD) or physical world (i.e., not on OHMD) (e.g., [53, 54] in AR context). When tasks are in different locations (i.e., physical or virtual), attending to virtual content (e.g., OHMD notifications) can cause attention/focus switching [19, 53]. This focus switching can affect the interruption of notifications and which may, in turn, affect the perception of fade-in animation.

Thus, to simulate primary tasks in different locations, text reading tasks on OHMD and desktop were used due to their common usage.

2.2 Participants

Sixteen volunteers (7 females, 9 males, age $M = 24.3$, $SD = 3.2$) from the university community with normal or corrected vision participated in the study. Four participants had prior experience using OHMDs for less than 2 hours, and all participants had professional working fluency in English. Participants received (self-reported) on average 108 ($MIN = 40$, $MAX = 400$) mobile notifications per day. Each participant was compensated ≈ USD 7.25/h for their time, and none of them participated in the pilot studies.

2.3 Apparatus

Since the viewability of OHMD contents depends on the background and lighting conditions [15, 17], the study was held in a quiet room with controlled indoor lighting to ensure a consistent user experience. The Epson Moverio BT-300 [16], a binocular OHMD (1280x720 px, 23° FoV), was used. A custom Android application was installed on the OHMD to display text and notifications (Figure 1). As OHMDs have around a 1m focal length [31], a black screen was placed 1m in front of participants during text reading on OHMD to provide a uniform color projecting surface. As for the desktop, a 27" LCD monitor (refresh rate = 60 Hz, resolution = 1920 x 1080 px) displayed text passages at eye level and was placed 70 cm from the participant due to common practice [5] and to simulate focus switching between physical and virtual world [19, 54]. A wireless keyboard was used to control the passages, and a Python program handled displaying passages, pushing notifications, and logging user inputs and timings. For both desktop and OHMD layouts, all texts were left aligned with text wrapping. Implementation details can be found at Appendix B.

2.3.1 OHMD Layout. As recommended by Debernardis et al. [15], all texts on OHMD were displayed in green sans serif font (Roboto). Based on an informal pilot study (N=4), 36 sp text font was clearly visible and was thus used for all texts.

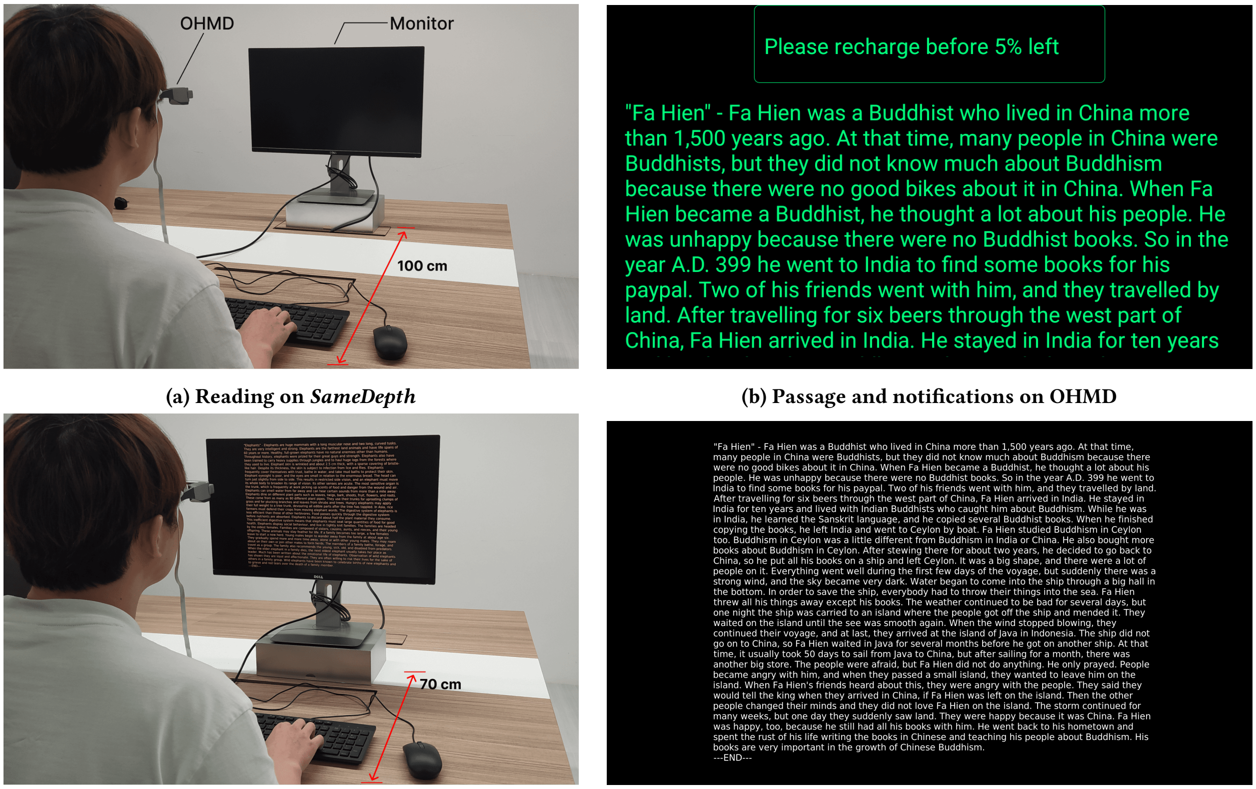
2.3.2 Desktop Layout. To display passages on desktop, 'dark-mode', white text on a black background with Arial font was used following previous studies [7, 10, 29]. Again, the informal pilot study showed a font height of 6 mm with line spacing of 3 mm was easier to read on a desktop monitor at a 70 cm distance which was then used for the formal study. The larger screen size allowed all text content to fit on display.

