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Designing for distraction in gaze-aware mobile notifications

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(1) Wenn eine der in den §§ 154 bis 156 bezeichneten Handlungen aus Fahrlässigkeit begangen worden ist, so tritt Freiheitsstrafe bis zu einem Jahr oder Geldstrafe ein.

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Die vorstehende Belehrung habe ich zur Kenntnis genommen:

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Abstract

While using mobile applications, people would like to keep aware of important information through mobile notifications. At the same time, the mobile notifications often cover users' interaction area and take users' attention away from the primary task so that people perceive them as distractive. In this Master's thesis, we focused on such trade-off of the mobile notifications and investigated how to balance unwanted visual distraction and awareness of the mobile notifications. First, we conducted a pre-study to understand the effect of design factors of the mobile notifications such as size and contrast level on users' reaction time and visual perception. The results showed that participants put a high value on the small-sized notifications which were perceived as less distractive despite the longer reaction time. Also, the intrinsic animation effects such as sliding down from the top for presentation of the notifications influenced on noticeability of the mobile notifications besides the visual design factors. Based on the findings of users' visual perception, we present the *gaze-aware notifications* utilizing users' gaze as the design option to improve the usability of the mobile notifications. The gaze-aware placement is based on users' eye gaze such that the notifications are presented on the opposite side of the current gaze point. In addition, we added visual effects to the notification design to explore how the visual effects we found from the pre-study can work together with the gaze-aware notifications. For evaluation, we implemented four different visual designs — STANDARD, NOT WHERE WE TOUCH, GAZE-AWARE PLACEMENT, and GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS — to verify the usability of the proposed gaze-aware notifications compared to other design options. We conducted a user study and collected users' feedback in terms of perceived visual distraction, attention to the primary task, and preference. Participants reported their overall impressions of the gaze-aware notifications in the follow-up survey. From users' feedback revealed that the gaze-aware notifications involving visual manipulations effectively reduce the perceived visual distraction compared to other design options and enable users to profit the informative characteristics of the mobile notifications. Lastly, we present the promising applications of the gaze-aware notifications and its further improvements.

Conventions

Throughout this thesis we use the following conventions.

Text conventions

Definitions of technical terms or short excursus are set off in coloured boxes.

EXCURSUS:
Excursus are detailed discussions of a particular point in a book, usually in an appendix, or digressions in a written text.

Definition:
Excursus

For the use of the first person, the pronoun ”we” is used.

Chapter 1

Introduction

Mobile notification is a visual and auditorial signal to draw users' attention besides their current task for conveying a certain amount of information in an effective way [Iqbal and Horvitz, 2010]. Since the use of smartphones is already deeply embedded in our lives, mobile users face lots of notifications everyday. People receive over 60 mobile notifications on average per day [Pielot et al., 2014] and the majority of smartphone users opt-in to receive important notifications. Despite high usage rates of mobile notifications, the actual reaction rate was surveyed as less than 5 percent.

Mobile notification is a common medium to deliver digital information to users by catching users' attention through the visual and auditory signal.

As part of reasoning such a low reaction rate of notifications, previous studies investigated how users have perceived and evaluated the notifications in relation to their primary task. Sigitov et al. [2016] examined the effect of visual pop-ups on users' attention to the primary task in the case of large display walls. In their study setting, the visual stimuli were designed similar to pop-up windows used in desktop environments and displayed in different visual areas around the current main task. They found that the performance of participants was negatively influenced by the visual distractors across overall conditions. In addition, users subjectively perceived notifications as interruptive and distractive to their ongoing tasks. The study of Mehrotra et al. [2016] revealed that mobile notifications were perceived as most distractive if they were presented in the middle of the ongoing task compared to the start-

The notifications were often perceived as distractive to the users' primary task. To reduce the distraction, previous studies proposed design implications with different aspects e.g. investigation on users' prioritization or delivery timing.

ing or idle state. Furthermore, the level of perceived disruption affects users' reaction time and the user's decision whether they accept the notification or not. To minimize such distractions, Fischer et al. [2011] and Avraham Bahir et al. [2019] found that the delivery time of notifications derived by the analysis of users' usage patterns decrease perceived distraction so that users' acceptivity rated increased.

People want to keep aware of information delivered by notifications despite perceived distraction.

Even though notifications are perceived as disruptive, people enable them since they do not want to miss necessary information. The informative characteristics of notifications are essential to fulfill the purpose of notifications. Iqbal and Horvitz [2010] and Fitz et al. [2019] found that users valued the awareness of information provided by the notifications and they were willing to maintain this awareness despite the potential disruption of notifications. To support users being aware of the notifications, previous works focused on the primitive visual design of notifications related to noticeability and users' visual attention. Tasse et al. [2016] and Avraham Bahir et al. [2019] found that visual components such as image, color, position, or the combination of such features had effects on the users' noticeability. The notifications could be designed using visual components to gain an appropriate level of attention.

This thesis investigates how to balance unwanted distraction and notification awareness to communicate information based on the visual perspectives of the notifications.

Notifications have such a trade-off. The nature of the notifications is disruptively caused by, for example, occlusion of the screen, and distraction of attention visually or auditorily. At the same time, the notifications are an important communication channel to deliver information to the users with instantaneous accessibility. However, there has been a lack of research to adress how to balance two aspects of notifications so that users get rewarding of notifications informativeness without unnecessary distraction. Also, most of the previous works have examined the notification designs on larger displays than smartphone, such as desktop monitors or display walls. To bridge this gap, this thesis investigates how to balance unwanted distraction and noticeability in terms of appropriate level of attention to improve the use of mobile applications. First, we examine the visual aspects of notifications in users' visual perception, especially for the mobile screen. Then we proposed a new type of notifications utilizing eye tracking with the purpose of reducing disruption and guarantee minimum attention to communicate information.

The pre-study was conducted with 10 users to extend the understanding of the effect of visual factors of mobile notifications on the users' reaction. During the primary task, participants saw different notification designs based on size and contrast level involving variation of luminance and opacity, and the reaction time was measured. The results revealed that participants' reaction times were influenced by SIZE of the notifications. Participants preferred the small-sized notifications despite the longer reaction time since it was less distractive. Also, they argued the low legibility of small-sized notifications compared to medium or large conditions.

In the pre-study involving 10 participants found that the size of notifications affected users' reaction time, preference and perceived legibility of contents.

Upon the baseline findings, I suggested a new type of mobile notification system –*Gaze-aware notifications*– utilizing eye-tracking technology. The user's gaze information was interpreted user's next intended interaction area such that the placement of presentation/dismissal of the notifications was determined by the current user's gaze. We conducted a study with 10 users to evaluate users' perception of the gaze-aware notifications and the adaptation of visual perception found in the pre-study. Participants performed a drawing task as the main task, and interacted with different notification designs with four conditions: STANDARD, NOT WHERE WE TOUCH, GAZE-AWARE PLECEMENT, GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS. Participants evaluated GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS as less distractive during the task and selected it as the most preferred notification design among study conditions. These results represented the suggested gaze-ware notifications might be one design approach for mobile notifications to balance unwanted distractions while users can take the informational benefits of mobile notifications. Additionally, we suggest further applications of the proposed gaze-aware notifications and the directions for further research based on users' feedback.

The proposed *gaze-aware notifications* utilizing eye-tracking were evaluated such that GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS were impressed as least distractive and informative.

Chapter 2

Related work

Distractiveness of notifications

Notifications play a role to deliver additional information while users perform their primary tasks. They require the user's secondary attention and it often causes undesired distraction to the ongoing task. The nature of notifications is disruptive. It is because, for example, the notifications always arise visual overlaps on the screen [Bahr and Ford, 2011] or auditorial interference [Cary Stothart, 2014]. Therefore, previous research has investigated how to minimize users' perceived disruption and improve the use of mobile notifications.

Notifications are often evaluated as distractive since they call attention besides a primary task.

The notification contents can be one criterion to filter out the unwelcome notifications. Sahami Shirazi et al. [2014] suggested a guideline of effective use of mobile notifications considering users' subjective preferences based on their empirical experiment. They collected the notifications that participants received on their actual smartphones and users' reaction time (from presentation to tapping the notifications). Also, they logged the app categories. Their analysis indicated that the importance of the notifications was usually decided by why and from whom the notifications were sent. Participants reacted faster and more likely to the notifications which they treated as important.

Sahami Shirazi et al. [2014] found that the creation of notifications depending on the user-defined importance could improve the use of notifications.

The analysis of the context of use in mobile applications enables notification systems to predict the best moments to deliver the notifications and it resulted in lower interruption and faster reaction time [Pejovic and Musolesi, 2014, Mehrotra et al., 2015]

The timing of interruption within the ongoing task affects significantly users' performance as well as their mental efforts such as annoyance and frustration [Adamczyk and Bailey, 2004]. Upon it, the questions of the timing have been also issued for the mobile notifications [Fischer et al., 2010, 2011]. In a system-driven way, Pejovic and Musolesi [2014] and Mehrotra et al. [2015] analyzed users' physical-(e.g. user's main activity, location) and mental(e.g. the sender-receiver relationship, emotions) mobile usage patterns and employed it to predict the opportune moments of the notification delivery. From their results revealed that the users assessed their context-aware notifications as less interruptive and reacted faster compared to the general notifications. These resulted in a high level of satisfaction to use the mobile notifications. The timing of the notifications was explored in a macro view of the contexts as well. People have different levels of attention or fatigue in their daily routines. Employing the "break time" as an appropriate timing to deliver notifications makes people feel less disruption and increase the likelihood to accept the notifications [Ogawa et al., 2021, Avraham Bahir et al., 2019].

Noticeability of notifications

The appropriate level of noticeability of notification enables users to keep aware of important information.

Despite the intrinsic distractiveness of notifications, people are willing to keep aware of important information conveyed from the notifications [Iqbal and Horvitz, 2010]. The informational notifications could support users' productivity within the use of mobile applications [Bentley and Tollmar, 2013]. Even people felt a high level of anxiety if they could not receive the notifications at all [Fitz et al., 2019]. In this meaning, the noticeability of the notifications is an important attribute to fulfilling the informational purpose of the notifications. To engage a sufficient level of noticeability, previous literature suggested the visual enhancements of notifications in terms of users' reaction time.

Visual enhancement of notifications using visual components such as image affect users' reaction.

Visual factors such as notification's position [Rzayev et al., 2019] and color [Tarasewich et al., 2004, Mairena et al., 2019] have been utilized to make the notifications stand-out to users' vision. Avraham Bahir et al. [2019] examined the effect of visual manipulations of mobile notifications on users' reactions measured by the click-through rates. They simply added visual components like emojis, buttons, or images to the standard notification design and presented the notifications from the top of the screen as usual. The results showed that users reacted much faster to the notifications with the images and it concluded such simple visual manipulations could also cause significant differences in users' reaction time.

