Attentive Notifications: Minimizing Distractions of Mobile Notifications through Gaze Tracking

Sebastian Hueber
RWTH Aachen University
Aachen, Germany
hueber@cs.rwth-aachen.de

Eunae Jang
RWTH Aachen University
Aachen, Germany
eunae.jang@rwth-aachen.de

Jan Borchers
RWTH Aachen University
Aachen, Germany
borchers@cs.rwth-aachen.de

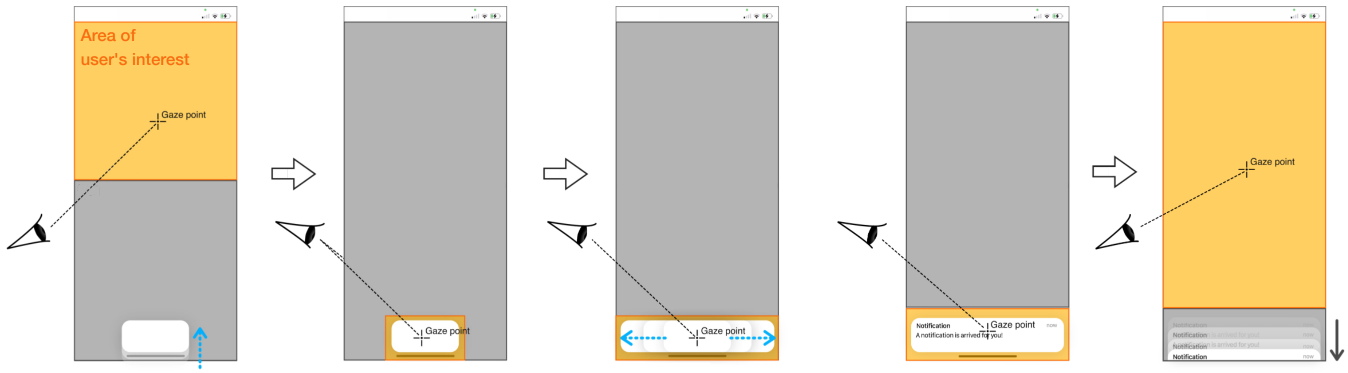

Figure 1: *Gaze-explicit* notifications reduce distraction and occlusion of the primary on-screen content. When a notification is about to be presented, the system checks the user's current gazing location to determine an area of her interest (yellow) in which no notifications are supposed to appear. A notification appears on the most distant screen edge (a). By shifting her gaze towards the notification (b), a user can enlarge it (c), revealing more content or additional options (d). Notifications are automatically dismissed when the user moves her gaze away from the notification back to the original position (e). For comparison, our *gaze-implicit* notifications appear in full width and omit steps (b) and (c). Instead, users press them to reveal more options.

ABSTRACT

Notifications on smartphones typically appear at the top of the screen, resulting in interruptions caused by content overlaps of toolbars and potential accidental activation of a notification. As returning to a workflow which got interrupted proves difficult for the general user, interface designers should thoughtfully design the visual disruption caused by notifications. We explore possible designs of gaze-attentive notifications to overcome this issue. By placing the notification banner as far from the user's current gazing point as possible they result in less visual overlap and our study participants experienced them as less distracting.

CCS CONCEPTS

• **Human-centered computing** → **Interaction techniques**; *Empirical studies in HCI*;

KEYWORDS

interaction techniques, notifications, occlusion, gaze tracking

ACM Reference Format:
Sebastian Hueber, Eunae Jang, and Jan Borchers. 2023. Attentive Notifications: Minimizing Distractions of Mobile Notifications through Gaze Tracking. In *25th International Conference on Mobile Human-Computer Interaction (MobileHCI '23 Companion), September 26–29, 2023, Athens, Greece.* ACM, New York, NY, USA, 7 pages. https://doi.org/10.1145/3565066.3608695

1 INTRODUCTION

Smartphone users receive over 60 mobile notifications every day [24]. Still, the number of notifications people actually react to is way lower, with some surveys reporting reaction rates under five percent. Reasons for low reaction rates are notifications being interrupting and distracting to the user's ongoing task [21, 27]. Designing mobile notifications to incorporate a suitable level of distraction has been an ongoing research challenge, e.g. by delaying the delivery of notifications based on usage patterns [3, 11]. However, this is not suitable for many types of information and people actually value the awareness of information provided by notifications [15].