2.3.3 OHMD Notification Layout. The top-center position was used for displaying the notifications in dual-task situations, as recommended by Chua et al. [11, 47]. Only the title of the notifications [4] was used, and the layout (Figure 1b) was simplified to isolate the animation effect. Notifications were covered with a green-color bounding box (580px X 210px) and were shown above the passages to distinguish them from reading passages [4]. Ten lines of text, each with a maximum of 64 characters (including spaces), fit on the OHMD. Due to the limited screen size, block scrolling of passages (i.e., showing a block of 10 lines each time) [20] was enabled using a wireless keyboard if content exceeded a single page.

2.3.4 OHMD Notification Animation. Each notification appeared for 10 seconds, including *fade-duration* [4, 35, 39]. As the study scope was on the animation of notification appearances, all notifications were configured to disappear instantly; for example, in *Slow-Fade* animation, the notification faded within 4 seconds, stayed on the screen for 6 seconds, and then disappeared instantly. A stepwise linear fading function was used to display fade-in animation (i.e., alpha color value changes from 0x00 to 0xFF during *fade-duration* in 100 ms steps) [35, 39]. The *Blast* animation appeared immediately, stayed on the screen for 10 seconds, and disappeared instantly. The *Scroll* animation scrolled down from the top with full brightness (i.e., alpha = 0xFF) for 333 ms and remained on screen for 9.66 seconds before disappearing instantly [4, 35]. Screen recordings of each animation can be found at https://tinyurl.com/notifade-recordings.

2.4 Tasks

2.4.1 Primary task and materials. Since text reading is common on OHMDs and desktops, a proofreading task was chosen, where certain correct words were substituted with incorrect words. To mimic mistakes from naturalistic reading [30], words with a variant that rhymes but differs grammatically were substituted [7, 14, 23, 29]. For example, in the sentence, "His army was big, and his *soldiers*



(a) Reading on ***SameDepth*** (b) Passage and notifications on OHMD

(c) Reading on ***DiffDepth*** (d) Passage on desktop

Figure 1: Apparatus in *SameDepth* and *DiffDepth* conditions. See example notifications at https://tinyurl.com/notifade-recordings. Note: Black color in OHMD represents the transparent background.

were also good at fighting", the word "soldiers" was replaced with "shoulders" to introduce errors. To ensure consistency, the passages were chosen from well-established reading materials [43, 48] on culture and history topics with a Flesch Reading Ease Score between 70-80 and an average word count of 549.3 (sd = 3.1, average sentence count = 39.6). Moreover, 11 substitution words per passage were uniformly distributed across each passage, so there was at most one substitution per sentence. Finally, two researchers cross-validated the complexity and corrected any issues related to the modified passages. Moreover, line breaks in passages were removed to amplify the interruption effects of notifications.

