Investigating Privacy Perceptions and Subjective Acceptance of Eye Tracking on Handheld Mobile Devices

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Although eye tracking brings many benefits to users of mobile devices and developers of mobile applications, it poses significant privacy risks to both: the users of mobile devices, and the bystanders that surround users, are within the front-facing camera's field of view. Recent research demonstrates that tracking an individual's gaze reveals personal and sensitive information. This paper presents an investigation of the privacy perceptions and the subjective acceptance of users towards eye tracking on handheld mobile devices. In a four-phase user study (N=17), participants used a smartphone eye tracking app, were interviewed before and after viewing a video showing the amount of sensitive and personal data that could be derived from eye movements, and had their privacy concerns measured. Our findings 1) show factors that influence users' and bystanders' attitudes toward eye tracking on mobile devices such as the algorithms' transparency and the developers' credibility and 2) support designing mechanisms to allow for privacy-aware eye tracking solutions on mobile-devices.

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CCS Concepts: • **Security and privacy → Human and societal aspects of security and privacy**; • **Human-centered computing → Empirical studies in HCI**.

Additional Key Words and Phrases: Eye tracking, Privacy Concerns, Smartphones, Gaze-based Interaction

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1 INTRODUCTION

With the availability of mobile devices equipped with high resolution front-facing depth cameras and high performance processors, eye tracking is becoming more pervasive and increasingly available on mobile devices [18]. For example, the new generations of iPhones are equipped with 12 megapixels TrueDepth front-facing cameras that support high quality pictures [2] and the new Google Pixel smartphones support a field of view up to 97° [30]. This makes it increasingly possible to accurately track eye movements during everyday tasks using front-facing cameras. Although eye tracking on mobile devices brings a lot of opportunities, like understanding people through their gaze or allowing hands-free gaze-based interaction [32], it poses new risks to the privacy of both 1) its users and 2) bystanders. We define bystanders as people that are within the tracking range of

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the front-facing cameras of gaze-enabled mobile devices. It was found that a field of view of 90° on front-facing cameras is sufficient to capture a majority of the scene around a user [30], thus this impacts the privacy of bystanders within the tracking range and the field of view of the camera. While a mobile device may ask for users' consent to track their eye movements, oftentimes users are not aware of the privacy risk induced by sharing their gaze data. This problem is exacerbated with bystanders, as collecting consent from them is challenging [15], and current systems do not offer bystanders options for opting out [20].

Threats to privacy that are caused by eye tracking can be severe. Prior research showed that gaze data can be used to reveal sensitive and personal information [23] such as: personality traits [12], sexual interests [24] and even political affiliations [7]. In addition, eye tracking data collected from gaze aware devices provides a rich picture of the lifestyle of the users' demographics and personal preferences [35]. While prior work provided insights on privacy aspects of eye tracking [40], the subjective acceptance and privacy perceptions of both users and bystanders are still unclear. This paper presents an investigation of the privacy perceptions and subjective acceptance of users toward eye tracking on handheld mobile devices. We conducted a four-phase user study where the participants started by 1) using a mobile application that allows gaze-based interaction. Then, 2) they provided their feedback to the interview questions. Unlike previous work, 3) we raised participants' awareness of the privacy implications of gaze data by presenting them with a video showing the amount of sensitive and personal data that can be derived from eye movements. After that, feedback was collected again to study how their perceptions as users and bystanders changed. Finally, 4) we measured participants privacy concern score. Our findings show that users are interested in eye tracking features on mobile devices – some even despite the privacy concerns. In addition, the transparency, credibility of the developer, and the level of control given to users over their data contribute to their trust and make them more inclined to use eye tracking on mobile devices. While bystanders are positive towards eye tracking on mobile devices, they lack awareness of its privacy implications. Our qualitative insights identify factors that influence subjective acceptance and privacy uncertainties towards eye tracking on mobile devices. Our study addresses the following research questions:

- **RQ1** To what extent do users/ bystanders subjectively accept eye tracking on mobile devices?
- **RQ2** To what extent do users/ bystanders perceive the privacy implications of eye tracking on mobile devices?
- **RQ3** How does the awareness video impact the users/ bystanders subjective acceptance and privacy concerns of eye tracking on mobile devices?

The study results are useful for developers and researchers who wish to leverage eye tracking on mobile devices in a privacy-aware and subjectively acceptable way.

2 RELATED WORK

Our work builds on prior research on 1) eye tracking privacy implications, 2) users' and bystanders' privacy concerns and subjective acceptance, and 3) eye tracking and users' privacy protection.

2.1 Eye Tracking Privacy Implications for Users and Bystanders

Eye tracking has been an important method in Human Computer Interaction (HCI) studies [25, 26]. Eye tracking has been used in different application domains such as determining users' visual interest and activities [16, 36, 44], understanding users' cognitive processes [3, 8, 9, 37, 41] and allowing hands-free gaze-based interactions across different platforms [17, 27, 33, 38, 39]. With the availability of mobile devices equipped with high resolution front-facing depth cameras and high performance processors, eye tracking is becoming more pervasive. The widespread use of devices capable of eye tracking poses new risks to the privacy of both its users and those around them [23, 40]. In addition, surveillance cameras, outdoor billboards that are used for advertising, and ticket machines all put users' privacy at higher risk [35] as cameras can also be used to track the eye movements of passersby. Many personality aspects could be revealed from only eye movements. For example, previous work [12] reliably predicted four of the big five personality traits including an individual's level of neuroticism, extraversion, agreeableness, and conscientiousness, in addition to perceptual curiosity from only eye movements recorded during everyday tasks. Analyzing eye movement characteristics like pupil diameter, fixations, saccades, and blinks can be used to determine sexual interests [24], levels of user attention [14], and political temperament [7]. Eye vergence also showed potential use in detecting the internal thoughts of users [14]. Moreover, data collected from gaze-aware devices provide a rich picture of users' lifestyles, demographics, and personal preferences [35].