We explored gaze tracking to enhance the presentation of notifications so information is delivered as timely as possible but still allows for less distraction from a primary task. We explored both the presentation characteristics of notification banners, like contrast levels and size, as well as how explicit gaze interaction

MobileHCI '23 Companion, September 26–29, 2023, Athens, Greece

ACM ISBN 978-1-4503-9924-1/23/09.
https://doi.org/10.1145/3565066.3608695

can enhance notification interaction. We also present qualitative feedback that helps to design further iterations of gaze-attentive notifications. Our research questions were:

RQ1 Can gaze tracking reduce undesired content overlaps when presenting notification banners?
RQ2 Can gaze tracking be used as an effective input modality in the context of notification UIs?

2 RELATED WORK

2.1 Distraction Caused by Notifications

While using a smartphone, notifications deliver additional information unrelated to a primary task. They require the user's secondary attention and distract from the ongoing task through visual overlaps [4], or auditory interference [28]. Despite users perceiving notifications as disruptive, they opt into them as they value the increased information awareness resulting from notifications [7, 15]. Thus, completely disabling notifications results in anxiety and fear of missing out [13].

As humans find it difficult to return to the previous task after being interrupted [9], researchers explored different approaches to minimize users' perceived disruption and improve the use of mobile notifications. One approach is to filter notifications based on their subjective importance, e.g. messages from friends or special events [26]. Another is the optimization of the timing of notifications to lower the disruption they cause – and thus annoyance and frustration [1, 8, 11, 12]. By learning physical or mental mobile usage patterns, a phone can obtain hints about when to deliver notifications [3, 20, 22, 23], reducing the perceived interruption and increasing user satisfaction as well as reaction times. Likewise, batching notification delivery to a few selected points in time can result in a slight productivity gain and less distraction [13].

2.2 Perception of Notifications

The visual appearance of notifications is an important aspect that allows them to fulfill their purpose. To engage a sufficient level of perception, especially when notifications are displayed in the peripheral vision, previous literature suggested visual enhancements of notification placement [25], extents [17], and color [19] to reduce users' reaction times or preference. Avraham Bahir et al. [3] examined the effect of visual manipulations of mobile notifications on users' reaction times. While disadvantages of adding graphics or images to notifications include covering more screen space and adding more clutter on smartphones, they also increase the response rates.

Tasse et al. [29] conducted a desktop-based user study to identify the effects of 15 different types of visual attention grabbers using different combinations of visual factors such as color, position, size, and animation. They measured their users' reaction times for each visual design while users played a memory game as a primary task. The more noticeable – and thus obtrusive – a notification was, the faster the measured reaction time. Overall they recommend pulsing glowing shadows as most likeable and effective way to capture the user's attention.

2.3 Awareness of User's Gazing

The distance between the gazing focus point and a notification affects the user's attention and subjective distraction [18]. While much research focuses on the visual perception of notifications on large screen setups and VR [17–19, 25, 29], these results might not be easily transferable to phones. Yet, as smartphones became bigger in recent years, their screen edges now move into mid-peripheral vision at a typical usage distance [5]. Thus, notifications are displayed in the area of the user's visual field where color perception and acuity already diminishes [2]. This means that reading a notification is actually impossible without moving the visual focus closer to it, and that the change in screen brightness caused by a notification appearing highly triggers the perception in mid-peripheral vision. In conclusion, notification designs with a smaller footprint should still reliably capture the user's attention.

3 DESIGNING ATTENTIVE NOTIFICATIONS

It is important to state that notification delivery is triggered by external events – and thus not in the user's control. When notifications appear right under the user's fingertips they are prone to trigger accidental inputs [14]. This issue worsens as on modern smartphone platforms, notification banners cover the whole toolbar at the top of the screen, overlapping important navigation and functionality buttons. Gaze tracking offers a promising way to mitigate this issue, as where a user is looking at provides indicative information on her intention or next likely action within a second [6]. With high-resolution front facing cameras in recent smartphones, gaze tracking with sufficient accuracy is now available on mobile devices, e.g. via usage of ARKit [30].

The interaction design of mobile notifications is a combination of factors influencing their visual design and delivery process [23], and enhancing current notification design requires looking into all of them. First, visual aspects (size, contrast, ...). For instance, reducing the visual footprint of notifications tends to be less disruptive and reduces content occlusion [18]. Second, the introduction and mapping of gaze data (notification position, size, ...). Interaction effects between these factors are also likely, e.g., increasing the spatial distance between the location the user is interacting on screen and the notification banners should have a similar effect to size reduction. Third, the possibility to use gaze explicitly as input arises. To find out more about how size and contrast influence perception and disruption, we conducted a preliminary study.