2.4.2 Secondary task and materials. The secondary task was to attend to the OHMD notifications and recognize the observed notifications during the post-test (sec 2.5.2). Notifications comprised 5-word sentences each with an average character count of 31.8 (sd = 1.6, min = 30, max = 35), which lies within the recommended notification character limits [22] (Figure 1b, e.g., "Please recharge before 5% left"). A total of 140 unique 5-word sentences related to common daily activities [45] were selected to eliminate any subjective biases from real notifications.

Similar to previous studies on notification animation evaluation [35, 38, 39], the focus of this study was the awareness of notifications (i.e., whether they have noticed the notification content); thus, notifications appeared at random intervals between 5 - 10 seconds with increased interference to the primary task.

2.5 Design and Procedure

A repeated-measures within-subject design was used to investigate the effects of notifications for the two task locations (*Location*: *DiffDepth* and *SameDepth*) and four notification animations (*Animation*: *Blast*, *Fast-Fade*, *Slow-Fade*, and *Scroll*). Also, a Latin square blocked by *Location* and then *Animation* counterbalanced the conditions. The passages in the primary task were presented in a fixed order. As the focus was on the comparison between *Animation*, a baseline without notifications was not used.

2.5.1 Procedure. After briefing participants on the study and collecting consent, participants underwent a training session to familiarize themselves with the apparatus, tasks (primary and secondary), and questionnaires under *DiffDepth* and *SameDepth Locations* without notifications and with *Blast* notifications. However, they were not informed about the different types of *Animations*, to minimize any biases due to priming and to understand their initial perception.

Once participants felt comfortable with the apparatus, they underwent eight testing conditions, blocked by two *Locations*. Participants read aloud the substitute words while an experimenter manually recorded them to calculate their reading accuracy. They were also instructed to attend to the notifications at their convenience while reading the passages as accurately and quickly as possible. At the end of each condition, participants completed a questionnaire that recorded their perceived behaviors and notification recognition accuracy. There was a minimum of 2-minute break between each condition to reduce fatigue.

Lastly, participants attended a 10-15 minutes post-interview. If they could not identify differences in the notification animations, the experimenter replayed the notifications. The entire experiment lasted for approximately 100-120 minutes per participant.

2.5.2 Measures.

Task performance: We consider the distraction as the interference from secondary tasks to primary tasks [6, 40]. Task performance based on task duration and accuracy was used to measure task interference objectively. The primary task's objective dependent variables were *Reading Time*, the time taken to finish proofreading the passage in seconds, and *Reading Accuracy*, the percentage of detected substituted/incorrect words. Also, the *Adjusted Reading Accuracy* [7, 29], the ratio of reading accuracy to reading time, was calculated, which accounts for the speed-accuracy trade-off.

The objective dependent variable for the secondary task was *Notification Accuracy*, the percentage of correct identification of appeared notifications [38], which was calculated using 16 Yes-No questions on whether the notifications were seen. Subjective measures of perception of notification animations were collected; they were *Noticeability*, how easy or difficult was it to notice the notification, and *Understandability*, how easy or difficult was it to understand what it stands for, using 7-point Likert scales (1 = Very Difficult, 7 = Very Easy) following Rzayev et al. [49].

Interruption of notifications: Furthermore, to quantify the interruption of notifications subjectively, *perceived task load* was measured using raw NASA-TLX (*RTLX*, 0-100 scale) [24] and *Perceived Interruption*, how much interruption did the notifications cause to the reading task when attempted to carry out both simultaneously, was measured using a 0-100 visual analogue scale. Finally, the preference rankings during multitasking for each *Location* and *Animation*, reasons, the process, and the multitasking experience were collected during the post-interview.

2.6 Results

Each participant completed eight (testing) proofreading tasks and received at least 64 notifications, through which 128 (16 participants × 2 *Location* × 4 *Animation*) data points were collected. See Appendix A.1 for analysis details. As for the interview recordings, they were transcribed and thematically analyzed following Braun and Clarke [9].

2.7 Quantitative data

Figure 2 indicates the participants' mean performance. See Appendix A.2, Figure 5 and Table 1 for details.

2.7.1 Primary task performance.

Overall, we observed significant (p<0.05) differences in *Reading Time*, but no significant differences in *Reading Accuracy* or *Adjusted Reading Accuracy*.