2.2 Users' and Bystanders' Privacy Concerns and Subjective Acceptance

The terms social acceptance and subjective acceptance are sometimes used interchangeably in HCI [19]. Previous research [22], presents a definition of social acceptance as the measure of perceptions and opinions towards technology due to influence through continuous exposure, media coverage, or greater societal, and cultural changes. In this work, we instead measure *individual subjective* perceptions of an emerging technology that is not yet ubiquitous enough to influence social acceptance. Hence, we use the term "subjective acceptance" to measure perceptions and opinions toward the use of eye tracking on handheld mobile devices. According to previous work by [21], context, situation, and usage intents were found to influence both users' and bystanders' privacy concerns and attitudes regarding head-mounted devices with integrated cameras. In an online survey ($N = 124$), Steil et al. showed that the majority of users agree to share their eye tracking data anonymously with research institutes and locally on their home cloud. Almost half of the users agreed to share their data anonymously with governmental health authorities. However, more than 60% disagreed with sharing their eye gaze data with public or private sectors or with companies [40]. Bystanders' privacy has been studied in different related domains, such as smart homes, drone surveillance, and Augmented Reality (AR) glasses. For example, Marky et al. contributed a detailed analysis of two roles in smart home ecosystems' privacy mental models (i.e., residents and visitors). According to their results, residents have a better understanding of the data collected about them and have fewer misunderstandings than visitors in smart home ecosystems. Furthermore, visitors' privacy mental models are distorted, preventing them from responding in a way that is consistent with their privacy demands and independent of their technical knowledge of the smart home ecosystem's data flow [29]. Moreover, Yao et al. investigated the privacy perceptions and design ideas of smart home bystanders. The authors conducted focus groups and co-design activities ($N = 18$) where they identified three impacting factors of bystanders' privacy perceptions and some design factors to mitigate their privacy concerns [42]. Bystanders' privacy has also been investigated in drone surveillance. For example, Yao et al. investigated how drone controllers and bystanders perceive different technology-based or policy-based privacy mechanisms for drones using a two-round survey [43]. They found that automatic face blurring received the most support from both controllers and bystanders. In the lifelogging and Augmented Reality (AR) fields, research has investigated bystander's privacy. For example, Denning et al. conducted field sessions in cafes and interviewed bystanders regarding their reactions to a co-located AR device. From their findings, they reported a set of design directions for privacy-mediating technologies [6]. From these findings, we can conclude that the privacy issues of bystanders are critical to be understood and addressed for any technology aimed to be used in the wild. Yet, as our literature review has revealed, no prior work investigated bystanders' concerns about using eye trackers on mobile devices.

2.3 Contribution over prior work

Prior work in eye tracking on mobile devices mostly focused on HCI applications, and few recent works proposed approaches to mitigate the risks to user privacy in eye tracking data. However, it is unclear how users perceive eye tracking on mobile devices in terms of privacy and subjective acceptance. We fill this gap by investigating the awareness level of users and bystanders toward eye gaze privacy issues on handheld mobile devices.

3 METHODOLOGY

This paper presents a four-phase user study to investigate the perceived privacy risks and subjective acceptance associated with eye tracking on mobile devices. A semi-structured interview was designed to build an understanding of users' concerns, preferences, and perceptions of gaze-based interaction on mobile devices. In step 1, we asked participants to use an eye tracking application on a smartphone. In step 2, we conducted interviews before presenting a video about the privacy implications of eye tracking data. In step 3, we interviewed participants after watching the said video. In the final step, we asked participants to fill in the Internet Users' Information Privacy Concerns (IUIPC) scale [28] which was used in the context of privacy concerns related to mobile developers.

3.1 Procedure & Materials

The user study was held on the university campus. Each participant was interviewed individually. The user study was conducted in English and lasted about 30-40 minutes.

Step 1: In the first step, the participants were asked to use the Hawkeye application which uses the TrueDepth camera on iPhone 12 to allow gaze interaction. The application supports browsing websites through eye movements. It works by looking at an icon or a link to highlight it, then selecting the icon by either smiling, blinking, or holding the gaze. We used the gaze interaction application because it allows participants to experience gaze interaction in real-time and understand how the system tracks their eyes. The Hawkeye application was selected for this study because it provides gaze interaction in an easy and smooth manner compared to other applications on the Apple store. The aim of using this application was to familiarize the participants with gaze-based interaction on mobile devices. The task was to select an icon using gaze, which takes about two minutes to complete. To perform the task successfully, the participants needed to look at the target and then either smile, blink, or hold their gaze. The participants tried all of the options and chose one to perform the task.

Step 2: In the second step, the participants were interviewed and asked questions related to the subjective acceptance and perceived privacy risks of eye tracking on mobile devices. Each participant had to answer the interview questions from a user perspective and a bystander perspective. The interview questions are available as supplementary material. Within the interviews, the participants were asked to indicate their subjective rating on a 5-point Likert scale with 1 representing extremely positive feelings and 5 representing extremely negative feelings, based on a pair of opposites that represent semantic differentials derived from a previous study [21]. In addition, we included three pairs of opposites that were derived from previous relevant work [21, 31]. The Pairs of semantic differentials used in the interview consist of the following positive and negative pairs: Stressed/Comfortable [31], Awkward [31] /Natural [31], Odd/Normal [31], Skeptic [21] /Outgoing [21], Threatened [21] /Safe [21] and Unsure [21] /Self-confident [21]. The semantic differentials are well-recognized and often used technique to measure emotional responses in psychology and HCI [21] and help to get more insights and comments from participants.