3.1 Exploration of Visual Factors

3.1.1 Apparatus and Task. In this study, 10 participants aged between 20 and 30 (6 male) were given an iPhone XS on which notification banners of different styles arrived silently during usage. They watched a video of their choice in landscape orientation which had to be at least 20 min long. The personal selection of a video was intended to capture the individual interest and guide the focus on the video content. Participants were asked to dismiss notifications by swiping whenever they noticed them on the screen. Notifications were presented in three different Sizes [small (23×10 mm), medium (60×10 mm), large (60×20 mm)] and three different Contrast levels [low (3:2 contrast, 70% opacity), medium (3:1 contrast, 85% opacity), high (7:1 contrast, 100% opacity)], as depicted in Figure 2b.

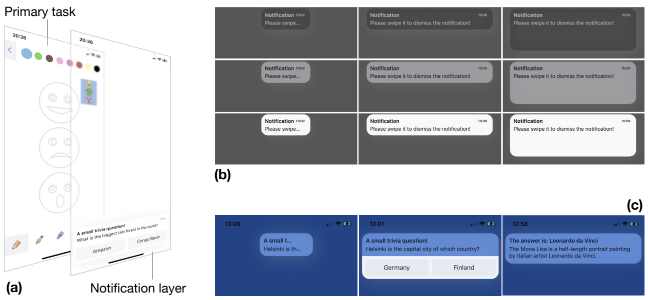

Figure 2: (a) In the study notifications could either be displayed along the top or bottom screen edge, resulting in an overlap of either the tool or color selection UI. (b) The nine different notification styles explored in the preliminary study differed in their size (from left to right: small, medium, large) and their contrast level (from top to bottom: low, medium, high). (c) In the main study, gaze-explicit notifications used a small-size medium-contrast style (left) expanded once the participant shifted her gaze towards the notification. The expanded state of interactive notifications (middle) provided two buttons, while read-only notifications (right) did not.

Each combination was tested three times with each participant in a random order in which the same condition was not presented two times in sequence. For reference, the design of the standard iOS notifications matches our look of a medium-size high-contrast notification. We measured the *Perception Time* as the time between the notification beginning to animate on screen and the moment the participant began to dismiss the notification. Moreover, participants rated their perceived distraction level and preference in a post-hoc questionnaire on a 5-point Likert scale.

3.1.2 Results. To analyze the effects of Size and Contrast on the mean response times, we used two-way ANOVA for evaluation and Student's t-tests for post-hoc pairwise comparisons on the aggregated data.

Size had a significant effect on the response time ($F(2, 18 = 10.379), p < .001$). Pairwise comparisons revealed that all three size classes performed significantly different ($p < .03$). On average, the response time was 2.0 s with large notifications, 2.4 s with medium-sized notifications, and 2.8 s with our smallest notifications. Contrast, on the other hand, had no significant impact on the perception time ($F(2, 18 = 2.843), p = .085$). We measured average response times of 2.3 s with medium and high contrast and 2.5 s with low contrast. There was also an interaction effect of Size×Contrast ($F(4, 36 = 3.512), p = .016$). Small-size low-contrast notifications were perceived significantly slower than any other notifications ($p < .01$). However, small-size medium-contrast notifications were already not perceived significantly slower than large high-contrast notifications ($p = .066$).

The ratings of our participants suggest that the distraction they perceived (Figure 3) correlated to their response times. However, our participants also mentioned that not much content will fit into the small notifications, limiting their use: *"I do not know think many messages will fit into that."* Regarding the Size, 6 participants responded that they preferred the small-sized notifications most, especially as they cover less screen real estate: *"The small ones blended in nicely with the video, so that both contents can coexist."*

3.2 Controlling Notification Placement

The data of the preliminary study shows promising optimization potential for the visuals of mobile notifications: Small notifications with sufficient contrast seem to provide a good trade-off between perception and screen occlusion. Even without the additional sound cue, they were perceived less than a second slower than the standard iOS notifications. However, by reducing the footprint of notifications the problem of fitting sufficient content into the notification arises. This could be compensated by enlarging the notification once the user actively gazes at it. To explore further aspects of the previously mentioned design factors, we designed interaction techniques utilizing gaze tracking and the previously tested visual designs to answer our research questions:

3.2.1 Gaze-Implicit. Our first interaction technique activates the front-facing camera to estimate the user's gaze location shortly before a notification is presented. Depending on whether the user looks at the upper or lower half of the screen, the notification will be displayed on the screen edge which is vertically farthest away. Thus, notifications are moved away from the user's central vision into the peripheral vision. They use the medium-size high-contrast design that is default on iOS. These notification can be pressed to expand them. They are dismissed by swiping or looking away from the notification for 1.2 s, a duration that fits into the range of typical dwell times with gaze interactions [10].