A repeated-measures of ANOVA on *Reading Time* showed significant main effects of *Location* ($F_{1,15} = 4.735$, $p = 0.046$, $\eta_p^2 = 0.240$) and *Animation* ($F_{3,45} = 3.260$, $p = 0.030$, $\eta_p^2 = 0.179$) but no interaction effect. Post-hoc analysis (Figure 2a) revealed reading on *SameDepth* ($M = 187.24$, $SD = 52.46$) took significantly ($p_{bonf} = 0.046$, $d = 0.544$) lower time than *DiffDepth* ($M = 196.32$, $SD = 61.32$), and *Slow-Fade* took significantly ($p_{bonf} = 0.050$, $d = 0.640$) lower than *Scroll*. The sorted order of *Reading Time* of each *Animation* from lower to higher was; *Slow-Fade* ($M = 187.54$, $SD = 56.92$) < *Blast* ($M = 188.23$, $SD = 56.78$) < *Fast-Fade* ($M = 196.62$, $SD = 56.62$) < *Scroll* ($M = 196.73$, $SD = 59.86$). Moreover, the same effects hold for individual analysis of *SameDepth* condition.

Although there is no significant interaction effect for *Adjusted Reading Accuracy*, Figure 2b shows a potential interaction effect between *Blast* (*fade-duration=0s*) and *Fast-Fade* (*fade-duration=2s*), where the *Adjusted Reading Accuracy* drops for *DiffDepth* after *fade-duration=2s*; yet it's not the case for *SameDepth*.

2.7.2 Secondary task performance.

Overall, there were no significant main effects or interaction effects on *Notification Accuracy*, *Noticeability*, or *Understandability*. However, as expected, according to Figure 2c, there is a decline in *Noticeability* when *fade-duration* increased from 0 to 4 seconds for both *Locations*.

2.7.3 Interruption of notifications.

Overall, there was no significant main effect of *Animation* or interaction effects on *RTLX* or *Perceived Interruption* (Appendix A.2). But a repeated-measures ANOVA after ART [58] for *Perceived Interruption* showed a significant main effect of *Location* ($F_{1,105} = 13.320$, $p < 0.001$, $\eta_p^2 = 0.159$). A post-hoc analysis revealed (Figure 2d), *Perceived Interruption* for *DiffDepth* ($M = 63.03$, $SD = 23.35$) was significantly higher ($p_{bonf} < 0.001$) than that of *SameDepth* ($M = 55.00$, $SD = 24.56$).

2.8 Qualitative feedback and Preference

2.8.1 Differences between SameDepth vs. DiffDepth conditions.

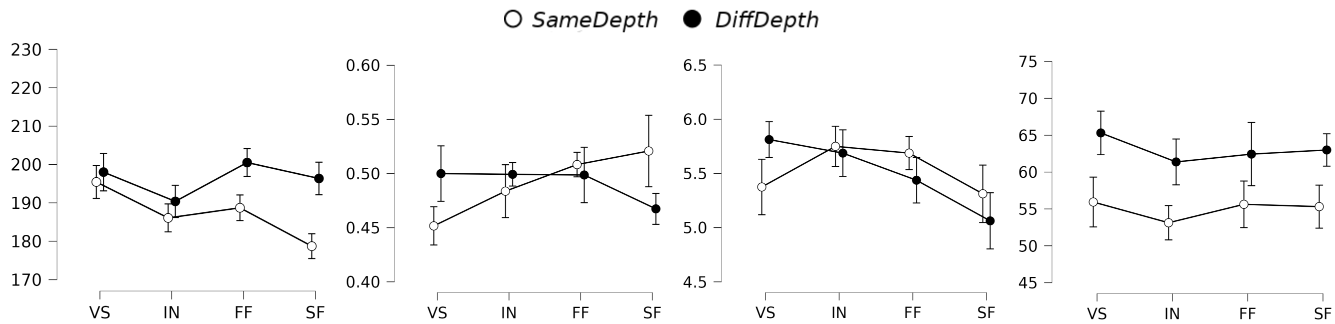
During post-interviews, the majority of participants (87.5%) revealed that proofreading on the *DiffDepth* was more challenging and time-consuming for three reasons: visual switching, task complexity, and occlusion. First, because notifications on the OHMD and proofreading passages on the desktop were of different visual depths, participants required more time to switch focus between tasks in *DiffDepth* than *SameDepth*. Second, given the desktop's increased real estate screen, the entire passage was always revealed. Thus, users switching back to proofreading on *DiffDepth* after attending to notifications took extra time to identify the location where they last stopped. Third, since notifications on OHMD remained in the users' line of sight regardless of head movements, two participants found that notifications sometimes blocked parts of the passage shown on *DiffDepth*. Users had to move or rotate their heads to read in such cases.