To test more complicated and intrinsic way of visual manipulations, Tasse et al. [2016] conducted a desktop-based user study to identify the effects of 15 different types of visual attention grabber on users' perceived noticeability and preference. They designed attention grabbers in different combinations of visual factors such as color, position, size, and animation by plotting their designs on the design space of notification systems introduced from McCrickard and Chewar [2003]. They measured users' reaction time for each visual design while users play a memory game as a primary task. The results showed that the noticeability of the attention grabbers depended on the different combinations of visual factors and it was highly correlated with users' reaction time: the more noticeable, the quicker react.

From the study of Tasse et al. [2016] revealed that users' visual perception affects users' reaction time and noticeability in desktop environments.

Nevertheless, these findings partially answered either how to minimize undesired distraction caused by the notifications or how to improve the visual noticeability of the notifications. Moreover, previous studies about users' visual perception of the notifications have been mostly conducted on large screens such as desktop monitors or digital walls. This thesis attempts to support designing notifications upon a comprehensive insight to balance unwanted distraction and awareness of notifications, especially in mobile environments. The mobile screen is relatively small and the entire screen is fully visible to human eyes according to the visual angle. Therefore, in the mobile environments, users' visual perception of the notifications might be more subtle and the effect of each visual component could have more impact on users' reactions.

This thesis aims to support designing notifications upon a comprehensive insight to balance unwanted distraction and awareness of notifications, especially in the mobile environment.

Users' locus provides useful information to understand users' next behavior and intention.

In the context of visual perspectives, users' locus i.e. where the user is looking could provide indicative information such as users' intention or next likely behavior within a second [Çığ and Sezgin, 2014, Shepherd, 2010]. Klauck et al. [2017] suggested the potential of gaze utilizations for the notification system in their study. They examined how size, opacity, blink frequency, and movement speed of the gaze-contingent notifications affect users' distractiveness and noticeability on a tv screen. They measured the number of responses to the notifications at different gaze distances. The results showed that the distance between the gazing locus and the notifications affects the user's attention and subjective distractiveness. However, the application of users' gaze to the mobile notifications has been still less discovered and it needs to understand how users' visual perception and users' locus effectively work together to enhance the use of the mobile notifications.

This thesis consists of 1) pre-study about users' visual perception of mobile notifications and 2) users' evaluation of proposed gaze-aware notifications.

Consequently, we proposed new type of notifications – *Gaze-aware notifications* – utilizing user's gaze information. Two user studies were sequentially conducted with the following research questions, firstly to explore users' visual perception of the notifications on the mobile screen (**RQ1**) and secondly to evaluate the suggested gaze-aware notifications involving additional visual manipulations in terms of preceived distraction and noticeability of the notifications (**RQ2**, **RQ3**).

Research questions

RQ1. How do the visual factors of notifications affect users' visual perception and reaction to notifications?

RQ2. Do the gaze-aware notifications enhance the usage of mobile applications by presenting notifications in the non-interactive area?

RQ3. How can users' visual perception work together with gaze-aware notifications to enhance the usage of mobile applications?

Chapter 3

Pre-study: Effect of visual factors on user's visual perception

3.1 Vision on the mobile screen

As the baseline information for the pre-study, we investigated how large an area on the screen is visible to human eyes and how people can visually focus on. The visible regions on the mobile screen were calculated by the visual angle.

VISUAL ANGLE:
Visual angle is the degrees of arc which represent the object's angular size depending on the viewing distance(Kaiser [2017]). It is formed by projecting from eyes to the linear size of an object. The visual angle V can be measured by the viewing distance D between eyes and the object and the linear size S of the object:

$$V = 2arctan\frac{S}{2D} \tag{3.1}$$

Definition:
Visual angle

Figure 3.1: An example of the visual angle on the mobile screen(iPhone XS): the visual field covers the entire area of the screen within the near-peripheral vision.

The entire mobile screen is fully visible to human eyes according to the visual angle, the visual impact of notifications should be controlled to reduce the distraction as well as to keep the minimum attention.

Using the results from Boccardo [2021], we calculated the visual angles with the viewing distance of 35cm (age group: 16-39, sitting posture) and the horizontal- and vertical linear screen size of iPhone XS which was used in the pre-study as an apparatus. As shown in Figure 3.1, the screen covers horizontally 10° and vertically 23° of visual angle and it indicates that the whole area of the screen is inside the near-peripheral regions. It means that the entire mobile screen is fully visible to human eyes. Based on this result, we found that visual effects of the mobile notifications should be reduced to minimize percieved distraction to the primary task. At the same time, we need to identify an appropriate level of visual attention to enable the notifications to relay necessary information effectively.

3.2 Study design

The experiment explored user's perception time to the different notification design approaches in terms of the visual factors. The participants reacted to the mobile notifications and responded to the survey with the aspects of distraction, attention and legibility of the notifications observed during the main task.

3.2.1 Participants

The study was conducted with ten participants. They are composed of six females and four males in the 20s to 30s age group, have various occupations like students, a cellist, a software engineer and a research assistant. Among them, only two participants had previous experience with an eye-tracking system and all of them use smartphones everyday.

3.2.2 Apparatus

We implemented a prototype application using iOS with iPhone XS. The application consisted of three layers. The lowest layer was for eye-tracking to collect users' gaze data while using the app. It was developed utilizing the face detection technology of ARKit. The second layer was a WKWebview to simulate the app in which users can watch videos. At the highest layer, the custom notification views involving different visual manipulations were presented according to the study conditions. These views looked like working in the background as the real notifications. They also simulated the behavior of the real notifications such as presentation with the ease-in animation and dismissal by the swiping input from users.

The prototype application automatically logged the following data during the study: timestamp (presentation- and dismissal of notification in ms), the type of visual manipulations (size, contrast level and position), coordinates (the center point of the notification on the screen, and center of

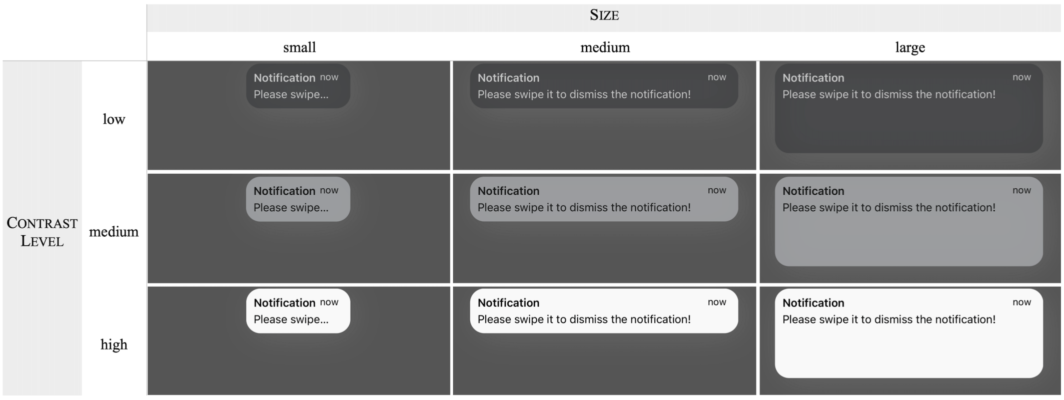


Figure 3.2: Example notifications according to the combination of two visual factors: SIZE and CONTRAST LEVEL

the gaze point), and visual distance between the notification and the user's gaze point.

3.2.3 Variables

The visualizations of notifications were manipulated by SIZE(small vs. medium vs. large) and CONTRAST LEVEL(low vs. medium vs. high).

Figure 3.2 depicts the example notifications used in the pre-study. The visual design of the notifications was manipulated based on the two independent variables: SIZE and CONTRAST LEVEL. SIZE has three different levels namely small(23.21mm $\times$ 9.98mm), medium(59.73mm $\times$ 9.98mm), and large(59.73mm $\times$ 19.97mm). The medium was set to the size of the standard iOS notification and the others were adjusted based on the medium. The levels of size were equally applied for both portrait- and landscape orientation. CONTRAST LEVEL was differed by the contrast ratio based on the average color distributions of the current screen and the opacity. It included three different levels: low(contrast ratio 1.5:1 with opacity 70%), medium(contrast ratio 3:1 with opacity 85%) and high(contrast ratio 7:1 with opacity 100%). The contrast ratio for each level were determined by the criterien of the Web Content Accessibility Guidelines (WCAG) 2.1. from W3C which guides how to design digital components to enable users to distinguish them clearly from its background.

To prevent the effects of the notifications' positions, the notifications were presented in an arbitrary position as one of the top-left, top-right, top-center(default), bottom-left, and bottom-right.

The study set PERCEPTION TIME and VISUAL PERCEPTION as dependent variables. PERCEPTION TIME was measured by *visual distance* and *reaction time*. *Visual distance*(mm) is the linear distance from the users' gaze point to the center of the notification. The *reaction time*(ms) is the time difference between the presentation of notifications and users' swipe gesture input to dismiss the notifications. They were calculated using the data logged by the prototype application described in 3.2.2. VISUAL PERCEPTION of the notifications was evaluated in the follow-up survey. The participants rated how they perceived *distractiveness*-, i.e. "It was easy to focus on the video while the notification was on the screen." and *noticeability of the notifications*, i.e. "I could quickly notice when the notification is presented on the screen." on a 5-point Likert scale, from "totally disagree" to "totally agree". The participants also ranked their *preferences* on each level of the visual factors from the best to the worst. To support participants not remembering all notification designs, we provided the example screenshots of the notification designs presented in the study.

The dependent variables of the pre-study were PERCEPTION TIME measured by *reaction time(ms)* and *visual distance* between the user's gaze point to the notification and VISUAL PERCEPTION collected by the follow-up survey.

3.2.4 Experimental design

The study was designed as a within-subject experiment with two independent variables for the visual manipulations of the notifications: SIZE(small, medium, large) and CONTRAST LEVEL(low, medium, high). The order of combination of conditions was randomized and two notifications in a row did not have the same combination. The experiment included: 3 SIZE $\times$ 3 CONTRAST LEVEL $\times$ 3 repetitions $\times$ 10 participants = 270 trials.

The within-subject experiment included: 3 SIZE $\times$ 3 CONTRAST LEVEL $\times$ 3 repetitions $\times$ 10 participants = 270 trials.

3.2.5 Tasks and procedure

At the beginning of the experiment, the instructor informed the participants about the purpose and the procedure of the study. The participants were asked to sit comfortably in front of a desk and keep the distance between the eyes and the camera on the smartphone constantly during the study. They held the smartphone in the landscape orientation with both hands.

The participants' usage distance could be applied to the gaze tracking at the beginning of the experiment through the calibration step.