3.2.2 Gaze-Explicit. Our second interaction technique additionally allows further gaze interaction with the notification. Notifications are placed using the same rule as gaze-implicit notifications, but use the small-size medium-contrast design to further reduce occlusion while being sufficiently perceivable based on the results of the preliminary study. When the user moves her gaze towards the notification, it enlarges as if it was pressed and all options are revealed (Figure 1).

3.2.3 Touch-Attentive. For comparison, we also created a notification presentation style that does not rely on gaze tracking as input modality. Touch-attentive notifications work like gaze-implicit notifications, but they use the last location of the user's finger instead of her gaze to determine on which side of the screen the notification is supposed to appear.

4 EVALUATION

To answer our research questions we conducted a user-study comparing these three techniques (*gaze-implicit*, *gaze-explicit* and *touch-attentive*) with a *baseline* condition that always slides in notifications from the top of the screen (as known from the default system style on common mobile platforms). All conditions used a slide-in animation from the screen edge that matched the default style in iOS. 10 people participated in this study aged from 20 – 30, three male.

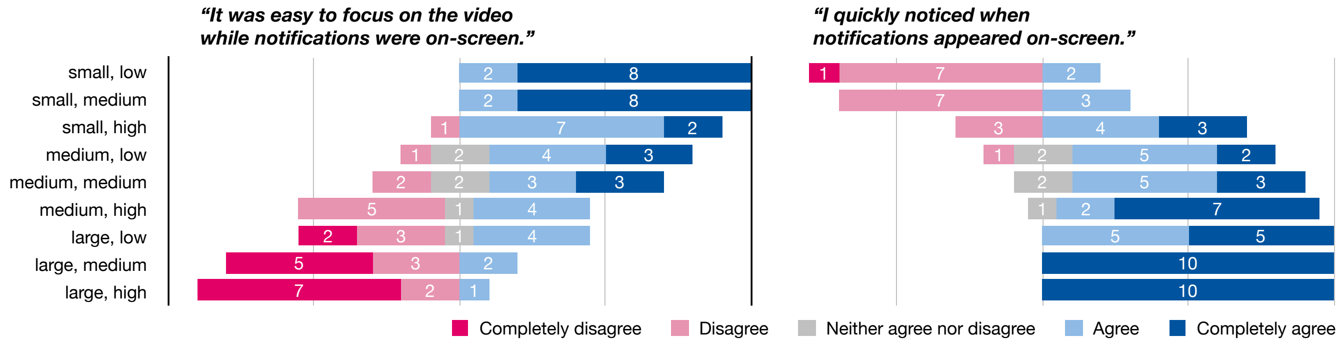

Figure 3: After the preliminary study participants were asked to specify their agreement to statements on 5-point Likert scales. The responses regarding the distraction (left) and perception (right) of different notification styles are presented in stacked charts. Overall, stacks that are aligned farther to the right suggest a higher agreement overall. The impact of notification size is stronger than contrast. Large notifications were rated only slightly better noticeably than medium-sized notifications, yet more distracting. Small high-contrast notifications provide a good compromise of self-reported perception and distraction.

4.1 Apparatus and Task

While we were interested in the usage of notifications, we needed to keep participants engaged in a primary task. Therefore, we created a simple drawing application in which users could pick different drawing tools and colors. A selection of different template outlines that participants could paint in was provided to assure their interest and make it unnecessary to think about an own design first. The drawing task was chosen as it requires focus to move the finger precisely to not cross the outlines while painting in. Typically for mobile UIs, toolbars for drawing tools and color selections were visible at the top and bottom of the screen. Thus, notifications resulted in an overlap with the primary task (Figure 2a).

We also aimed to create an interesting secondary task for the notification interactions that covers both interactive (that require a user action, such as messaging apps or reminders) and non-interactive notifications (do not require user interaction; only deliver information). Therefore, we created a trivia quiz that was completely operational from within notifications. When a new question was ready to be answered, a notification appeared on screen. People could, depending on the condition, touch the notification, or with gaze-explicit notifications shift their gaze towards them to enlarge them. In the enlarged state, buttons for two possible answers are visible and can be selected by tapping (Figure 2c). The next queued notifications presented a short explanation of the solution to the previous quiz question. It did not require any explicit interactions and only had the purpose to deliver information to the users. By varying the types of the notification contents, we tried to cover both use cases of the notifications; notifications with- and without action. After a notification was dismissed, the system waited a random time interval between 15 and 30 seconds before presenting a new notification.