Step 3: In the third step, a short video demonstrating the privacy implications of eye tracking was presented to the participants. Some of the content of this video was derived from the work of Kröger et al. that reported on the sensitive and personal data that can be inferred from eye movements [23]. This was followed by repeating the interview questions to compare the differences in participants' privacy perception and subjective acceptance towards eye tracking on mobile devices. The step aims to investigate the impact of the awareness video on participants' privacy perception and subjective acceptance of eye tracking on mobile devices.

Step 4: In the final step, the participants provided their demographic data and filled in the IUIPC scale (7 points Likert scale anchored with 1 = strongly disagree and 7 = strongly agree) to determine the privacy concerns across participants. The IUIPC scale was derived from a previous study that developed a framework for analyzing the consumers' concerns about privacy threats on the Internet [28]. In our study, the scale was adapted for the context of privacy concerns related to mobile application developers. The results of the scale are in the supplementary materials.

3.2 Participants, Compensation and Recruitment

We advertised the study via mailing lists, social media, and word of mouth. Participants were compensated with a £5 Amazon voucher. Participants started by reading an information sheet and filling out a consent form. To minimize bias, the study was framed as "A study on the perception of gaze-based interaction", and we intentionally refrained from mentioning "privacy" and "subjective acceptance". We recruited 17 participants (10 males and 7 females). Participants ages varied between 35 and 20 ($Mean = 27$). The participants came from different educational backgrounds such as: podiatry, cognitive psychology, investment, electrical engineering, software engineering, and computer science. Four participants did not know anything about eye tracking before the study and 6 knew a little about eye tracking before the study e.g., heard of it, but never tried it. The remaining 7 used eye tracking before but were not experts in it e.g., they used it for gaming or for fun. None of the participants had experience with the Hawkeye application before the study.

3.3 Data analysis

The data collected from the user study was analyzed quantitatively and qualitatively.

3.3.1 Quantitative data. The rating responses of the interview questions were analyzed using Wilcoxon signed rank test as the data is non-parametric and not normally distributed. We analyzed the participants' responses based on two independent variables: 1) knowledge (i.e., before and after awareness about the privacy implications of eye tracking as shown in the video) and 2) role (i.e., whether the participant took the role of the user or the bystander) on the perception of eye tracking on mobile devices. We compared the results based on two conditions for each independent variable.

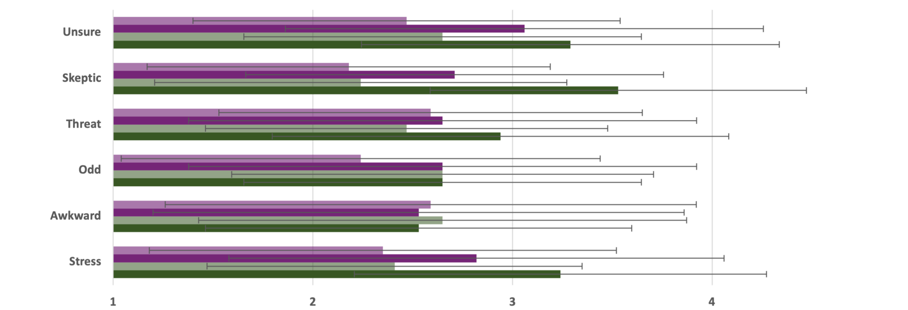
3.3.2 Qualitative data. The qualitative data resulting from the interviews were inductively analyzed using Braun and Clarke's thematic analysis technique [4], which allows for identifying patterns in qualitative data. We followed the six-phase process defined by Braun and Clarke for managing, coding the data, and developing the themes [5]. In the beginning, the lead author started with data familiarization by reading all the responses transcripts, paying attention to every idea and term mentioned, and checking for errors by comparing the recordings with the responses. Next, similar responses were coded then grouped into categories. The categories then were mapped to themes. Then, the specifics of the themes were refined. In the end, the codes and categories were discussed and verified with the co-authors. The codebook of the themes can be found in the supplementary materials.

4 RESULTS

In the following, we report on the study results. We first present the semantic differential analysis, then we reflect on users' responses before and after the awareness video.

4.1 Semantic Differential

This presents a quantitative interpretation of the rating responses collected during the interview about participants perceptions towards mobile eye tracking. Figure 1 visualises the mean values obtained from users and bystanders before and after the awareness video.



	Stress	Awkward	Odd	Threat	Skeptic	Unsure
Bystander before	2.35	2.59	2.24	2.59	2.18	2.47
Bystander after	2.82	2.53	2.65	2.65	2.71	3.06
User before	2.41	2.65	2.65	2.47	2.24	2.65
User after	3.24	2.53	2.65	2.94	3.53	3.29

Fig. 1. The figure visualizes the mean values obtained from the semantic differential for the users and bystanders (role) before and after the awareness video where 1 represents extremely positive feelings and 5 represents extremely negative feelings. Error bars show standard deviation.