The remaining participants (12.5%), who found proofreading on *SameDepth* more difficult, reasoned that they could not estimate the remaining passage length and pondered when to stop.

2.8.2 Preference.

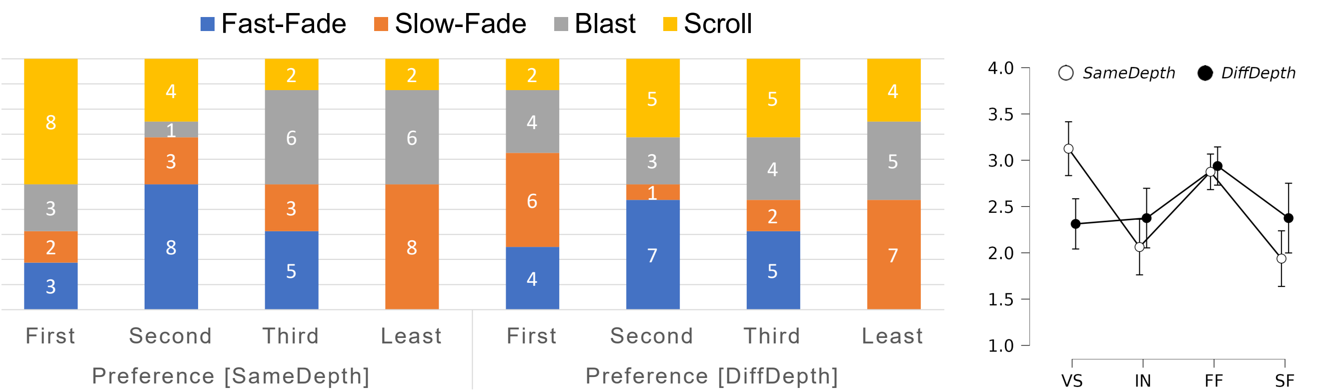
During the session, eleven participants (68.8%) could discern between *Animations* correctly; however, only two participants (12.5%) recognized differences between *Fast-Fade* and *Slow-Fade*.

As seen in Figure 3a, the majority chose the *Scroll Animation* for *SameDepth* and *Slow-Fade* for *DiffDepth* as their first preference.



(a) ***Reading Time*** **(seconds)** (b) ***Adjusted Reading Accuracy*** (c) ***Noticeability*** **(1-7)** (d) ***Perceived Interruption*** **(0-100)**

Figure 2: Measures on the primary task and secondary task performance with 16 participants. Here, VS = ***Scroll*****, IN =** ***Blast*****, FF =** ***Fast-Fade*****, and SF =** ***Slow-Fade*****. Error bars represent standard error. See Appendix A.2, Table 1, and Figure 5 for details.**



(a) **(b)**

Figure 3: (a) ***Animation*** **preference for OHMD notifications during** ***SameDepth*** **and** ***DiffDepth*** **conditions. (b) Weighted preference for each** ***Animation*****. The weighted preference was calculated by averaging the weighted rankings, where the first-preference weight was 4 and the fourth-preference weight was 1. Here, VS =** ***Scroll*****, IN =** ***Blast*****, FF =** ***Fast-Fade*****, and SF =** ***Slow-Fade*****. Error bars represent standard error.**

However, by examining the participants' preference choices together (for *SameDepth* AND *DiffDepth*) and weighted preference (Figure 3b), the overall tendency was for *Fast-Fade* as it provided extra time for users to prepare for the secondary task which in turn allowed to resume faster: "If it's a slow one [fade-in], I will finish reading the sentence before jumping to notifications. If it's a sudden one [*Blast*, *Scroll*], I will jump to the notification without finishing the sentence... finish the sentence fully, to avoid re-reading the sentence and find where I left off quickly."

In general, participants who preferred *Scroll* said that it was more noticeable and familiar. Those who liked *Blast* preferred the direct display of notifications; they could more rapidly attend to notifications and resume proofreading. By contrast, participants who disliked *Blast* or *Scroll* mentioned that these styles were too abrupt, distracting them from proofreading, "I was forced to attend notifications when popping down from [the] top". Participants who preferred fade-in felt it gave them time to prepare for incoming notifications, cueing them in advance to stop proofreading. Opponents of the fade-in (mainly *Slow-Fade*) did not like to wait for notifications as it took their attention away from proofreading.