In each condition, people received at least 10 notifications. The order of conditions was randomized for every participant. Before the first notification of every condition, the app explained the current condition to the participants. Additionally, the instructor explained how the notifications will be presented, enlarged, and how one could interact with them. After the task, participants ranked their agreement to statements about their experience on 5-point Likert scales. They also expressed their impressions in a follow-up interview during which they were still allowed to test the systems again if needed. One study run took around 50 minutes.

4.2 Results

As we already measured response times in the preliminary study, our goal in this study was to learn more about the experience our participants had while operating the phone. The agreement on the Likert scales was expressed from totally disagree (-2) to totally agree (2). We analyzed the participant responses using Friedman tests and Dunn-Bonferroni post-hoc tests.

4.2.1 Attention to Primary Task. First, participants rated their agreement to the statement "I could easily keep my attention on the drawing while notifications were presented on-screen". On average, our participant were indifferent about this statement in the baseline condition (M=0.1), and slightly agreed in the gaze-explicit condition (M=0.6). There was, however, no significant effect in the responses ($\chi^2(3) = 1.691, p = .639$). The responses of participants are depicted in Figure 4. Moreover, our participants expressed agreement to the statement "I could easily return to drawing after I dismissed a notification" with the same average across all conditions (M=1.3, SD=1.2).

4.2.2 Disruption caused by Notifications. Regarding the perceived disruption participants rated the statement "The notifications rarely occluded the screen area I interacted with". There was a significant difference between the conditions ($\chi^2(3) = 18.357, p < .001$). Participants disagreed using the baseline (M=-0.7) and the touch-attentive (M=-0.8) conditions. On the other hand, participants agreed favorably with both gaze-implicit (M=1.4) and gaze-explicit (M=1.5) notification styles. Both gaze based techniques were rated significantly better than the other two ($p < .02$). In addition, our participants agreed to the statement "It was easy to finish my current drawing action while a notification was displayed" using gaze-explicit notifications (M=1.1, SD=1.1). They only slightly agreed using gaze-implicit (both M=0.5, SD=1.5), and were indifferent in the baseline condition (M=0.1, SD=1.6).

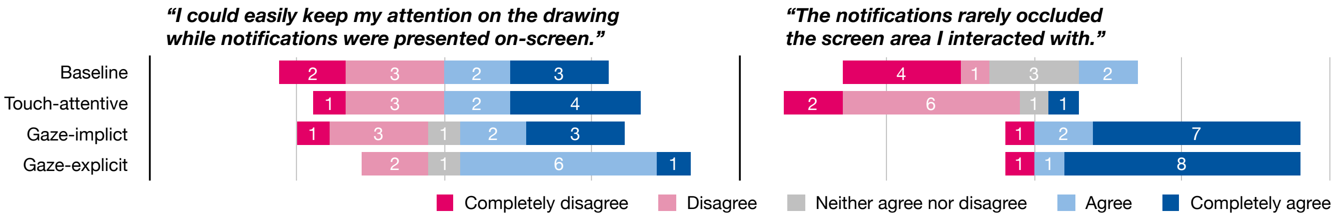

Figure 4: After the study participants were asked to specify their agreement to statements on 5-point Likert scales. The responses regarding distraction (left) and occlusion (right) caused by the notifications in the four conditions are presented in stacked charts. It is apparent that the visual representation of gaze-explicit notifications might have a benefit on distraction. Our participants felt that both gaze-attentive conditions greatly reduce undesired occlusion effects.

4.2.3 Preference Ranking. After using all four designs, our participants were asked to "rank the experience the different designs offered from 1–4 with 1 being their favorite". There was a significant effect ($\chi^2(3) = 11.160, p = .011$) with participants preferring gaze-explicit (M=1.8), and gaze-implicit notifications (M=2.1) the most. Both of them were ranked significantly better than touch-attentive notifications (M=3.6, $p < .02$). While not significant, even the baseline condition received a better average rating (M=2.5).

5 DISCUSSION

The follow-up interviews provide explanations for these results. The major source of disruption our participants identified was in fact not that the notification required attention while they were performing another task. Instead, notifications impeded them from continuing their drawing by occluding tool selections, or appearing right at the moment they were about to tap on a different color, resulting in accidental activation. Eight participants mentioned that they experienced undesired content overlaps themselves in gaming and streaming apps. Gaze-explicit notifications not only provided benefit by staying away from the area the user was about to interact with, they also had a smaller footprint than the other notification styles: *"Especially the small size was useful. For example, I can easily notice which app sends me the notification [which is] enough to communicate the type of information provided." "The short version of the information in the small size notifications is totally enough to decide whether I need to pay attention to the notification or not."* This is in line with the findings of Klauck et al. [18], which we confirmed here for the mobile setting.