Finding 1: Users who are aware of the privacy implications of eye tracking on mobile devices are more prone to feel stressed, skeptical, and unsure about the eye tracking feature. Further analysis was run to measure the impact of the awareness video on user responses of the semantic differential. Results revealed that showing the awareness video (knowledge) has a significant impact on user stress level about using gaze-based interaction on mobile devices using front facing cameras ($Z = -2,226; p = .026$) with effect size $r = .53$. Median of user stress score rating was 2.0 (1= extremely comfortable and relaxed, 5= Extremely stressed) pre-watching the video and 3 (neutral) post-watching the video. It was also shown that Knowledge significantly increased skepticism level about using gaze-based interaction on mobile devices using front facing cameras ($Z = -2.616; p = .009$) with effect size $r = .63$. Median of user skepticism score rating was 2.0 (1=extremely outgoing,5=extremely skeptic) pre-watching the video and 4 (skeptic) post-watching the video. Also, Knowledge has a significant impact on unsureness level about using gaze-based interaction on mobile devices using front facing cameras ($Z = -2.373; p = .018$) with effect size $r = .57$. Median of user unsureness score rating was 3.0 (1=extremely self-confident, 5= Extremely unsure) pre and post-watching the video. No statistical evidence of significance was found regarding the impact of the Knowledge on the threat, awkwardness, and oddness levels taking the role of users of gaze-based interaction on mobile devices.

Finding 2: Bystanders who are aware of eye tracking privacy issues are more prone to feel unsure about accepting to be in the range of the mobile camera capable of eye tracking. We found that Knowledge has a significant impact on the bystander's unsureness level about passing by a user of gaze-based interaction on a mobile device ($Z = -2.066; p = .039$) with effect size $r = .50$. Median of the bystander unsureness score rating was 2.0 (self-confident) pre-watching the video and 3 (neutral) post-watching the video. No statistically significant impact was found ($p > .05$) of the Knowledge on bystander's skepticism, threat, awkwardness, oddness, and stress levels. Figure 1 Shows the mean values obtained from the semantic differential for the user and bystander (role) before and after watching the awareness video.

Finding 3: Privacy-aware bystanders are skeptical about eye tracking on mobile devices. We found that the role (i.e., user vs bystander) has a significant impact on the skepticism level after watching the awareness video) ($Z = -2.810; p = .005$), with effect size $r = .68$. Median of user skepticism score rating was 4.0 (skeptic) post-watching the video and the bystander's was 3 (neutral) post-watching the video. This implies that in response to watching the video, the participant's role had an impact on skepticism levels, which rose more in the user role.

4.2 Participants' Views on Eye Tracking on Mobile Devices Prior to the awareness video

In this section, we report on a set of semi-structured one-to-one interviews on the use of gaze-based interaction on mobile devices. We provide an overview of the feedback from users and bystanders perspectives prior to the awareness video. We show the number of interviewees who mentioned a particular theme to indicate the proximate importance of each theme elicited from the coded responses.

4.2.1 Users' subjective Acceptance of Mobile's Eye Tracking. The inductive thematic analysis provided various aspects of subjective acceptance of the eye tracking feature on mobile devices from users' point of view, in particular, users' interest and preferences of mobiles' eye tracking.

Interesting type of interaction. Participants ($N = 12$) found that gaze-based interaction is an interesting new way of interaction. Their feedback implies that the use of eye tracking on mobile devices is perceived positively, especially for performing hands-free tasks. For instance [P10] *"it is very convenient or comfortable and very interesting idea[...]very easy, especially in the future we will not need to touch the screen a lot[...]it will be very interesting to use it"*. Users ($N = 9$) see the gaze-based interaction as a good way to free the hands **code: hands-free interaction**. [P01] notes: *"It definitely has its advantages[...]If you don't have a hand,[...]if you're holding[...]a child[...]I think it's great. It's an amazing way of using your phone."* and a handy way of interaction while cooking [P11]: *"like cooking[...]change a song[...]with your eyes"* or for reading [P14]: *"do some readings before sleeping[...]"* and supporting people with disabilities [P08] points out *"for people with certain[...]disabilities to help them to interact independently without the support of others and with ease"*. **code: ease of use** ($N = 6$) was additionally mentioned by users, for instance [P05] mentions: *"doesn't[...]need efforts to do so[...]easier because it follows my eye movement and directly choose the application"*. Related to this, some users indicated that gaze-based interaction does not differ from other types of interactions **code: similar to other types of interaction** ($N = 2$) *"I didn't really feel like it is different than any other way of interacting[...]in the end, it's still the same."*[P04], implying that users' prior experience with using touch input might be supporting the learnability of gaze input.

Preference over touch interaction. Participants' responses ($N = 2$) indicate that gaze-based interaction feels more natural and is preferred over the conventional touch interaction, [P09] states: *"it's actually more natural than touch in a way[...]feels very comfortable to use and very natural,[...]organic way to interact with your phone[...]much more natural than touch here."*. Responses additionally show that **code: adaptation to new technology** ($N = 2$) contributes to the subjective acceptance of gaze-based interactions as a natural way to interact with a device. [P15] *mentions: "it's a technology so everything gets accepted"* and the **code: technical background** of the user has an impact as noted by [P07] *"I'm a software engineer and can adapt to new technology."*. In contrast, a participant raised an issue of subjective acceptance in terms of worries of being **code: judged** by others: "I would be careful that I don't want to be judged by other people[...]if I'm in a social gathering, I wouldn't feel[...]confident using it because I would have the issue of social acceptability but if I'm in isolation and I'm confident in using it, then I don't mind having using it."[P08].

4.2.2 Users' Views on Technical Usage Issues. Next, we discuss insights into participants' views of usage issues of eye tracking on mobile devices.