3 DISCUSSION

This study provides an initial understating of using fade-in animation in OHMD notifications and associated trade-offs.

Q1. How does the fade-in animation compare to blast and scrolling animations?

Our results suggest that fade-in animation improves the performance of the primary task as *Reading Time* was significantly lower than *Scroll* animation. Although there seems to be a peak at *Fast-Fade* in *Reading Accuracy* and interaction at *Fast-Fade* for *Adjusted Reading Accuracy*, there were no statistically significant differences in *Reading Accuracy* or *Adjusted Reading Accuracy*. Thus, fade-in animation reduces the interference to the primary task for task duration but not for accuracy.

Moreover, while qualitative feedback (sec 2.8.2) suggests that fade-in helps to minimize interruptions, there were no significant differences between *Animations* in *Perceived Interruption* or *RTLX*; thus, lacks statistical evidence to support fade-in animation is less distracting and cognitively less demanding than *Blast* or *Scroll*. Lastly, given that there were no significant differences between *Animations* in *Adjusted Reading Accuracy* and *Notification Accuracy*, there is insufficient statistical evidence to support that there is an optimal fade-in duration. However, according to qualitative feedback, *fade-duration=2s* (*Fast-Fade*) helped participants to prepare for incoming notifications (compared to *fade-duration=0s*, *Blast*) and reduced the waiting for notifications (compared to *fade-duration=4s*, *Slow-Fade*), suggesting a potential optimal *fade-duration* around 2 seconds.

Q2. Does the effect of fade-in animations depend on the primary task's location?

According to the participants' feedback and the significant main effects of *Location* and *Animation* for *Reading Time*, there is evidence to support that interruption of OHMD notification will be lower for task duration but not accuracy when the notifications are presented in the same depth as the primary task. However, additional studies are needed to isolate the effect of location, as the complexity of the primary task may confound current results. For example, in the *SameDepth* condition users had to scroll through the passage, while in the *DiffDepth* users did not, which affected the switching between notifications and proofreading (sec 2.8.1). Finally, given that there were no significant main or interaction effects in *Adjusted Reading Accuracy*, there lacks statistical evidence to support or refute that the optimal fade-in duration depends on primary task location.

3.1 Fading notifications on OHMD

The fade-in animation performs comparably to *Blast* and *Scroll* in *Noticeability*, *Understandability*, and *Notification Accuracy*. Fade-in animation can reduce interference to primary tasks, allowing users to prepare for incoming notifications. This can be explained using the Unified Multitasking Theory [52] (Figure 4), in which fade-in provided an interruption lag (with the *fade-duration*) which allowed participants to remember the state of the primary task before attending to their notifications. Thus, it allowed participants to resume their primary task faster (sec 2.8.2, sec 2.7.1) by reducing the resumption lag related to remembering where participants paused the primary task. However, the benefits of fade-in animation depend on its *fade-duration*, location, and complexity of the primary task. If the *fade-duration* is too short, fade-in animation can attract attention to the notification too quickly, interrupting the primary task, and vice versa. Moreover, the fade-in animation helps users to prepare for focus switching between the OHMD notifications and their non-OHMD primary task, supporting different task locations. Similarly, when the primary task complexity increases, the interruption of notifications increases [6, 8]; thus, fade-in animation that provides sufficient interruption lag to remember the primary task state minimizes interruption.

As expected, when the *fade-duration* increases, notifications become less noticeable. As the noticeability of OHMD content is affected by the lighting of the external environment [17], the optimal *fade-duration* also depends on external lighting. Thus, the *fade-duration* and OHMD display brightness should be dynamically adjusted according to users' lighting conditions.

Although fade-in animation can reduce the interference to primary tasks, its practical usage should depend on the utility of notifications [21, 40]. As expressed by two participants, how notifications appear can signal their level of importance and urgency; slow fade-in notifications can and are suited to signal lower levels of urgency [18]. Although perceived urgency and importance are influenced by *fade-duration*, the maximum delay of notifications was 4-seconds. This may mean that *fade-duration* is not the biggest fact in attendance to notifications.

Given that the features used in our OHMD prototype are a subset of those from advanced OHMDs (e.g., Microsoft HoloLens) supporting higher field-of-view and various anchoring techniques (e.g., world anchoring), we believe that by using similar configurations, we can replicate our results in advanced OHMDs [28].