Interestingly, while participants valued the system awareness of their interactive area, six out of ten rated the touch-attentive version as the worst design tested: *"The notifications based on the last touches were later than my gazing, so notifications often covered the toolbar at the moment when we wanted to change the tool"* and *"The touch-attentive version covered the color palette many times. It was very annoying that notifications covered [the UI] just before I tried to select a different color"*. This is especially surprising as we chose a drawing task specifically for the reasons of fairness, as during drawing fingers and eyes move in parallel. Thus, mobile gaze tracking is clearly a better input than touch to identify the interactive screen area of the phone (RQ1).

Regarding their capability of paying attention to the drawing task, participants slightly favored gaze-explicit notifications, especially due to the reduced content overlap. The type of disruption caused by notifications in our study was perceived rather pragmatic than cognitive. The task was not cognitively challenging, and thus our participants also had no issues returning to the drawing task after they dismissed a notification across all conditions. With device usage in the wild, however, this would likely change: With complex tasks the effects of disruption worsen as more time is required to resume with the primary task [9].

When explaining their overall ranking, our participants explained that *"gaze-explicit notifications were comfortable because they [...] avoid where [we] want to interact with". "I really liked that notifications disappeared automatically if I looked at another part of the screen. I did not have to move my finger to close the notifications and I could quickly resume drawing"*. However, we saw that gaze-explicit notifications had the most variance in their rankings. This was partially because it had a different design than the well-known default look, but also because it introduces a Midas touch problem [16]: *"if this was a chat program it would have sent a read receipt despite me not wanting to mark it as read yet"*. Thus, our participants were only concerned about undesirably activating a notification, whereas they enjoyed automatic dismissal. Future versions of gaze-explicit notifications should therefore only resize the notification accommodate more text without triggering the enlarged state of the notification instead to increase acceptance (RQ2). In terms of privacy, one participant criticized that even if the camera system is activated only shortly when a notification appears, she *"could not cover the camera with a sticker anymore."*

6 SUMMARY AND FUTURE WORK

This work serves as a first exploration of possible designs for gaze-attentive notifications that reduce unnecessary distraction and content overlaps. In two user studies we identified suitable parameters for the implementation of gaze-attentive notifications. We also collected valuable feedback from participants that helps shaping refined iterations of gaze-attentive notifications.

The key findings of these studies are as follows. (1) Our participants enjoy notification styles which raise information awareness without distracting them from their current task. (2) They liked the gaze-explicit notifications for introducing low visual distraction and the elimination of additional input for dismissal. (3) Resizing the gaze-explicit notification during interaction reduced distraction without lowering its information content. (4) While gaze can effectively be used to determine a suitable placement of notifications, this is not the case with touch inputs: In fact, the touch-attentive placement of notifications felt quite random to our participants.

Based on these findings our next steps are to continue refining gaze-attentive notifications and conducting a more extensive study to analyze their impact. The feedback we obtained from the study participants made clear to us that occlusion is even more of a problem than we already expected. Alternative notification designs could completely resolve occlusion problems, for instance, slightly decreasing the screen's viewport on the screen edge of the notification and presenting it vertically next to the actual content of the current app. Secondly, we learned that enlarging the notification when gazing at it is an effective way to display more textual content when the user wants to pay attention to it. However, directly expanding the notification and providing buttons, chat options, etc. leads to reservations with the users. Moreover, adapting gaze-attentive notifications to tablets will provide new challenges: With tablet computers more screen space moves even further into the peripheral vision, so that determining a notification size or contract level based on the gaze location becomes an interesting factor.

A current limitation of this work are the small studies and that they were only conducted in a lab setting. Moreover, while the drawing task was intended to introduce fairness between the touch and gaze conditions, it might have not been cognitively challenging enough. Therefore, we want to test the refined gaze-attentive notification design with a more extensive in the wild study to capture actual usages across different contexts.

REFERENCES

[1] Piotr D. Adamczyk and Brian P. Bailey. 2004. If Not Now, When? The Effects of Interruption at Different Moments within Task Execution. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vienna, Austria) *(CHI '04)*. Association for Computing Machinery, New York, NY, USA, 271–278. https://doi.org/10.1145/985692.985727

[2] Stuart Anstis. 1998. Picturing Peripheral Acuity. *Perception* 27, 7 (1998), 817–825. https://doi.org/10.1068/p270817

[3] Ravit Avraham Bahir, Yisrael Parmet, and Noam Tractinsky. 2019. Effects of Visual Enhancements and Delivery Time on Receptivity of Mobile Push Notifications. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI EA '19)*. Association for Computing Machinery, New York, NY, USA, 1–6. https://doi.org/10.1145/3290607.3312993

[4] G. Susanne Bahr and Richard A. Ford. 2011. How and why pop-ups don't work: Pop-up prompted eye movements, user affect and decision making. *Computers in Human Behavior* 27, 2 (2011), 776–783. https://doi.org/10.1016/j.chb.2010.10.030 Web 2.0 in Travel and Tourism: Empowering and Changing the Role of Travelers.