Difficulty of control: Participants ($N = 7$) reported difficulty in the control using the gaze-based interaction, due to the eye's fast-moving nature as stated by [P02]: *"I felt it's[...]a bit hard because you still have to use your eyes too because the eyes by nature[...]it keeps on moving so to use it for* *selecting is quite difficult."* It was also indicated that gaze-based interaction is **code: slower than using fingers.** and not as **code: efficient** ($N = 2$) as using the hands for interaction.

Accuracy issues: It was quite common among responses that participants ($N = 10$) were worried about providing false input using the gaze-based interaction. [P01] notes: *"The only concern that I would have[...]the accuracy of the technology, like[...]where it was just exactly where I was looking was exactly where the thing was then I think it would get annoying to use".* An extra implication was spoken of as a problematic side effect of inaccurate gaze interaction to perform a sensitive task by mistake as mentioned by [P12] *"I guess from a user standpoint[...]Am I going to accidentally do something that I shouldn't do it. if that was something like a bank Interaction or something I wouldn't accidentally want to send someone money with an extra 0 or something."*

Eye fatigue: Participants ($N = 5$) expressed that gaze-based interaction can result in eye exhaustion as it requires more concentration and effort to control the device, [P13] mentions: *"Eye fatigue[...]because you're going to be like focused more on [...]choosing stuff on the screen rather than just like zone out or while you're watching or something"* and others highlighted that eye movement interaction might not be suitable for long tasks as hand interaction requires less effort to do it.[P08] mentions: *"we get tired a lot because[...]for every click we have to use the eye gaze, so I think it's going to be[...]more hectic for the eyes".*

Training: on the other hand, participants ($N = 6$) stated that gaze-based interaction requires learning how to use it in order to master control over it. [P02] highlights: *"because we usually use the eyes to see[...]so you use it for input[...]will need to learn how to use".*

Scalability: The scalability of gaze-based interaction to support different user groups such as visually impaired users, was also spoken of by one participant as a major technical problem to the technology of eye tracking. As mentioned by [P17]: *"I think for people who are visually impaired[...]I think that's going to be a challenge[...]in terms of the scalability[...]the number of applications[...]would depend on only people who can actually see".*

4.2.3 Users' Concerns about Eye Tracking . **code: Privacy** related concerns was noted over many responses ($N = 10$), even before showing the awareness video to participants. Users expressed their worries about **code: collecting personal data** out of eye movements ($N = 8$) that can be used for developing **code: targeted advertisements**. Additionally, it was mentioned that it is a bit threatening to feel that their **code: eyes are being watched**. In contrast, some users claim that they are **code: not concerned about privacy** ($N = 3$): *"I think[...]privacy doesn't really do much for me here[...]whether it's through face ID or[...]eye gaze interaction my data is just there"*[P09] and it is **code: safe** ($N = 3$) to use gaze-based interaction as no one can control the device other than the user: *"it's safe because[...] except if[...]someone from the back he used his eye movement[...]also controlled the application, but I would imagine the application would only work based on[...]my facial features"*[P03]. Other than privacy, participants expressed concerns over the ability of other users to control their devices by their eye movements, such as **code: security**, as stated by [P15]: *"someone can hack your phone, he can see or[...]use your eyes[data] for other actions"* . A few participants also highlighted a safety issue of using gaze-based interaction in some daily activities such as walking on the street or while driving. They mentioned that this will be **code: distracting** to the users: *"if someone is using[...]their device in order to control something on the street[...] it would be distracting"*[P06].

4.2.4 Users' Views on Trustworthiness. Participants expressed **code: credibility** ($N = 5$) and **code: transparency** ($N = 3$) of the developer as factors that contribute to their trustworthiness of the technology. They also mentioned trusting specific brands and being skeptical to others based on the developer's reputation. In addition, explaining what exactly is being collected and how the eye movement data are being used was spoken by participants as a factor that will boost their confidence of the eye tracking. **Code: reliability** and **code: accuracy** of the technology was also highlighted to contribute to user's trust. On the other hand, some participants expressed **code: same level of trust** ($N = 2$) towards eye tracking like any other type of technology due to previous experience with the technology or as a fact that every technology on mobile devices has advantages that overcomes the disadvantages: *"I will trust it[eye tracking] [...]every new technology[...]have like bright and dark side and most of the time the light side will affect more "*[P10].

4.2.5 Bystanders' Views on subjective acceptance. Participants expressed that **code: prevalence** ($N = 12$) is one factor that affects their feelings about seeing people around them using eye tracking on mobile devices. The more common the technology becomes the more normal, relaxed, and less awkward bystanders feel about the technology and vise versa: *"I think it's a cool technology, and[...]if more people use it[...]becomes[...]more normal"*. Participants highlighted that they will be **code: welcoming** ($N = 9$) the idea of seeing users around them using eye tracking: *"It's good to see the future happening now, like seeing other people use eye move interaction"[P15].* It was also expressed that eye movement interaction is not different from other interaction means as it is **code: similar** to the use of the hands or face ID: *"I don't see that there's a huge difference between using [...]their eyes and using [...]fingers[...]it's the same way where in touch ID was replaced with face ID[...]People just got used to it immediately"*[P09]. Some participants think that it is code: comfortable to see someone using eye tracking since it doesn't affect them as bystanders: *"will not be bothered by that as long as the[...]the one that controlled their device with the eye tracking in their own lane, so they will not intervene with my daily life tasks"*[P06].