As the first step, the participants started the calibration step. They looked at the indicators in the order of coloring in blue on the screen. The indicators are located in each edge (top, bottom, left, and right) and the center of the screen. When participants precisely enough gazed at the indicator, they tapped anywhere on the screen. The calibration step was repeated twice.

While the users performed the primary task i.e. watching a video, the notifications with visual stimli were presented. The participants should dismiss it when they noticed it.

After then, the participants could select a video from a given playlist. While watching a video, the notifications were presented with different kinds of visualizations on the screen. The time interval between two notifications was randomly selected between 15-30 seconds, so the participants could see three notifications per minute on average. Therefore, each video was around 20 minutes-long to present all 27 trials. The participants were asked to dismiss the notifications by swiping them up or down when they noticed, however they could also leave them without any reaction. In this case, the notifications automatically disappeared after 10 seconds.

After all trials were finished, the participants could see an alert to inform the end of the experiment. The instructor should confirm if logs are saved to the smartphone. The participants were able to take a break and then responded to the follow-up survey. The whole experiment took around 25-30 minutes per participant.

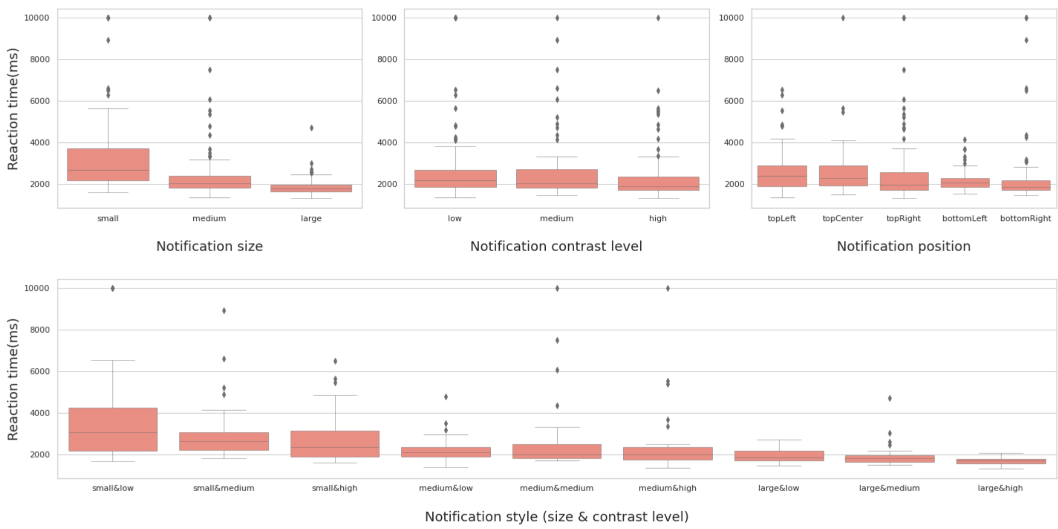


Figure 3.3: Boxplots describing the distributions of *response time* depending on the notification size(top left), the contrast level of the notifications(top center), the position of notification(top right), and the notification styles which is the combinations of size and contrast level(bottom).

3.3 Results

3.3.1 Perception time

Perception time was measured by *reaction time* and *visual distance*. The overall average of *reaction time* was M = 2,55(sec) (SD=1.52). An one-way ANOVA reveals that Size has a significant main effect on *reaction time*, F(2,267) = 22.55, p < .0001. Post hoc analyses using the paired t-test indicated that *reaction time* on large(M=1.87(sec), SD=0.44) was significantly shorter than on small(M=3.28(sec), SD=1.86), t(9)=4.6, p=.0012, and followed by on medium(M=2.51(sec), SD=1.52),t(9)=2.27, p=.048. The participants also reacted significantly quicker to medium than to small, t(9)=4.09, p=.0027. On the other hands, the main effect of Contrast Level on *reaction time* was not statistically significant,F(2, 267)=1.11, p=.3307. and the interaction was also not significant, F(4, 261), p=.056. Overall results are described in Figure 3.3.

The global average of *reaction time* is 2,55(sec) (SD=1.52). One-way ANOVA reveals that Size has siginificant effect on *reaction time*, F(2,267) = 22.55, p < .0001.

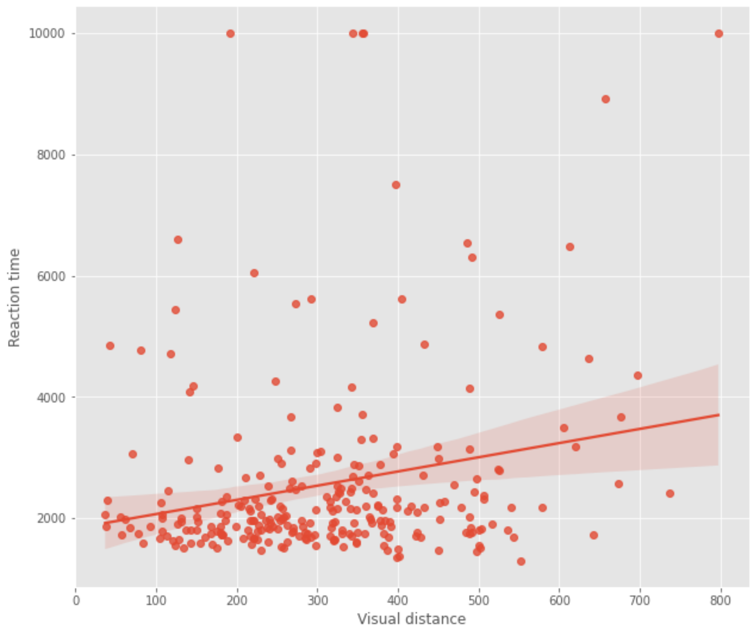


Figure 3.4: Scatter plot depicting Pearson's correlation between *reaction time* and *visual distance* which represents the distance between the notifications and user's gaze point. r(8)= 0.22, p=.0002.

Reaction time and *visual distance* were moderately positively correlated, Pearson's r(8)= 0.22, p=.0002.

A Pearson correlation coefficient was calculated to assess the linear correlation between *reaction time* and *visual distance*. The result shows that there is moderate positive correlation between two variables as shown in Figure 3.4, r(8)= 0.22, p=.0002.

3.3.2 Visual Perception

Participants evaluated, in general, that the small-size notifications were less distractive to the primary task.

Distraction of notifications – The item for perceived distraction of the notifications was designed to identify the effect of visual factors on users' perceived distraction to the primary task. To analyze participants' responses, the Likert scales were coded from 5: "totally disagree" to 1: "totally agree" since the lower score means a lower distraction level. The median responses to the different levels of SIZE were small: 1, medium: 2, large: 4. As shown in Figure 3.5, most participants indicated strong agreements on

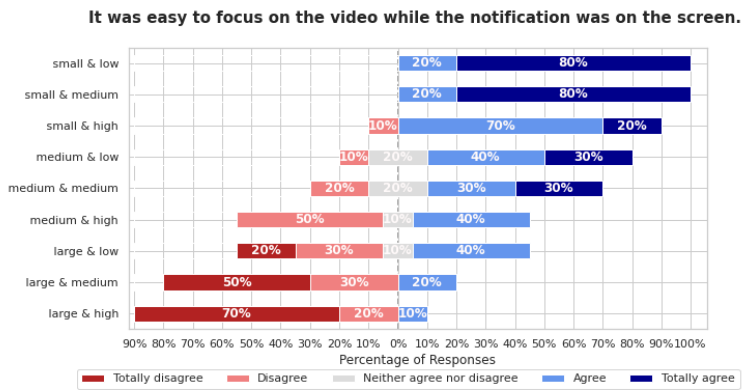


Figure 3.5: The results of perceived *distraction*: percentage of 5-point Likert scale responses(totally disagree to totally agree) for the question about low level of distraction on the primary task depending on the notification styles. The y-axis describes the notification styles consisting of the combination of SIZE & Contrast Level.

which it was easy to focus on the primary task while the small-sized notifications were on the screen in contrast to the large-sized notifications.

Regarding CONTRAST LEVEL, the median of each level(low, medium, high) were respectively 2, 2, 3.5. The plot shows that the participants did not indicate a specific tendency in their perceptions of distraction based on Contrast Level. With the aspect of the notification styles (SIZE × CONTRAST LEVEL), the small-sized notifications with the low- and the medium contrast level were the most positively evaluated i.e. the least distractive.

CONTRAST LEVEL did not significantly influenced on user's perception of the visual distraction.

Noticeability of notifications – To analyze the results, the Likert scales were coded from 1: ”totally disagree” to 5: ”totally agree” to score participants' perceived noticeability of the notifications. The median responses to the different levels of SIZE were small: 2, medium: 4, large: 5. The distribution of responses (Figure 3.6) shows that, in general, the medium- and large-sized notifications were highly noticeable to users during the task. Regarding CONTRAST LEVEL, the medians of the responses for the different levels(low, medium, high) were respectively 4, 4 and 5 such that the

The notifications were more noticeable in the medium- and large sizes than in the small size. However, the results do not show any specific tendency for CONTRAST LEVEL.

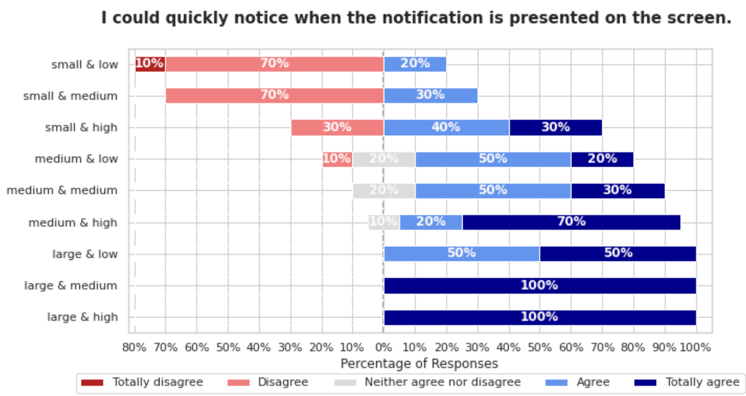


Figure 3.6: The results of percieved *noticeability*: percentage of 5-point Likert scale responses(totally disagree to totally agree) for perceived *noticeability of the notifications*. The y-axis describes the notification styles consisting of the combination of SIZE & Contrast Level.