[5] Laura Boccardo. 2021. Viewing distance of smartphones in presbyopic and non-presbyopic age. *Journal of Optometry* 14, 2 (2021), 120–126. https://doi.org/10.1016/j.optom.2020.08.001

[6] Çağla Çığ and Tevfik Metin Sezgin. 2014. Gaze-Based Virtual Task Predictor. In *Proceedings of the 7th Workshop on Eye Gaze in Intelligent Human Machine Interaction: Eye-Gaze & Multimodality* (Istanbul, Turkey) *(GazeIn '14)*. Association for Computing Machinery, New York, NY, USA, 9–14. https://doi.org/10.1145/2666642.2666647

[7] Xi-Jing Chang, Fang-Hsin Hsu, En-Chi Liang, Zih-Yun Chiou, Ho-Hsuan Chuang, Fang-Ching Tseng, Yu-Hsin Lin, and Yung-Ju Chang. 2023. Not Merely Deemed as Distraction: Investigating Smartphone Users' Motivations for Notification-Interaction. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 650, 17 pages. https://doi.org/10.1145/3544548.3581146

[8] Kuan-Wen Chen, Yung-Ju Chang, and Liwei Chan. 2022. Predicting Opportune Moments to Deliver Notifications in Virtual Reality. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 186, 18 pages. https://doi.org/10.1145/3491102.3517529

[9] Mary Czerwinski, Eric Horvitz, and Susan Wilhite. 2004. A Diary Study of Task Switching and Interruptions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vienna, Austria) *(CHI '04)*. Association for Computing Machinery, New York, NY, USA, 175–182. https://doi.org/10.1145/985692.985715

[10] Augusto Esteves, Yonghwan Shin, and Ian Oakley. 2020. Comparing selection mechanisms for gaze input techniques in head-mounted displays. *International Journal of Human-Computer Studies* 139 (2020), 102414. https://doi.org/10.1016/j.ijhcs.2020.102414

[11] Joel E. Fischer, Chris Greenhalgh, and Steve Benford. 2011. Investigating Episodes of Mobile Phone Activity as Indicators of Opportune Moments to Deliver Notifications. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services* (Stockholm, Sweden) *(MobileHCI '11)*. Association for Computing Machinery, New York, NY, USA, 181–190. https://doi.org/10.1145/2037373.2037402

[12] Joel E. Fischer, Nick Yee, Victoria Bellotti, Nathan Good, Steve Benford, and Chris Greenhalgh. 2010. Effects of Content and Time of Delivery on Receptivity to Mobile Interruptions. In *Proceedings of the 12th International Conference on Human Computer Interaction with Mobile Devices and Services* (Lisbon, Portugal) *(MobileHCI '10)*. Association for Computing Machinery, New York, NY, USA, 103–112. https://doi.org/10.1145/1851600.1851620

[13] Nicholas Fitz, Kostadin Kushlev, Ranjan Jagannathan, Terrel Lewis, Devang Paliwal, and Dan Ariely. 2019. Batching smartphone notifications can improve well-being. *Computers in Human Behavior* 101 (2019), 84–94. https://doi.org/10.1016/j.chb.2019.07.016

[14] Ankit Guleria and Ramandeep Kaur. 2021. Unintended Notification Swipe Detection System. In *2021 Third International Conference on Inventive Research in Computing Applications (ICIRCA)* (Coimbatore, India). IEEE, 1614–1620. https://doi.org/10.1109/ICIRCA51532.2021.9544898

[15] Shamsi T. Iqbal and Eric Horvitz. 2010. Notifications and Awareness: A Field Study of Alert Usage and Preferences. In *Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work* (Savannah, Georgia, USA) *(CSCW '10)*. Association for Computing Machinery, New York, NY, USA, 27–30. https://doi.org/10.1145/1718918.1718926

[16] Robert J. K. Jacob. 1990. What You Look at is What You Get: Eye Movement-Based Interaction Techniques. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Seattle, Washington, USA) *(CHI '90)*. Association for Computing Machinery, New York, NY, USA, 11–18. https://doi.org/10.1145/97243.97246