Finally, this study used text reading, a structured visual searching task, which lacks support for resumability [53]. Thus, the results can be applied to similar tasks such as browsing, gaming, and driving. However, if the primary task supports resumability (e.g., grid searching), the fade-in may not have an advantage over other animations regarding task performance.

3.2 Limitations and Future Work

In this study, 5-word single-color text notifications were used to isolate the effect of animation. However, real notifications have additional elements such as colors, icons, and multiple text contents [4] that can impact the effects of fade-in [6, 34] and need further exploration. Although subjective ratings with a 2-second interval were used to get an initial understanding of *fade-duration*, fine-grain details can be obtained with eye-tracking and more granular intervals (e.g., 1, 0.5 seconds). Moreover, this study only examined notifications for short durations for tech-savvy participants in lab settings on a specific OHMD; results do not capture long-term effects and may not apply to other populations, such as people with visual impairments. Hence, these results must be validated in realistic settings where external lighting can dynamically change with different OHMDs. Since the notification duration was fixed (i.e., 10s), the *fade-duration* influenced the time available for reading notifications, potentially affecting the interference with the primary task [44]. However, participant feedback showed that they did not read notifications even when notifications appeared for longer periods (e.g., *Blast*), suggesting that the results were not influenced by the available time.

4 CONCLUSION

Using a controlled study, we identified that fade-in animations could minimize the interference of OHMD notifications to primary tasks, compared to prevalent *Blast* and *Scroll* animations. Moreover, we found that the effectiveness of fade-in animations depends on *fade-duration* and primary task location (i.e., depth). Results also hint the optimal *fade-duration* depends on primary task and is around 2 seconds for stationary reading tasks. This also indicates the need for designing an adaptive notification system for OHMD, where animation and its properties (e.g., fade-duration for fading, scroll-duration for scrolling) are dynamically changed based on user

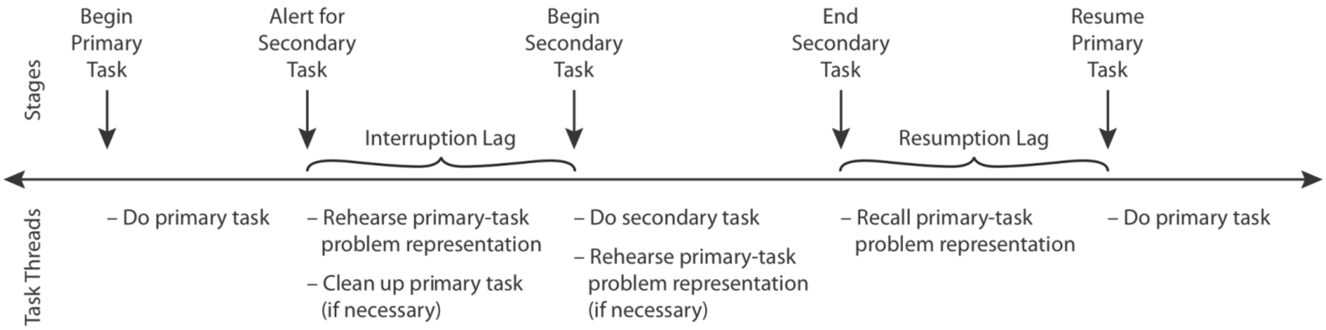


Figure 4: The stages of interruption and resumption and the task threads associated with each stage (Source: [52, Figure 3]). The *interruption lag* can help users remember the primary task state before attending to a secondary task, allowing users to resume primary tasks faster and minimize the distraction from the secondary task.

context (e.g., environmental brightness), primary task (e.g., mobile reading), and message content (e.g., importance or urgency of notification) to provide notifications that align with user expectations (e.g., minimize distractions).

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A CONTROLLED STUDY

A.1 Analysis

Factorial repeated measures ANOVAs or factorial repeated measures ANOVAs after Aligned Rank Transform (ART) [58], in cases of violation in ANOVA assumptions, were applied to analyze the data. The Shapiro-Wilk and Mauchly tests were used to test normality and sphericity. Lastly, paired-sample t-tests or Wilcoxon signed-rank tests were used as posthoc tests, and Bonferroni correction was applied for multiple comparisons. When non-parametric distributions could take a large range of values (e.g., NASA-TLX, which ranged from 0-100) and followed parametric assumptions, parametric tests were used.