Some participants think that the eye tracking feature on mobile devices using the front facing camera is **code: unnoticeable** ($N = 7$), therefore, they highlighted that there would be no issues about being around people using eye tracking as it seems like users are just looking at their phones: *I don't think I would realize[...]it's so subtle[...]it's just their eyes moving."*[P01]. Other participants think as a bystander, they would prefer the eye tracking for **code: security reasons** ($N = 2$) as stated by [P08]: *"it would be more secure [...]protects you from if someone is like trying to guess what you are typing[...]that would be a nice security mechanism"*. Interestingly, **code: relationship** ($N = 1$) of the eye tracking user to the bystander was found to have the bystander feel more skeptical about being in the range of the eye tracking user: *"If it's someone professional or someone from[...]university then[...]I won't be like skeptical about it, but if it's someone quite close to me, then I would be concerned why are they using eye gaze? are they trying to hide something or doing something secretive?"*[P08].

4.2.6 Bystanders' Concerns about Eye Tracking. Bystanders raised some concerns regarding the ability of **code: controlling users devices** ($N = 5$) behind their backs: *"I will not feel[...]very comfortable because [...]maybe my mother reading something and I'm passing and[...]if it's follow my eyes[...]I will destroy what she was watching"[P14].* Some bystanders think it is not preferred to use eye tracking in **code: public spaces** ($N = 2$) for privacy reasons: *"it is not good idea if we are in public places because maybe they can catch something from another people devices[...]it is good if you are in private space"*[P10]. On the other hand, it was found that participants are **code: unaware** ($N = 11$) about the possible privacy implications on bystanders' data that can be captured by the front facing camera: *"if I am the bystander, then I'll feel extremely safe[...]I don't see[...]how can this be threatening to me as a bystander"*[P03].

4.3 Participants' views on Eye tracking on mobile devices post to the awareness video

In this section, we report on a set of semi-structured one-to-one interviews on the use of gaze-based interaction on mobile devices after the awareness video.

4.3.1 Users' views on subjective acceptance, technical issues, and possible uses of eye tracking on mobile devices. Interestingly, participants expressed their acceptance towards the amount of data that can be captured by eye tracking technology after being presented with the awareness video.

They explained that collecting eye movements data is **code: beneficial** ($N = 5$) as such data would open the opportunity to potential enhancements to their daily activities, and they are willing to share their data for health tracking purposes: *"it's likely that I use it.I think[...]all this information[...]be gathered[...]from my eyes [...]collect this kind of data and present it to me[...]for example,[...]you didn't get enough sleep last night[...]you need to do more exercise etc[...]that would even give me a further motivation to use it"*[P09]. Responses additionally indicate that once the technology becomes more common, users will **code: adapt to it** and will not be bothered by collecting eye movements data ($N = 3$): *"the more people are using them[eye tracking] the more we forget about the data [...] are being collected[...]we'll have to adapt with that".*[P02]. Participants still expressed their **excitement** ($N = 3$) about the technology after knowing how much data can be derived from the eye movements because it is **code: useful to perform hand free tasks** ($N = 4$) and this might open lots of potential for interaction in the future: *"I am still excited about it[eye tracking][...] It could be much more powerful than,... what we think it is right now[...]the potential is huge..."*[P04]. Participants also think it is **code: easier** ($N = 3$) to control the applications on their phones using their eyes instead of hands which makes them more willing to use eye tracking: *"it's going to be a lot easier[...]if I can use my eyes [...]to control an app"*[P17]. We also observed from responses that the **code: pervasiveness** ($N = 8$) of collected data over the internet make participants still inclined to use eye tracking despite the privacy issues. They think that the **code: usability** and the **code: accuracy** ($N = 4$) of the eye tracking will have an impact on the decision to use the eye tracking feature or skip it: *"I was surprised by the amount of data you can gather just from a picture of the eye but I think I might be inclined to still use it regardless because I think this amount of data that can be collected [...]will be available[...]through other means such as your Facebook profile[...]I would not use it only if it was uncomfortable or not accurate."*[P03]. Once the technology becomes **code: common** ($N = 4$) participants reported that they will be more encouraged to use it as it is normal to **code: use biometrics** ($N = 2$) in technology and they don't think it has any difference from other kinds of interactions. In addition, **code: eye fatigue** ($N = 3$) was highlighted by users as a result of relying on eye movement interaction which they think that will cause exhaustion due to a multitude of interactions at the same time.

4.3.2 Users' concerns post the awareness video. Participants raised many concerns after being shown the awareness video. The majority of the responses showed concerns about the **code: privacy** ($N = 12$) because of the **code: collection of personal data** ($N = 15$) without prior consent and the possibility of misusing these data: *"the amount of data makes me feel threatened, because [...]a lot of information can be[...]interpreted from the data that can be extracted from the eye"*[P06]. Although the raised concerns, participants think they would still be interested in the technology but will use it **code: cautiously** ($N = 3$). On the other hand, one participant stressed that **code: privacy is not a priority** these days: *"I just don't feel that privacy is a particular priority for me"*[P09], and thinks that the **code: distraction** caused by the use of eye tracking feature on mobile devices is more important aspect to worry about: *"again if I'm walking in a mall[...]or in the street I'd worry that they'd crashing to me because they're paying attention to their phones."*[P09].

4.3.3 Users' views on trustworthiness post the awareness video. Post the awareness video it was commonly expressed by participants that **code: transparency** ($N = 17$) and **code: credibility** ($N = 7$) of the developer is an essential factor contributing to enhance the trust of the eye tracking feature. Participants highlighted that they would trust some companies more than others. Also, the eye tracking feature providers must be clear about what data is being collected and how these data are being used. Additionally, responses addressed the need to provide a clear coherent privacy policy about how the data are being dealt with: *"I think there would need to be a way of showing what exactly is happening with this data?[...]"*[P01]. Responses also showed that providing a **code: privacy protection mechanism** ($N = 3$) will even enhance the trust of the eye tracking feature.