[17] Nuwan Nanayakkarawasam Peru Kandage Janaka, Shengdong Zhao, and Shardul Sapkota. 2023. Can Icons Outperform Text? Understanding the Role of Pictograms in OHMD Notifications. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 575, 23 pages. https://doi.org/10.1145/3544548.3580891

[18] Michaela Klauck, Yusuke Sugano, and Andreas Bulling. 2017. Noticeable or Distractive? A Design Space for Gaze-Contingent User Interface Notifications. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI EA '17)*. Association for Computing Machinery, New York, NY, USA, 1779–1786. https://doi.org/10.1145/3027063.3053085

[19] Aristides Mairena, Carl Gutwin, and Andy Cockburn. 2019. Peripheral Notifications in Large Displays: Effects of Feature Combination and Task Interference. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300870

[20] Abhinav Mehrotra, Mirco Musolesi, Robert Hendley, and Veljko Pejovic. 2015. Designing Content-Driven Intelligent Notification Mechanisms for Mobile Applications. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Osaka, Japan) *(UbiComp '15)*. Association for Computing Machinery, New York, NY, USA, 813–824. https://doi.org/10.1145/2750858.2807544

[21] Abhinav Mehrotra, Veljko Pejovic, Jo Vermeulen, Robert Hendley, and Mirco Musolesi. 2016. My Phone and Me: Understanding People's Receptivity to Mobile Notifications. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 1021–1032. https://doi.org/10.1145/2858036.2858566

[22] Hiromu Ogawa, Kinji Matsumura, and Arisa Fujii. 2021. Appropriate Timing and Length of Voice News Notifications. In *ACM International Conference on Interactive Media Experiences* (Virtual Event, USA) *(IMX '21)*. Association for Computing Machinery, New York, NY, USA, 194–198. https://doi.org/10.1145/3452918.3465488

[23] Veljko Pejovic and Mirco Musolesi. 2014. InterruptMe: Designing Intelligent Prompting Mechanisms for Pervasive Applications. In *Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (Seattle, Washington) *(UbiComp '14)*. Association for Computing Machinery, New York, NY, USA, 897–908. https://doi.org/10.1145/2632048.2632062

[24] Martin Pielot, Karen Church, and Rodrigo de Oliveira. 2014. An In-Situ Study of Mobile Phone Notifications. In *Proceedings of the 16th International Conference on Human-Computer Interaction with Mobile Devices & Services* (Toronto, ON,

Canada) *(MobileHCI '14)*. Association for Computing Machinery, New York, NY, USA, 233–242. https://doi.org/10.1145/2628363.2628364

[25] Rufat Rzayev, Sven Mayer, Christian Krauter, and Niels Henze. 2019. Notification in VR: The Effect of Notification Placement, Task and Environment. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Barcelona, Spain) *(CHI PLAY '19)*. Association for Computing Machinery, New York, NY, USA, 199–211. https://doi.org/10.1145/3311350.3347190

[26] Alireza Sahami Shirazi, Niels Henze, Tilman Dingler, Martin Pielot, Dominik Weber, and Albrecht Schmidt. 2014. Large-Scale Assessment of Mobile Notifications. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Toronto, Ontario, Canada) *(CHI '14)*. Association for Computing Machinery, New York, NY, USA, 3055–3064. https://doi.org/10.1145/2556288.2557189

[27] Anton Sigitov, Ernst Kruijff, Christina Trepkowski, Oliver Staadt, and André Hinkenjann. 2016. The Effect of Visual Distractors in Peripheral Vision on User Performance in Large Display Wall Systems. In *Proceedings of the 2016 ACM International Conference on Interactive Surfaces and Spaces* (Niagara Falls, Ontario, Canada) *(ISS '16)*. Association for Computing Machinery, New York, NY, USA, 241–249. https://doi.org/10.1145/2992154.2992165

[28] Cary Stothart, Ainsley Mitchum, and Courtney Yehnert. 2015. The attentional cost of receiving a cell phone notification. *Journal of Experimental Psychology: Human Perception and Performance* 41, 4 (aug 2015), 893–897. https://doi.org/10.1037/xhp0000100

[29] Dan Tasse, Anupriya Ankolekar, and Joshua Hailpern. 2016. Getting Users' Attention in Web Apps in Likable, Minimally Annoying Ways. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '16)*. Association for Computing Machinery, New York, NY, USA, 3324–3334. https://doi.org/10.1145/2858036.2858174

[30] Simon Voelker, Sebastian Hueber, Christian Holz, Christian Remy, and Nicolai Marquardt. 2020. GazeConduits: Calibration-Free Cross-Device Collaboration through Gaze and Touch. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3313831.3376578