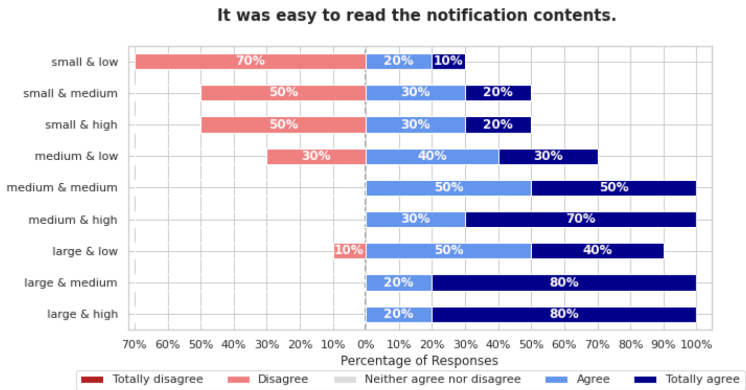


Figure 3.7: The results of preceived *legibility*: percentage of 5-point Likert scale responses(totally disagree to totally agree) for perceived *legibility of the notifications*. The y-axis describes the notification styles consisting of the combination of SIZE & Contrast Level.

visual manipulations using Contrast Level were not distinguishable to participants in terms of *noticeability*. Overall, perceived *noticeability* of notifications was higher on the medium- and large-sized notifications than the one in the small size.

Legibility of notifications – The median responses to *legibility* in terms of Size were small: 2, medium: 4.5, large: 5. Participants perceived that the contents of the notifications were easier to read for the medium- and larger-sized notifications than the small-sized one. On the other hands, the overview of responses (Figure 3.7) suggested that the variation of *Contrast Level* resulted in no-tendency for *legibility* of notifications(median - low: 4, medium: 4.5, high: 5). The participants, in general, read the notification contents easier when the notifications were bigger than the medium size.

In general, the legibility of the notification contents were positively evaluated in medium- and large size. Again, no tendency for CONTRAST LEVEL were found.

Preference on the notification designs – Participants ranked the notification designs used in the study according to SIZE and Contrast Level separately. To calculate scores of *preference* for each visual factor, rank scales were coded as 1(the best):3 - 3(the worst):1. For SIZE, 6 out of 10 participants responded that they preferred the small-sized notifications the most. They commented the reasons for ranking such that the small-sized notifications were not distractive to watch the video (e.g. "it didn't get my attention much which makes me comfortable to watch the video.", "the small ones blended in nicely with the video, so that we could continue watching the video"). The medium size was ranked in the second place by 7 participants out of 10. Participants noted, for example, "I fill familar with medium size that seems like normal notifications", "I like the normal size of notifications. The small size is too small, ... the large sizes occupy too much space on the screen.". In terms of Contrast Level, 6 participants among 10 ranked the medium level as the best since the medium level looked 'appropriate' as the notification design (e.g. "I think the medium level is appropriate for notifications.", "The medium level might have an appropriate level for color and brightness as a notification.", "The contents are readable and the notification doesn't distract me to watch video as well."). The overall results of the scoring are shown in Table 3.1.

6 participants ranked the small-sized notifications and the notifications with medium contrast level in the first place according to their preference respectively.

Manipulated visual factor		Score	The number of responses ranked to the best
SIZE	**small**	**24**	**6**
	medium	23	3
	large	13	1
CONTRAST LEVEL	low	19	3
	medium	**26**	**6**
	high	15	1

Table 3.1: Scores of responses for participants' *preferences* for visual manipulations of the notifications(SIZE, CONTRAST LEVEL and the number of responses ranked to the best.

3.4 Discussions

The results indicate the possibility of utilizing the user's gaze for the mobile notification design based on design purpose.

The results support the full visibility of the entire mobile screen illustrated in 3.1 by confirming the non-significant effect of notification's positions on *reaction time*. Moreover, *reaction time* and *visual distance* are significantly correlated. It implies that user's gaze can be utilized to design the mobile notifications for specific use cases in which the users' reaction time plays an important role.

The results of the significant effect of SIZE might be explained by the small size of the mobile screen. Besides the visual design, the animation effect of mobile notifications might influence users' visual perception.

The study also shows that the size of the notifications influence on the users' reactions and their visual perception. Understandably, the participants reacted most quickly to the large-sized notification since the mobile screen is relatively small and fully visible, the effect of Size on *reaction time* might therefore be remarkable. It means that the larger the notification is, the more area it occludes and visually stands out to the users. Nevertheless, the difference of *reaction time* between the large- and the small-sized notifications was, however, even less than 2 seconds. The overall *reaction time* was measured around 2 seconds on average and the variation of the notification styles (SIZE $\times$ CONTRAST LEVEL) did not influence on the user's reaction time same as the findings of [Mairena et al., 2019]. It might be explained by the embedded visual changes (in our case, sliding down from the bottom of the screen or sliding down from the top) in the line with the findings of [Tasse et al., 2016, Sigitov et al., 2016], but for the mobile environments in our study. Especially, dynamic visual stimuli (e.g. motion, flashing) has constant accuracy across visual angles [Gutwin et al., 2017]. Therefore, the presentations of the notifications might draw users' visual attention besides the appearance of the notifications. The animation effects could be one crucial factor influencing user's reaction within the entire visual area of the mobile screen.

By reducing the size, the notifications can be perceived as less disruptive as well as enough noticeable supported by animation effects. To relay information, the medium size involving sufficient texts and the impression of familiarity might be considered as one design option.

The participants preferred the small size of the notification even though they reacted to it after the longest time. According to the participants' comments, the small-sized notifications enabled them to focus on the primary task with less visual interference, and it was enough to 'notice' with the support of the animation effects. However, the informative characteristics of the notifications were still considered important to the participants since they argued about the worse legibility of the small-sized notifications. The contents' legibility of the medium- and the large-sized notifications were evaluated positively. However, users noted that the large-sized notifications occupied unnecessarily 'big' space on the screen and it occurred annoyances. Consequently, most of the participants evaluated the medium size better than the large size. This might be derived from the experience of the standard mobile notifications as clarified in the participants' comments. The participants are already familiar with the medium-sized notifications since it might be visually imprinted. The high legibility and the visual familiarity of the medium-sized notifications might be one design approach to enable users to accept them without any surprise or awkwardness.

Even though the results showed that CONTRAST LEVEL had no significant effect on the users' reaction and visual perception, participants still evaluated the medium as an 'appropriate' contrast level for designing the mobile notifications. The defined color and opacity for the medium contrast level could make the impression that the notifications were well blended in the background view so that people might visually feel natural to use the application. Therefore, the medium contrast level could be also considered for desinging the mobile notifications to evaluate the comprehensive users' perceptions.

Design implications carried out to the main study

Design implication 1: gaze-aware placement

- The placement of notifications can be determined by where the user is looking i.e. gaze-aware notifications - to evaluate if it enhances the use of mobile notifications by reducing the distraction level on the primary task.

Design implication 2: utilizing user's visual perception on SIZE, animation effect, and CONTRAST LEVEL of notifications.

- The notifications are visually manipulated based on the effect of SIZE and animation considering noticeability and legibility. Also, the medium level of contrast color, luminance and opacity is applied to the notificaion design to reflect participants' perception - to examine how user's visual perception works in the case of gaze-aware notifications.

Chapter 4

Gaze-aware notifications

4.1 Implementation

4.1.1 Gaze-aware notifications

The gaze-aware notifications were implemented by utilizing eye-tracking technology. The developed notification system tracked the area where the user is looking i.e. where the user is likely to interact (or not to interact). Based on this information, the placement of the notifications was determined by the current gaze point on the screen when the notifications were presented (or dismissed). As shown in Figure 4.1, if the user is looking at the upper half area of the screen, the notification will be presented from the bottom of the screen and vice versa.

The placement of gaze-aware notifications was determined by users' gaze i.e. the area they are likely to interact with.

In addition, the implemented notification system eliminates additional user inputs to dismiss the notifications. For example, the standard notifications require users to swipe it up if they want to dismiss the notifications. Without such inputs, the users have to wait a few seconds until the notifications are automatically dismissed by the system. To improve it, we utilized eye-tracking also for the dismissal of the notifications. Figure 4.2 shows how the automatic dismissal is triggered by utilizing the user's gaze information. People gaze at the notifications when they

The gaze-aware notification system triggered the automatic dismissal if the users gaze at the outside of the notification bound i.e. the users do not interact with the notification anymore.

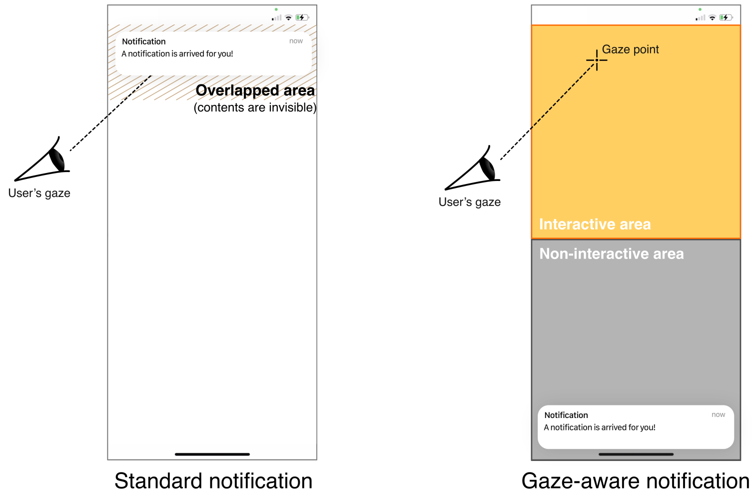


Figure 4.1: Comparison of the method of the notification placement between the standard notification(left) and the suggested gaze-aware notification(right) with the aspect of the user's gaze input. The gaze-aware notification system interpreted gazed area as the likely interactive area within a few second so that it aimed to improve the screen occlusion problems of the standard notifications.

read the contents of it, and then turn their gaze away from it to return to their primary task. Based on this behavior, once the users' gaze point enters the notification bounds and then moves away from the notification, the system interprets that the users want to perform the primary task and make the notifications disappear automatically. It can reduce the unnecessary user input and keep users continuing their job with less interference.

Gaze-aware notifications with visual manipulations

The notification design had two goals: (1) minimizing unwanted distraction and (2) effectively deliver information

The notifications were designed with the two aspects in terms of the research questions and the findings of the pre-study: (1) minimizing unwanted distraction by reducing the size of notifications and (2) strengthening informative characteristics of the notifications by giving an animation effect.