All of this was spoken by participants to make them feel less stressed and more safe about using eye tracking. Moreover, the **code: control over the data** was raised as a prerequisite feature that needs to exist before having the users decide about using the eye tracking feature: *"It would be great if I could[...]delete it[eye data] forever, not[...] only from my device, but it's saved on a remote[...]something."*[P13].

4.3.4 Bystanders' views on subjective acceptance post the awareness video. The majority of participants were **code: unaware** ($N = 15$) of the possible privacy implications of eye tracking through the front facing camera on bystanders. They expressed that they don't have any issues about being in the range of the user of the eye tracking feature: *"I'm a bystander so I know that I'm not the one who's information are taken by the eye movement"*[P03]. Others conversely, stated that they will try to **code: avoid being in the camera view** ($N = 3$) of the eye tracking user. Responses additionally indicated that figuring out that people are using eye tracking for interaction is **code: hardly noticeable** ($N = 4$) and looks **code: similar to any other type of interaction** ($N = 3$), thus it feels normal and natural in the social context to see people looking at their phones. On the other hand, it was expressed by participants that eye movement interaction is **code: uncommon** ($N = 5$) nowadays so they cannot picture any harm or discomfort regarding seeing people using this feature.

4.3.5 Bystanders' concerns post the awareness video. Some participants explained that they are not worried about their privacy as bystanders rather than feeling **code: sorry about unaware users** ($N = 6$) and might **code: share awareness** ($N = 3$) with them about the amount of sensitive and personal data that could be derived from their eye movements. They additionally mentioned that users might have agreed to share their data before using the eye tracking feature. However, bystanders' data can be collected with **code: no consent** ($N = 2$) which is a big privacy concern for the bystanders. Therefore, there is a need for a **code: protection mechanism for bystanders**: *" something could be integrated through the application[...]it detects the bystander[...]give notification[...]*[P07]. Some concerns related to the **code: scope of eye tracking camera** ($N = 4$) and the possibility of affecting the passers by, were raised by participants as a factor that might contribute to making bystanders' feel stressed about the eye tracking feature on mobile devices.

5 DISCUSSION

This section reflects on the qualitative and quantitative results of the presented study and answers the research questions: **RQ1**-to what extent do users/ bystanders subjectively accept eye tracking on mobile devices?, **RQ2**-to what extent do users/ bystanders perceive privacy implications of eye tracking on mobile devices? and **RQ3**-how does the awareness video impact the users/ bystanders subjective acceptance and privacy concerns of eye tracking on mobile devices? Although our results indicate some changes in privacy concerns post watching the awareness video, we do not anticipate a direct behavior change as knowledge definitely does not necessarily lead to attitude or behavior change. In the study, our method was designed to allow participants to familiarize themselves with eye tracking. For this reason, we had to have participants experience eye tracking from the user's perspective first. One of the limitations of the study is that the bystander role was only imagined. Future work should investigate the bystander's perspective in a more ecologically valid setting. In addition, there is a possibility that bystanders might have built their responses based on false assumptions that their privacy is protected.

5.1 Users are Concerned about the Transparency and the Credibility of the Eye Tracking Developer on Mobile Devices

In our work, we conducted interviews to get a deeper understanding of participants' perceptions of privacy and subjective acceptance toward eye tracking on mobile devices. This research provides findings on privacy perceptions which pave the way for future work to design awareness based solutions and privacy protection mechanisms that meet users and bystanders needs. In relation to RQ2 and RQ3, the interview results show that users are still willing to use the eye tracking feature on mobile devices post to the awareness video and despite their claims to be concerned about their privacy and the collection of sensitives data, this is in line with the findings of previous work [40]. Our research extends this finding by showing that the transparency, credibility of the developer, and the level of control given to users over their data, contribute to enhancing users' trust thus making users more inclined to use the eye tracking feature on mobile devices. This echoes findings in mobile applications and other domains including Extended Reality (XR) and Augmented Reality (AR) in which transparency [1, 10, 11] and providing users with varying levels of data control [1] were shown to enhance users' trust. Eye tracking data is a rich resource of personal and sensitive data as shown in previous research [12, 23], for example: the eye movement data can reveal age, health conditions, personality traits, and mental reasoning. To this end, our quantitative results show that the awareness video impacts users' perceptions by making users more stressed, skeptical, and unsure toward the eye tracking feature. However, these perceptions, as shown by the interview insights, do not discourage users from using eye tracking, but will make them more cautious about picking more trusted providers of the eye tracking feature on mobile devices. This leads to the need for future research to design awareness based solutions and develop privacy protection mechanisms to enhance users' privacy since the feature is welcomed by users.

5.2 Bystanders raised a need for privacy protection mechanisms for their data

In reference to RQ3, bystanders raised a concern related to consent, stressing that the applications usually ask for the consent of the users but not the bystanders. This highlights the need to develop mechanisms for protecting bystanders' data and allowing them to opt-out from being captured by applications that might affect their privacy. This echoes findings from prior work about how bystanders' privacy is impacted by eye tracking and that their data could be recorded without their consent [6, 20, 34].