A.2 Measures in the controlled study

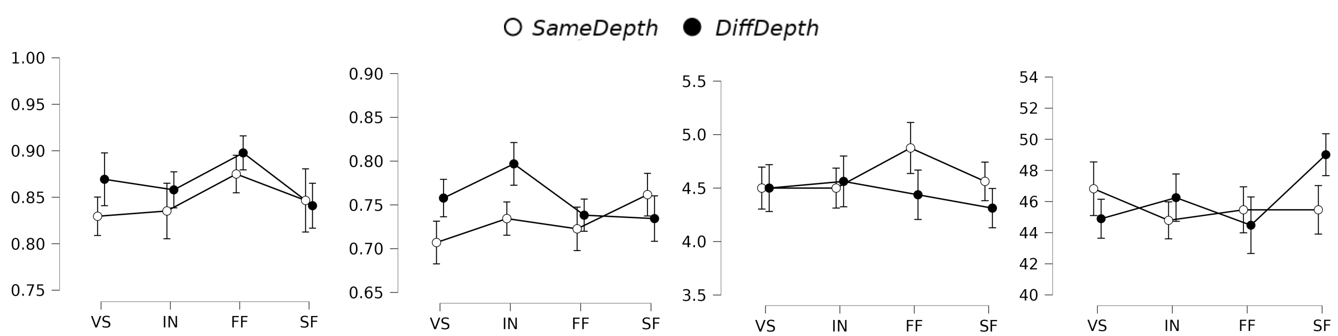
Table 1 and Figure 5 indicate participants' mean performance ('mean (sd)') related to primary and secondary task performance.

B PROGRAMMING CODES

Codes for this study can be found at https://github.com/NUS-HCILab/FadingNotifications. If you encounter any issues accessing them, please get in touch with the authors.

Table 1: Average performance (*'mean (sd)'*) in the formal study with 16 participants. The first column represents the *Location-Animation* combination using the first letters of each (S = *SameDepth*, D = *DiffDepth*; VS = *Scroll*, IN = *Blast*, FF = *Fast-Fade*, SF = *Slow-Fade*).

	Primary task performance			Secondary task performance			Interruption of Notifications	
	Reading Time	*Reading Accuracy*	*Adjusted Reading Accuracy*	*Notification Accuracy*	*Noticeability*	*Understandability*	*Perceived Interruption*	*RTLX*
S-VS	195.4 (59.4)	0.830 (0.109)	0.452 (0.123)	0.707 (0.071)	5.38 (1.15)	4.50 (1.37)	55.9 (25.5)	46.8 (19.1)
S-IN	186.1 (55.9)	0.835 (0.176)	0.484 (0.147)	0.734 (0.098)	5.75 (1.13)	4.50 (1.83)	53.1 (20.8)	44.8 (19.0)
S-FF	189.0 (54.9)	0.875 (0.104)	0.508 (0.177)	0.723 (0.129)	5.69 (1.14)	4.88 (1.63)	55.6 (25.5)	45.5 (20.2)
S-SF	178.7 (50.6)	0.847 (0.127)	0.521 (0.221)	0.762 (0.132)	5.31 (1.62)	4.56 (1.68)	55.3 (27.2)	45.5 (19.7)
D-VS	198.0 (68.4)	0.869 (0.105)	0.500 (0.211)	0.758 (0.140)	5.81 (0.83)	4.50 (1.75)	65.3 (20.4)	44.9 (16.1)
D-IN	190.4 (59.4)	0.858 (0.115)	0.499 (0.178)	0.797 (0.120)	5.69 (0.87)	4.56 (1.83)	61.4 (25.0)	46.3 (17.9)
D-FF	200.5 (59.6)	0.898 (0.093)	0.499 (0.206)	0.738 (0.110)	5.44 (1.15)	4.44 (1.67)	62.4 (27.1)	44.5 (19.3)
D-SF	196.4 (63.0)	0.841 (0.139)	0.467 (0.146)	0.734 (0.124)	5.06 (1.06)	4.31 (1.70)	63.0 (22.6)	49.0 (15.6)



(a) *Reading Accuracy* (0-1) (b) *Notification Accuracy* (0-1) (c) *Understandability* (d) *RTLX* (0-100)

Figure 5: Remaining measures on primary and secondary task performance. Here, VS = *Scroll*, IN = *Blast*, FF = *Fast-Fade*, and SF = *Slow-Fade*. Error bars represent standard error. See Table 1 for details.