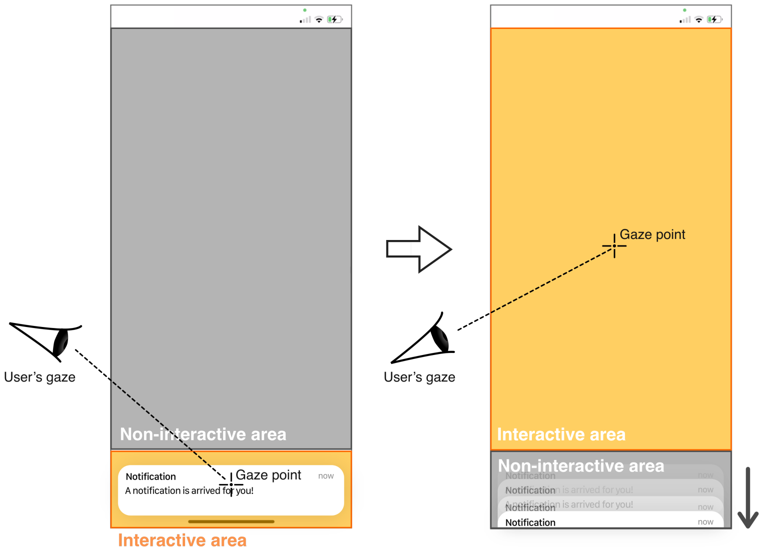


Figure 4.2: Automatic dismissal of the gaze-aware notifications; if the user gazes at the out of the notification bound i.e. the interaction area is away from the notification, the automatic dismissal is triggered without additional user input.

(1) Minimizing distraction

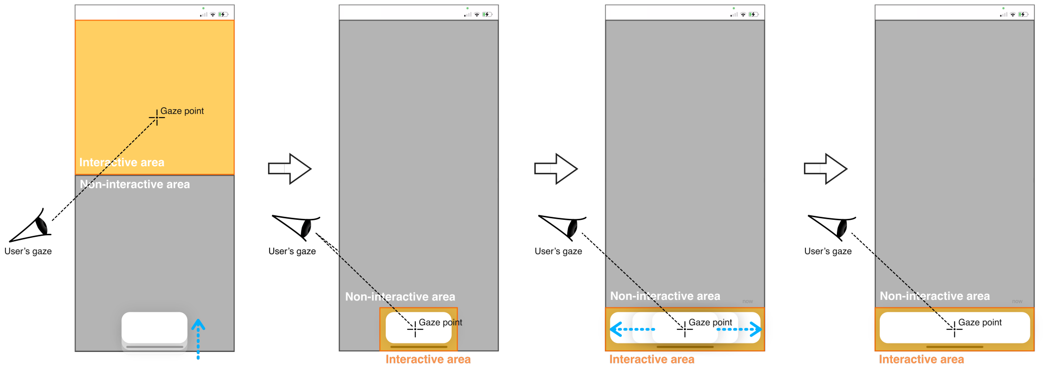
To reduce perceived disruption, the notifications were initially presented in the small size(23.21mm × 9.98mm) which was tested in the pre-study as shown in Figure 4.3(a). We found that the entire mobile screen is visible to the users as described in the 3.1 and therefore the small-sized notifications were sufficiently noticeable with the support of the animation effect according to the results of pre-study in 3.4. Also, it covered obviously less space of the screen than the standard notifications. Therefore, we expected that the users might feel less disruption while performing a primary task if the notifications are presented initially in the small size.

The size of the notifications was reduced at the presentation to achieve less occupation of the space and sufficient noticeability confirmed from the pre-study.

(2) Conveying information

The information delivery is the purpose of the notification system [McCrickard and Chewar, 2003]. People do not want to miss information conveyed through the notifications, therefore the notifications need to be attentive and legible enough to communicate with users. To fulfill these

To deliver information effectively, the notifications could be enlarged up to the medium size by the users' gaze input.



(a) Presentation initially in the small size

(b) User's gaze input to the notification

(c) Trigger the activation with enlarging animation

(d) The activated notification in the medium size

Figure 4.3: User interactions on the gaze-aware notifications with visual manipulations.

purposes, the notifications we present were designed with the following features:

Users' gaze at the notifications triggered the animation effect: enlargement the notifications from the small- to the medium size.

- Attentiveness: Enlarging animation effect
  As discussed in 3.4, the users reacted to the animation effect of the notifications. We likewise applied the animation effect not only for the presentation but also for the informative purpose to effectively grab users' attention. If the users notice a notification on the screen and gaze at the notification, the gaze-aware notifications interpreted it as an user input and triggered the enlarging animation to display the whole contents of the notifications i.e. the notifications is activated. Figure 4.3(b) and Figure 4.3(c) describe the interaction flow for the activation of the notifications.

The activated notifications by enlarging animation took the medium size to promise a sufficient level of legibility and to enable users to focus on the contents rather the visual design.

- Legibility: taking the medium size
  The enlarged notifications were taken the medium size(59.73mm × 9.98mm) similar to the standard iOS notifications as shown in Figure 4.3(d). Once the notification is enlarged, it should have only the purpose of conveying information. In other words, the visual design of notifications should not distract people to focus on the contents. In the pre-study revealed that participants evaluated that the medium-sized notifications were as legible as the one in the large size so that it was enough to understand the notification contents. Moreover, they felt that the medium size

was visually familiar. We expected to support users to naturally focus on the the notification's contents based on their embodied experience on the standard mobile notifications. To keep the size of notifications without ellipsis of contents, the length of the entire contents was limited to 60 characters to fit into the medium size.

4.2 Evaluation

We conducted a user study to examine how the users perceived the gaze-aware notifications that are described in 4.1 compared to other design options while they performed a primary task. We collected feedback from the participants through the follow-up survey. They responded to the questionnaires for identifying users' perception of attention to the primary task, visual distraction of the presented notifications, and subjective preferences on the given notification designs. At the end of the survey, the participants were asked to answer several open-ended questions to understand users' comprehensive impression of the gaze-aware notifications.

A user study was conducted to collect users' subjective perceptions for the suggested gaze-aware notifications in terms of usability of the mobile applications.

4.2.1 Prototype application

The basic structure of the prototype application was the same as the app used in the pre-study. As described in Figure 4.4, it consisted of the three layers: the lowest layer for eye tracking, the layer for the primary task in the middle, and the highest layer for presenting implemented notifications. The eye-tracking layer was developed same as the prototype app for the pre-study. Since the primary task was fixed to the portrait orientation, the coordinates of the gaze point on the screen were recalculated corresponding to the orientation. The primary task was performing drawing using the prototype app to test the responses to the notifications in the situation reflecting the real use cases such as using the apps which demand the explicit inputs such as

The prototype app used in the study consisted of the eye-tracking layer, the embedded drawing app for the primary task, and the uppermost layer for presenting the notifications.

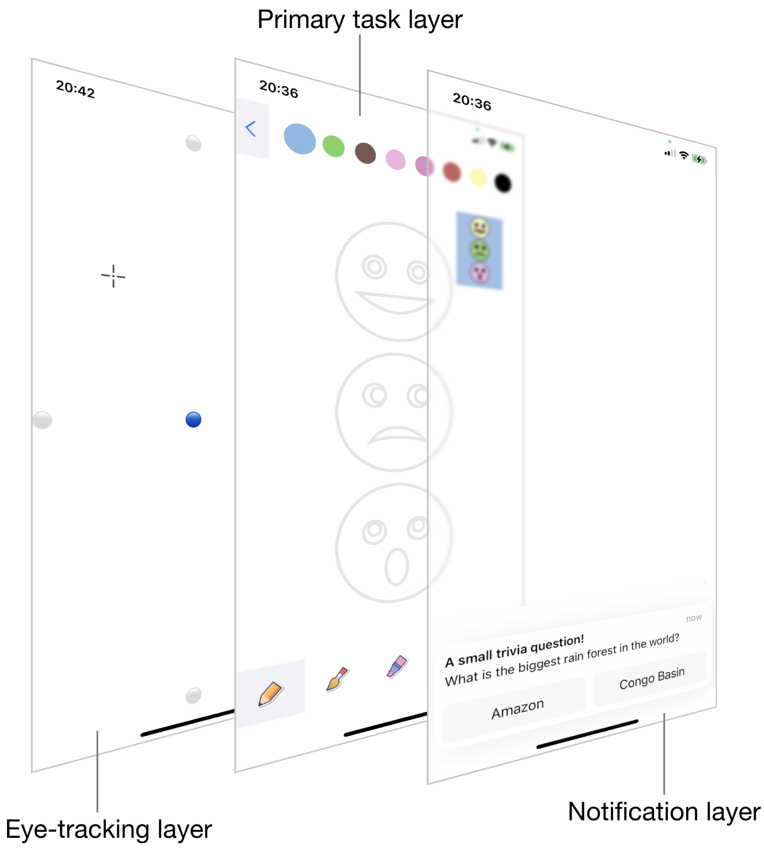


Figure 4.4: Structure of the prototype application used in the study

tapping or dragging whereas the pre-study tested only the case of consuming the contents i.e. watching videos rather 'interacting' with the app. We provided some templates to draw at the background of the canvas so that it encouraged users to keep continue to interact with the app during the study. To examine the improvement of the occlusion problems of the standard notifications, the candidate area for displaying the notifications covered user's interaction area for drawing as much as possible. For example, a color palette and a toolbar were located at the top and bottom of the screen respectively where the notifications will slide down or up.

While performing the drawing task, the notifications were presented with two types of contents. The one was the quiz notifications containing a question and two option buttons to answer it. It simulated the use cases of the notifications which required an user action such as for the messaging apps or context menus. Unless the users tap one of the buttons, it continuously stayed on the screen. The other 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.

The notifications presented in the study contentwise varied as the quiz notifications and the solution notifications. They represented the notifications with- and without an action respectively.

In terms of the placements and visual designs, the notifications were varied by four conditions: STANDARD, NOT WHERE WE TOUCH, GAZE-AWARE PLACEMENT, GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATION.

STANDARD

As the baseline, the standard notifications were always presented from the top of the screen and has white background color with black font color similar to the standard iOS notifications as shown in Figure 4.5. The users could dismiss the solution notification using a swipe gesture same as the standard iOS notifications. If the users do not react to the notifications, they will disappear automatically after 10 seconds.

STANDARD: the baseline condition with default iOS notification design and presentation always from the top of the screen.

NOT WHERE WE TOUCH

In this condition, the appearance of the notifications (Figure 4.5) and the interaction for the dismissal were same as the standard notifications. Since the tap gesture is one of most frequent interactions while using the smartphone, we set up NOT WHERE WE TOUCH as one design option to compare the usefulness between tap information and gaze information. The notifications of the condition NOT WHERE

NOT WHERE WE TOUCH: the placement of notification based on the user's last touchpoint on the screen.

WE TOUCH were presented based on the user's last touchpoint on the screen. If the last touchpoint was in the top half area of the screen, the notification was sliding up from the bottom of the screen and vice versa.

GAZE-AWARE PLACEMENT

GAZE-AWARE PLACEMENT: the placement of notifications based on the user's gaze point i.e. the current interaction area.

As described in 4.1, the placement of notification was determined by where the user is looking (Figure 4.1). The dismissal of the notifications was triggered by returning user's gaze to the primary task away from the notifications(Figure 4.2). To test only the effect of gaze-aware placement in this condition, the visual design of gaze-aware notifications was designed the same as the standard notifications (Figure 4.5).

GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATION

GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATION: the users' visual perception resulted from the pre-study was applied to the gaze-aware notifications

As elaborated in 4.1.1, the notifications for the condition GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATION involved the visual change according to the use's gaze input and the application of the medium contrast level based on the results from the pre-study. Figure 4.6 depicts the activation of the notifications with the enlarging animation. The height of the quiz notifications was additionally modified to include two buttons below since it was designed to cover the case of the notifications requiring an user action. To apply the users' perception of the medium-sized notifications, the height of the notification's content view was limited to the height of the medium size(9.98mm). To sum up, the height of the quiz notifications was responsive to the length of its contents, but it could not be longer than 9.98mm. The logics for the presentation and the dismissal of the notifications were equally set to the condition GAZE-AWARE PLACEMENT.

Ten notifications were presented for each condition during five minutes. After a quiz notification disappeared, we provided 10 seconds of time interval before the next solution notification to enable users to return and perform the primary task with sufficient time. Two notification sets (each

Figure 4.5: Examples of visual design for the notifications presented in the study conditions Standard, Not where we touch, and Gaze-aware placement: a quiz notification(left) and a solution notification(right).

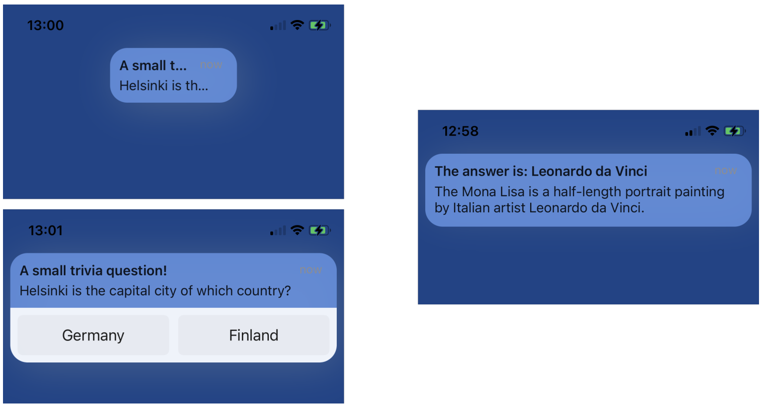


Figure 4.6: Examples of visual design for the notifications presented in the study for the condition Gaze-aware placement with visual manipulation: a quiz notification in initial presentation(left upper), a quiz notification after activation by user's gaze input(left below), and a solution notification(right).

set consisted of a quiz- and a solution notification) had random intervals between 15-30 seconds. At the beginning of each study condition, the app showed an alert with a short explanation about how the notifications will be placed in the current condition and how the users can react to the notifications under the condition.

4.2.2 Participants

Ten participants were recruited with the age group from the 20s to 30s: 5 students, 2 software engineers, 1 cellist, 1 graphic designer, and 1 research assistant. Three of them were males. All participants have never used an eye-tracking system before, and use smartphones every day.

4.2.3 Task and procedure

After the calibration step as the first step, the participants performed the drawing task as the main task.

At the beginning of the study, the instructor introduced briefly the purpose and the procedure of the study and asked about the agreements of the participation. The participants took a comfortable position to use the given smartphone and held it in the portrait orientation. The instructor asked participants to keep their posture as constant as possible during the study for eye tracking. To adapt the usage posture, the participants started the calibration for eye-tracking. It was the same process like the one in the pre-study 3.2.5. After the calibration step, they opened the drawing app and started drawing as the primary task using a template in the given drawing templates.

While performing the primary task, the participants were asked to react to the notifications with the four conditions. After the experiment, they filled out the follow-up survey to give their subjective perceptions of the gaze-aware notifications.

While they did the primary task, and the notifications were presented with the four conditions. Before the first notification of every condition, the app notified the users about the current condition through a short explanation. The instructor explained additionally how the notifications will be presented and activated, and how the participants could interact with them. For the quiz notifications, the participants were asked to respond to them by tapping a button. After all notifications with the four study conditions were presented, the app informed the end of the study with the score that the users earned during the study by reacting to the quiz notifications. The participants then filled out the follow-up survey to evaluate the gaze-aware notifications. The average time for completing the survey was 10 minutes and the study took around 30-40 minutes in total.

4.2.4 Experimental design

The study included:
4 conditions ×
10 notifications per condition ×
10 participants
= 400 trials

A within-subject study was conducted with the four conditions: Standard, Not where we touch, Gaze-aware placement, Gaze-aware placement with visual manipulation. For each condition, the participants received five quiz- and five solution notifications. Each quiz- and the corresponding solution notification were presented in a row. The order of the conditions was randomized for every participants. In total, the study included: 4 notification conditions × 10 notifications per condition × 10 participants = 400 trials.

4.3 Feedback

4.3.1 User's perception of the gaze-aware notifications

The survey consisted of three sections (Table 4.1): Attention to the primary task, visual distraction of the presented notifications during the study, and subjective preferences for those notification designs.

Users' perception of the gaze-aware notifications
Attention to the primary task (5-point Likert scale: totally disagree - totally agree) - "I could easily pay attention to the drawing task again after reading or checking notifications." - "I could easily keep paying attention to the drawing while the notification was presented on the screen."
Disruption of the primary task (5-point Likert scale: totally disagree - totally agree) - "The notification rarely covered the area where we had interactions." - "It was easy to focus on the drawing task with the notification visual design."
Preference on the notification designs (1: best - 4: worst) - rank Standard, Not where we touch, Gaze-aware, Gaze-aware visual manipulation - (open-ended question) "Why did you as above?"
Comprehensive impression of the gaze-aware notifications
(open-ended question) "What was your impression of the gaze-aware notifications?"
(Yes/No/Maybe/Other...)"Are you willing to use gaze-aware notifications in your daily life?", "Why?"
(open-ended question) "What could be the typical use cases in which the standard notifications from the top are destructive?"
(multiple selections) "The gaze-aware notification should be comfortable for ..." - lifestyle apps (e.g. Fitness, Music, ...) - games/Entertainment (e.g. Youtube, ...) - social media (e.g. What's app, telegram, ...) - productivity apps (e.g. Docs, Evernote, Books, ...) - news/Information apps (e.g. Google News, Weather app, ...) - photo apps - others

Table 4.1: The Questionnaire used in the follow-up survey to collect users' feedback for the gaze-aware notifications

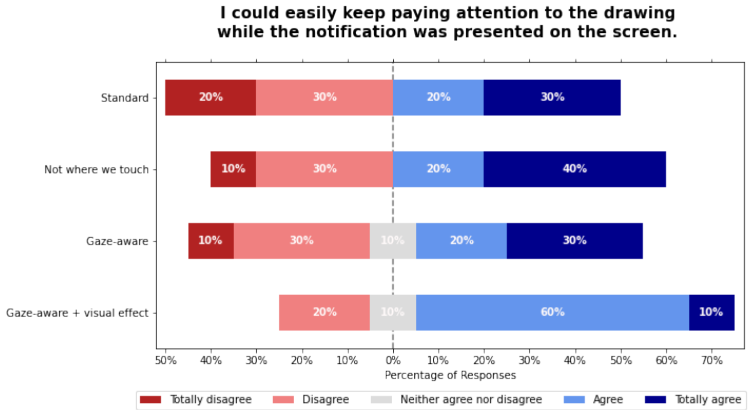


Figure 4.7: Participants' responses to perceived attention to the primary task **while** the notifications were on the mobile screen: percentage of 5-point Likert scale responses(totally disagree to totally agree). The y-axis describes different notification designs presented in the study.

Attention to the primary task in terms of perceived distraction was evaluated similarly across all conditions.

Attention to the primary task – The first section was about users' perceived attention to the primary task while the notifications were on the screen and after users checked the notifications. The items for this section represented perceived distraction of the notifications in the middle of the ongoing task and perceived workload to return to the primary task after the interruption. Participants responded on a value on the 5-point Likert scale (Totally disagree: 1, Disagree: 2, Neither agree nor disagree: 3, Agree: 4, Totally agree: 5). The participants perceived attention to the primary task while the notifications were on the screen similarly across the four conditions (median: STANDARD=3, NOT WHERE WE TOUCH=4, GAZE-AWARE PLACEMENT=3.5, GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS=4) as shown in Figure 4.7. For the item about attention to the primary task after checking the notifications, the results do not show any differences among the four study conditions. The median of every condition were 5 (totally agree) (Figure 4.8).

Visual distraction of notifications – Participants reported the perceived visual distraction of the notifications to the two items on the 5-point Likert scale (Totally disagree: 1,

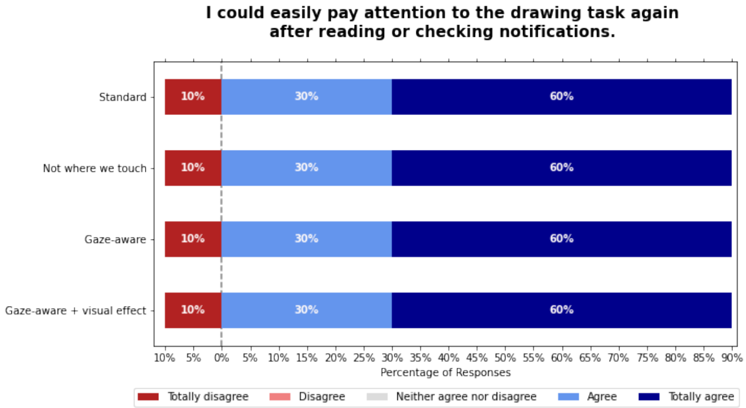


Figure 4.8: The results of perceived attention to the primary task **after** the notifications disappeared: percentage of 5-point Likert scale responses(totally disagree to totally agree). The y-axis describes different notification designs presented in the study.

Disagree: 2, Neither agree nor disagree: 3, Agree: 4, Totally agree: 5). The item "The notification rarely covered the area where we had interactions" implies the improvement of the visual distraction in each notification design. The participants assessed that the gaze-aware placement less likely occluded the interaction area on the screen as shown in Figure 4.9(median: STANDARD=2.5, NOT WHERE WE TOUCH=2, GAZE-AWARE PLACEMENT=5, GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS=5). Particularly, 8 of 10 participants responded to GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS with "totally agree" for the perceived freedom of occlusion. Among the conditions, more than 50% of participants evaluated that the notifications in the condition NOT WHERE WE TOUCH often covered the interaction area of the primary task.

In terms of occlusion of interaction area, participants perceived visually two conditions using gaze-aware placement as least distractive whereas NOT WHERE WE TOUCH as most distractive.