5.3 Bystanders are Lacking Awareness of Mobile's Eye Tracking Privacy Implications

Regarding RQ3, our quantitative analysis shows that the knowledge of sensitive and personal data that could be derived from eye movements would have an impact on bystanders' perceptions, by being more unsure about passing by close to the range of a user's front facing camera that might operate an eye tracking feature. In relation to RQ2 and RQ3, our interview analysis showed that bystanders lacked awareness and understanding of how the eye tracking feature could invade their privacy. In reference to RQ2, bystanders expressed no issues related to their privacy, stressing that their main concern is about the privacy of the user. Interestingly, bystanders expressed their willingness to share awareness with users about how much data can be collected from the users' eye movement. An interesting concern that was voiced by bystanders is the possibility to control users' devices behind their backs. This reflects our quantitative results that the role the participant portrayed had an impact on skepticism levels, which rose more when the participants played the user role since bystanders believe that the privacy implications of eye tracking is limited to users not bystanders. This indicates an increased privacy literacy of bystanders. Thus, future research might investigate this area further by replicating the study with more emphasis on privacy implications on bystanders and considering validating the additional pairs that were used in this study. Although our study focuses only on eye tracking through a front facing camera on mobile devices, we expect our findings and the codebook to generalize to other uses of eye tracking on other devices.

5.4 Users are Willing to Use Eye Tracking on Mobile Devices

It was found that the social context has an impact on improving the acceptance [21]. Other research showed that users location and activity are related to perceived privacy [13]. In reference to RQ1, we investigated the subjective acceptance toward eye tracking on mobile devices. Our results show that users are welcoming eye tracking features on mobile devices, seeing them as interesting hand-free interactions. They also expressed their preferences for using eye movements over the conventional way of gestural interaction. They stated that the subjective acceptance of this feature would be enhanced by the adaptation to the new technology and the technical backgrounds of the users. Moreover, they expressed that the eye tracking has the potentials to benefit their daily life activities such as for health tracking purposes and authentication to enhance security mechanisms. In addition, they stated that it's normal to use biometrics in technology. On the other hand, they expressed some technical usage issues related to the accuracy, efficiency, and training needed to learn how to use this feature. Interestingly, the scalability of the feature to serve more user groups was raised as a social aspect challenge that needs to be solved. This assumes that eye tracking promises subjectively acceptable sensing on mobile devices and thus, further exploration of enhancing privacy and communicating privacy implication could open doors for future work in this direction.

5.5 Bystanders are Welcoming the Use of Eye Tracking

Relating to RQ1, our results show that bystanders do not express subjective acceptance issues about seeing people around them using eye tracking on mobile devices. Participants highlighted that they are welcoming the use of eye tracking stating that it is not different from other types of interaction. They also mentioned the possibility of using the technology for security enhancement purposes. On the other hand, it was also highlighted by bystanders that it is hard to notice whether users are using their eyes for interaction or just looking at their phones. However, it was required by the application used in our study to either smile, blink, or hold gaze to perform one successful task. To this end, participants mentioned that if they observe someone for example smiling at his phone, they would consider this awkward as it is not something common in the meantime, but also they expressed to be still not bothered about the feature. In addition, participants expressed that the prevalence of the feature makes the gaze interaction appear more "normal". This might indicate that the pervasiveness of the eye tracking feature can improve acceptability. Our results shed light on significant factors that influence users' and bystanders' acceptance of eye tracking such as transparency and credibility. Thus developers of eye tracking features can utilize these findings to design transparent mechanisms for communicating privacy and data handling for both users and bystanders. In addition, this motivates the need of developing methods to allow bystanders to give their consent for capturing and using their data.

6 LESSONS LEARNED AND RECOMMENDATIONS

In this section, we reflect on our study results by presenting three main implications for designers of gaze-enabled applications for handheld mobile devices.

1) **Lack of awareness and false assumptions put bystanders' privacy at risk:** Our results show that bystanders were unaware and lacked an understanding of how eye tracking could affect their privacy. Bystanders raised no concerns about their privacy and reported they believe that the major concern is the user's privacy rather than their privacy. Thus, there is a need to raise awareness about the implications of eye tracking on the privacy of bystanders, and develop ways to make bystanders aware they are in the field of view of a mobile device that is running eye tracking.
2) **There is a need for communicating privacy implications and data handling for both users and bystanders:** Concerns were expressed by our participants about transparency and the developer's credibility. To gain users' trust, application developers should grant users control over their data in a way to support them decide whether to opt-in or out from sharing

their data. A potential design solution that would allow higher levels of transparency, is to show within the eye tracking application, the associated sensitive features that can be extracted by a smartphone eye tracker. In addition, the solution should also clarify what data is being collected and how the captured data is being used.

3) **The development of methods to allow bystanders to give their consent for capturing and using their data is required:** In our study results, bystanders stressed that there is a lack of options and mechanisms that allow them to opt-out of being captured by an eye tracking application on mobile devices. As a result, it becomes necessary to create protective measures for bystanders' data or to provide them with the option of opting out from the collection of their data to avoid compromising their privacy.

7 CONCLUSION

In this paper, we presented qualitative and quantitative results of a user study to understand privacy perception and subjective acceptance of eye tracking on mobile devices using the true-depth front facing camera. We identified factors that influence privacy perception and subjective acceptance for both users and bystanders prior to and post to an awareness video. Our findings showed that users are interested in eye tracking features on mobile devices despite privacy concerns. Our results additionally, indicates that the transparency, credibility of the developer, and the level of control given to user over their data, contribute to enhancing users' trust thus making users more inclined to use the eye tracking feature on mobile devices. Bystanders are concerned about the collection of their data without their consent, however, they are welcoming the use of eye tracking. Bystanders are also lacking awareness of the privacy implications that could invade their privacy. We expect our findings and codebook to generalize to other uses of eye tracking on other devices. In addition, since eye tracking is welcomed by users, we suggest future work to design awareness-based solutions and develop privacy protection mechanisms to enhance the privacy of eye tracking on mobile devices for both users and bystanders.

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