Figure 4.10 depicts users' visual perception of the visual designs. 8 out of 10 participants evaluated that the notifications in the condition GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATIONS did not visually distractive besides the primary task. However, the median of the responses is slightly higher than other conditions: STANDARD=3.0, NOT

The result of distractiveness of the visual design itself did not indicate big differences between the four study conditions.

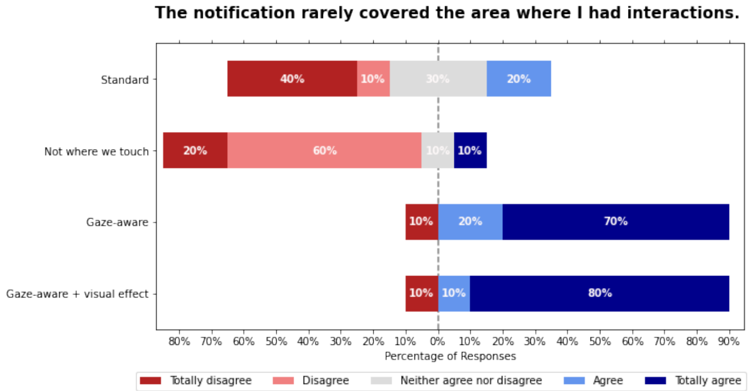


Figure 4.9: Participants' perception against visual occlusion of the primary task: percentage of 5-point Likert scale responses(totally disagree to totally agree). The y-axis describes different notification designs presented in the study.

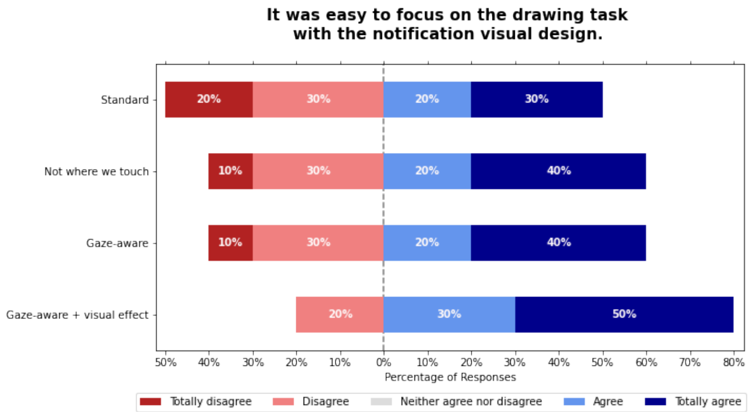


Figure 4.10: The distributions of participants' agreements for freedom of visual distraction derived from the notification designs: percentage of 5-point Likert scale responses(totally disagree to totally agree). The y-axis describes different notification designs presented in the study.

WHERE WE TOUCH=4.0, GAZE-AWARE=4.0, GAZE-AWARE NOTIFICATIONS WITH VISUAL MANIPULATIONS=4.5.

Preference on the notification designs – The participants were asked to rank the four notification designs used in the study according to their preferences on a scale of best=1 to worst=4 and to give comments about the reasons for their choice. To sort participants' preferences, we encoded the best to the score of 4 and the worst to the score of 1. The accumulated scores are shown in Table 4.2.

The result shows that 7 out of 10 participants assessed GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATION as the best design and the overall score is 32 which is the highest score among the four conditions. Participants' comments indicated that the notifications of the condition GAZE-AWARE NOTIFICATIONS WITH VISUAL MANIPULATIONS were visually least distractive so that participants could keep paying attention to the primary task without perceptible interruption. Regarding the effect of the visual manipulations on perceived distraction, they reported, for example, *"The small size of notification did not disrupt my work at all."*, *"It had a similar color to the background what we drew, so we could easily focus on the drawing task without any noticeable distraction."* and *"The small size of notifications were not opened until we looked at it. Therefore, we could see the screen without any distractions(covering) and it made me keep paying attention to the drawing task."*. One participant mentioned *"The short version of the information in the small size notifications were enough to decide whether we need to pay attention to the notification or not."*. GAZE-AWARE PLACEMENT without visual effects was ranked as the second most preferred design after the one with visual effects. Although the condition did not receive the best score from all participants, 9 out of 10 participants selected the design as the second preferred design. Participants commented: *"Gaze-aware notifications were comfortable because it could detect my gazing and then the notifications avoid where we want to interact with"*, *"The gaze-aware notifications were itself really helpful to focus on the primary works"* and *"I really liked the notifications were disappeared automatically if we saw another parts of the screen. I didn't have to move my finger to close the notifications and therefore we could keep going drawing task."*.

According to users' subjective preference, GAZE-AWARE PLACEMENT WITH VISUAL MANIPULATION was ranked as the best notification design, followed by GAZE-AWARE PLACEMENT, STANDARD, NOT WHERE WE TOUCH.

In contrast, 6 out of 10 participants rated the condition NOT WHERE WE TOUCH as the worst notification design as shown in Figure 4.11. The accumulated score for NOT WHERE WE TOUCH is the lowest value among the four designs (Table 4.2). Five comments addressed the problem

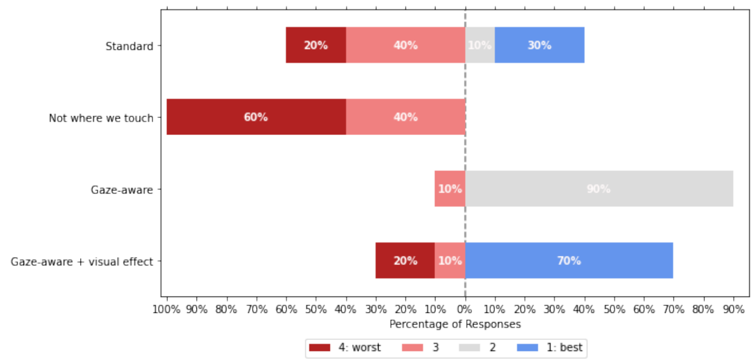


Figure 4.11: Participants' responses for the preference on the different notification designs: percentage of ranking scale(4: the worst design to 1: the best design). The y-axis describes different notification designs presented in the study.

of visual occlusion from the condition NOT WHERE WE TOUCH. Such comments include *"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 *"Not where we touch covered many times the color palette. It was very annoying that notifications were covered just before we tried to select a different color."*.

Regarding STANDARD condition, 50% of responses indicated the visual- and behavioral familiarity of the notifications e.g. *"I'm used to the standard notifications, so we could easily accept them."*.

Notification design approach	Score	The number of responses ranked as the best
Standard	25	3
Not where we touch	14	0
Gaze-aware placement	29	0
Gaze-aware placement + visual manipulations	**32**	**7**

Table 4.2: Scores of responses for participants' *preferences* for the different notification design approaches presented in the study and the number of responses ranked to the best

4.3.2 Comprehensive impression of the gaze-aware notifications

General impression of the gaze-aware notifications

In terms of usability, 8 out of 10 participants perceived the gaze-aware notifications as useful based on the low level of perceived distraction. The comments, for example, *"I have never felt I was distracted from the gaze-aware notifications"*, *"It was very useful."*, *"It is very useful specifically for the dismissal"*. Two respondents reported that the time to be accustomed to the gaze-aware notifications should be needed (e.g. *"If I am getting familiar with it, then I will put the gaze-aware notification on the first place in the ranking"*). One participant argued about the privacy problem since she felt that she was continuously monitored through the camera.

Low level of perceived distraction was the dominant impression of the gaze-aware notifications.

Willingness to use the gaze-aware notifications

Participants gave feedback to a Yes/No/Maby/Other question asking about the willingness to use the gaze-aware notifications with comments. Out of 10 participants, 5 participants responded 'Yes' with the reasons for usefulness. They phrased in the open-ended question *"Especially the visual effect should be very useful if I imagine using the real apps like watching video or driving."*, *"Visual effect should be very useful because I can save several steps to handle notifications, for example swiping to dismiss or tapping to read the contents..."* and *"If I can use it on my daily basis, it should be possible to avoid not intended opening other apps..."*. Three participants selected 'Maybe'. One of them expressed interest in the gaze-aware notification, however, she felt uncomfortable since the camera should be always turned on whenever the notification is about to be presented. Another participant personally does not prefer to turn on the notifications, but only for the important app, he would like to use the gaze-aware notifications. The other participant from the 'Maybe' group mentioned the learning curve of the new technology. However, he commented *"If I can easily accept it, I might use it."*. Two respondents to 'Other' conditionally wanted to use the gaze-aware notifications for the fol-

50% participants are willing to use the gaze-aware notification in daily life. The rest of the participants were doubtful but still considered possibilities to use.

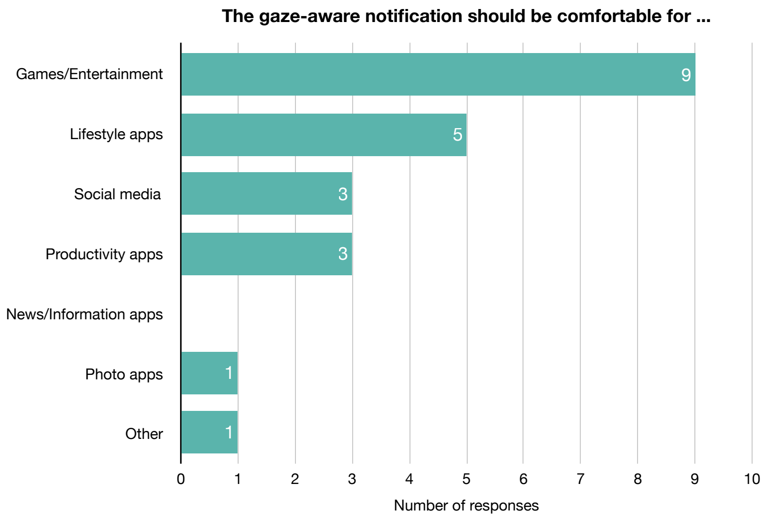


Figure 4.12: Participants' responses about the expected app categories for applications of the gaze-aware notifications(Multiple answers were possible.)

lowing reasons: improvement on the technical precision of eye-tracking, using only the dismissal interaction.

Effective applications of the gaze-aware notifications

'Game/Entertaining' was selected as the most effective application app category.

First, we asked about the typical use cases in which they felt disruptive because of the standard notifications. The responses include the keywords 'Game', 'Watching videos', 'Using toolbar', and 'accidental input'. According to the participants' comments, they frequently tap the notification which enforces them to switch to another app by mistake because of the sudden occlusion of the standard notifications. Specifically they mentioned the following moments of the accidental input: tapping back/close button on the navigation bar, iPhone's scroll-to-top gesture by tapping the status bar and entering input in the search bar of mobile web browser. Based on these responses, they selected the app categories in which the gaze-aware notifications might be comfortable. They could select multiple categories and the results are described in Figure 4.12.'Games/Entertainment' was chosen by 9 out of 10 participants and followed by 'Lifestyle apps' (5 participants), 'Social media' (3 participants), 'Productivity apps' (3 participants), 'Photo apps'(1 participant), and 'Other'(1 participant). One participant selected 'Other' suggested *'embedded apps in the car'* such that people do not need to move their hand to dismiss the notifications on the smartphone while driving.

4.4 Discussions

This chapter presents the proposal of the gaze-aware notifications as one design approach for mobile notifications involving the visual enhancements to achieve minimizing unwanted distraction and provide an appropriate level of awareness. We explored users' perception of the suggested gaze-aware notifications and their visual enhancements.

The gaze-aware notifications were perceived as less distractive and most preferred based on their occlusion-free placement.

The results show that the gaze-aware notifications derive lower perceived distraction than the standard notifications. The gaze-aware placement is less likely to occlude the screen, especially within the interaction area reported from users' feedback (e.g. *"I have never felt I was distracted from the gaze-aware notifications"*). On the other hand, participants reported negative aspects of perceived distraction to the placement of the notifications based on the user's last touchpoint. The dominant reasons were that the notifications utilizing the user's last touch frequently covered the interaction area. It can be explained from the literature that the gaze input is much faster than touch input [Lutteroth et al., 2015] and users' gaze provides fixation of target slightly before the touch input is generated [Weill-Tessier and Gellersen, 2017]. In other words, the user's gaze point is ahead for the next likely interaction point while the last touchpoint as in NOT WHERE WE TOUCH might represent the "past" interaction in the momentary view. In particular, in our study, the drawing task involved the interaction sequences '(1) finish the current touch - (2) look at the next color/tool - (3) touch(select) the next color/tool' when the users tried to change the current tool or color. Most of the users who evaluated NOT WHERE WE TOUCH was slower were in the case that the notifications covered the palette or the tool bar at the moment between (1) and (2). Thus, it could frequently happen that the notifications in the condition NOT WHERE WE TOUCH covered the interaction area at which the user's gaze point already reached while the last touchpoint did not. The interesting finding is that such conflicting evaluation of the gaze-aware placement to the last-touch-based placement continued to the users' subjective preferences on the notification designs with the similar results. From those correlations noted that participants might prioritize the aspects of the visual interruption and distraction derived from the notifications in the context of the multitasking behavior. This could also lead users' positive impression of the gaze-aware notifications regarding the usability during the use of mobile applications.

The straightforward interaction of the gaze-aware notifications reflecting users' intention can save the additional user input to handle the notifications and prevent input errors like tapping the notifications by mistake.

In addition, the positive evaluations on the gaze-aware notifications were attributed to the nature of the gaze input in addition to the lower distractiveness. By utilizing users' gaze to the mobile notifications, the indicative gaze-flows could naturally derive the intended interaction output such as the activation- and the dismissal of the notifications as reported by the participant(e.g. *"straightforward way"*). This natural interaction-intention continuity of the gaze-aware notifications might be a solution for the problems of unintended tapping of the standard notifications that many participants complained in the survey. Also, the gaze-aware notifications could save extra hand gestures to interact with the notifications, unlike the usual standard notifications. Participants phrased that *"I didn't have to move my finger to close the notifications"* and *"the gaze-aware notifications with visual effect should be very useful because I can save several steps to handle notifications, for example swiping to dismiss or tapping to read the contents."*. Such comments indicate that the additional gestures i.e. moving their hands away from the primary task to handle the notifications might be one of the perceived distractions along with the visual distractions. By providing promising interactions utilizing user's gaze, the gaze-aware notifications were evaluated as useful and convenient since it enabled users to return to the primary task quickly.

Regarding the visual enhancements, the major of the participants gave the common feedback about the small-sized notifications that were initially presented at the notification's arrival. The small-sized notifications covered the smaller area of the screen and therefore participants could perceive the gaze-aware notifications as less distractive. This result is the line with the findings from Klauck et al. [2017], but we confirmed it in the mobile settings. Of course, if we compare the small- and the default notifications (in our study, the medium-sized notifications) on the same plane, the small size might be less noticeable. However, we carried out the results of the pre-study i.e. the presenting animation might compensate users for the sufficient awareness of the arrivals of the notifications.

The visual manipulations on the visual change in size were positively perceived as less distractive and sufficiently noticeable to detect the notification arrivals.

Likewise, the users' feedback indicates that the visual manipulations of the suggested notifications do not harm the informational characteristics of the mobile notifications. For example, *"Especially the small size would be very useful for example I can notice only which app sends me the notification."*, and *"it was enough to give what kinds of information were about"* and *"The short version of the information in the small size notifications were totally enough to decide whether I need to pay attention to the notification or not."*. In means, the amount of information brought from the small-sized notifications was enough to understand the source of the notifications and it enables users to decide to accept it or not. Additionally, all participants finished the quizzes i.e. interacted with the notification contents without passingly answering the solution.

The visual manipulations could support users to decide whether to accept the notifications or not by conveying sufficient information.

In conclusion, the findings of this study about users' perception of the gaze-aware notifications and visual enhancements allude to the demanding applications of the smartphone usage. It might support users to focus on the primary task with a well-blended visual design without any recognizable distractions. For example, the apps that users consume the contents through the entire mobile screen such as games and streaming apps might be the opportune app categories to use the suggested gaze-aware notifications effectively. Such expectations were also observed in our two studies. The other possible applications of the gaze-aware notifications is preventing the visual occlusions by reflect-

The gaze-aware notifications with the visual enhancement can adapt effectively to various mobile usages such as games, streaming apps, or productivity apps.

ing users' intention. Most apps leave the top space of the mobile screen for a navigation bar or a toolbar, and the standard notifications necessarily block the interaction on it. As reported in the users' feedback, this issue might be the other place to adapt the gaze-aware notifications effectively to enhance the use of users' mobile interactions.

The key findings of this study are:

- Participants put high values on the notification design involving the low level of perceived visual disraction.
- The gaze-aware placement is perceived as useful based on the low level of perceived visual distraction and eliminating additional user inputs.
- The visual manipulations using size and animation improve the disruption of mobile notifications.
- The visual manipulations upon the gaze-aware placement do not harm the informational purpose of mobile notifications.

Chapter 5

Summary and future work

5.1 Summary and contributions

In this Master's thesis, we focused on how to design mobile notifications to enhance the use of mobile applications in terms of perceived distraction as well as the awareness of notifications. We explored users' visual perception of the mobile notifications in terms of visual factors such as size and color. Based on this, we proposed a new type of mobile notification design utilizing users' gaze — *Gaze-aware notifications* — and conducted a user study to investigate users' comprehensive impression of the gaze-aware notifications and its visual manipulations.

Key contribution 1: we conducted a study about the effect of visual factors (size, contrast level) on users' visual perception of mobile notifications.

As the baseline, I conducted a pre-study to understand the effect of visual factors such as size and contrast level on the reaction time, users' visual perception, and their preference. Participants perceived the small-sized notifications as least distractive despite the longer reaction time and the lower noticeability, and it resulted in higher preferences compared to other design options. Moreover, the presenting animation of notifications compensated users to notice the arrival of small-sized notifications sufficiently.

Key contribution 2: we propose the *Gaze-aware notifications* as a design approach to balance the unwanted visual distraction and sufficient level of awareness of mobile notifications

Based on the findings of users' visual perception, we developed the *gaze-aware notifications* involving visual enhancements. Tracking of the current user's gaze point represents the user's current intention so that users perceived the interaction flows of the gaze-aware notifications as natural and straightforward. Depending on where users is currently looking, the position of notifications and timing of dismissal are determined. For example, if users gaze the top area of the screen, the notifications are presented and placed at the bottom of the screen and it disappear when users return their gaze to the primary task. Upon it, the notifications react visually to the user's gaze. They are presented in the small size to minimize visual distraction and if users gaze point enter to the notification area, the enlarging animation is triggered i.e. the notifications are activated to deliver the contents to users.

Key contribution 3: we provide users' comprehensive evaluations for the *Gaze-aware notifications* by conducting a user study and confirm the possibilities to enhance the use of mobile applications in terms of research questions.

Overall, the results of users' evaluation indicate participants were overall satisfied with the gaze-aware notifications since they supported users to focus on the primary task with the low level of perceived distraction and minimum awareness guaranteed by the animation effect. Users' positive perception toward the proposed gaze-aware notifications can expectedly support the use of mobile applications in various contexts. In the line with users' feedback, the lower visual distraction might be utilized for the case in which users consume the contents displayed on the entire screen content such as games or streaming applications. In a more broad context, mobile applications could adapt the gaze-aware notifications to prevent blocking the interaction arising on the navigation bar or toolbar at the top area of the mobile screen. In conclusion, the key contribution of this thesis is the gaze-aware notifications we proposed to balance the unwanted visual distraction and sufficient level of awareness of mobile notifications. In addition, users' perception of the positive usability of the gaze-aware notifications can provide design suggestions to improve the current mobile notification design and extensively enhance the use of mobile applications.

5.2 Future work

For further improvements of the gaze-aware notifications, we suggest conducting a user study with a large number of participants and diverse participants in terms of, for example, age and field of study. We have several other suggestions to improve the reliance of the results as follows:

Suggestion 1: conducting a user study with diverse- and a large number of participants

Evaluation in a specific context of use
As shown in our results, the participants' perceived attention was similary reported in all conditions of our study such that they could easily keep paying attention to the primary task. It might be because the drawing task that the participants performed as the primary task was not complicated and did not require a high level of concentration. Accordingly, further study can be conducted to find an optimized use of the gaze-aware notifications with the different complexities of the primary task or the app categories. For example, a cooperative game could be a promising candidate as a primary task for discovering how the gaze-aware notifications enable users to communicate effectively without blocking visual- and contextual interactions.

Suggestion 2: exploring the usability of the gaze-aware notifications in more specific and complexed use cases

Conduting a longitudial study
The gaze-aware notifications can be improved by conducting a longitudinal study in a real-world context. Collecting users' feedback for a long time can figure out how we improve the design of the gaze-aware notifications to enable users to accept them more smoothly and easily in their daily use of mobile applications. Moreover, it could be additionally analyzed how users react to the gaze-aware notifications with the aspects of temporal usage patterns or personal relevances of notification contents. Based on it, we can confirm the possibility of personalized use of the gaze-aware notifications.

Suggestion 3: conducting a longitudinal study in a real-world context to understand the receptivity- and the possibility of personalized uses of the gaze-aware notifications

Overall, we can collect extensive users' perceptions of the gaze-aware notifications in various contexts of mobile usage. The subtle analysis of such evaluations can improve the receptivity- and the usability of the gaze-aware notifications for enhancing the use of mobile applications.

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