Evaluating the Potential of Glanceable AR Interfaces for Authentic Everyday Uses

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Figure 1: Using Glanceable AR interface in three everyday scenarios: (a) working in front of a desktop computer with glanceable widgets residing at the edge of the physical monitor; (b) cooking with recipe and timer widgets following the user for hands-free access of information; (c) walking outside with music, fitness and map widgets following the user; a notification notifies the user about accomplishing the daily step goal.

Abstract

In the near future, augmented reality (AR) glasses are envisioned to become the next-generation personal computing platform. They could be always on and worn all day, delivering continuous and pervasive AR experiences for general-purpose everyday use cases. However, it remains unclear how we could enable unobtrusive and easy information access without distracting users, while being acceptable to use at the same time. To address this question, we implemented two prototypes based on the Glanceable AR paradigm, a promising way of managing and acquiring information through glancing at the periphery of AR head-worn displays (HWDs). We conducted two separate studies to evaluate our designs. In the first study, we obtained feedback from a large sample of participants of varied age and background about a video prototype that showcased some envisioned scenarios of using Glanceable AR for everyday tasks. In the second study, we asked participants to use a working prototype during authentic real-world activities for three days. We found that users appreciated the Glanceable AR approach. They found it less distracting or intrusive than existing devices in authentic everyday use cases, and would like to use the interface on a daily basis if the form factor of the AR headset was more like eyeglasses.

Index Terms: Human-centered computing—Mixed / augmented reality; Human-centered computing—User interface design

1 Introduction

Conventional Augmented Reality (AR) systems have typically been expensive, bulky, and technologically limited. Thus, they have been used primarily for special-purpose tasks, such as navigation, training, or maintenance. With recent advancements in display technology and tracking, however, AR systems are becoming increasingly accessible and affordable. It is now possible to deliver convincing AR experiences to users via relatively lightweight AR head-worn displays (HWDs).

Commercial HWDs to date for general-purpose use can be categorized into two types: (1) untracked wearable displays in which information is fixed to the display (e.g., Google Glass[1], North Focals[2]); and (2) wearable displays with tracking capabilities to register information to the physical environment (e.g., nreal glasses[3]). The benefit of both types is that they are worn on the head and directly visible to the eyes, which makes rapid information access viable. However, an advantage that only a tracked display can offer is that it allows registration of virtual content to the real-world (locations, objects, or even the user's body) instead of only on the display.

In 2016, Grubert et al. proposed "Pervasive AR," which refers to "a continuous, omnipresent, and universal augmented interface to information in the physical world" [20]. With augmented virtual information being pervasive and always available, certain issues could be introduced in everyday scenarios. The virtual information might become overwhelming, occlude real-world objects of importance, distract or disrupt users from their real-world tasks, and further lead to privacy issues when interactions are visible by co-present others. As pointed out by Grubert et al., when AR experiences become omnipresent, we need to design "appropriate information display and interaction, which is unobtrusive, not distracting, and is relevant and safe to use [20]."

Glanceable AR, proposed by Lu et al., is an interaction paradigm that proposes to address these issues. Glanceable AR allows information acquisition through quick glances at the periphery of the visual field (see Fig. 1) [31]. The paradigm builds upon existing research on glanceable displays [3, 9, 33, 35] and peripheral awareness [24, 48], which are proven to be viable for quick access and monitoring of secondary information . It allows unobtrusive display of information together with quick intake, which could be a promising way to achieve Pervasive AR in everyday scenarios.

To demonstrate the potential of Glanceable AR, two major challenges need to be addressed. First, we must address the *design*

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[1]https://www.google.com/glass/start/
[2]https://www.bynorth.com/
[3]https://www.nreal.ai/

2642-5254/21/$31.00 ©2021 IEEE
DOI 10.1109/VR50410.2021.00104

challenge of creating practical Glanceable AR widgets that are combined into a usable system for real-world tasks. Existing work on Pervasive and Glanceable AR has produced small proof-of-concept implementations, but has stopped short of implementing a practical system that can be actually used in everyday situations. Second, we need to address the *validation* challenge by demonstrating that such a system can provide a high-quality user experience, a high level of user acceptance, and a high level of usefulness for everyday tasks in real-world scenarios. Conventional AR user studies typically happen in controlled lab settings; there are a very limited number of studies that have explored in-the-wild use of AR interfaces, especially with unsupervised users in real-world scenarios.

In this research, we address these challenges. We describe two Glanceable AR prototypes and two studies in this paper. First, we implemented a video prototype and distributed it broadly, along with a survey, to understand user perceptions and acceptance of Glanceable AR. Second, we implemented a working Glanceable AR system on the Magic Leap One AR headset. The application is able to display time, weather, and news, along with the user's personal calendar events, incoming email, to-do list, and fitness data as glanceable widgets. Using this prototype, we conducted an in-the-wild study in which participants freely used the application in their everyday lives for at least 2.5 hours.

The contributions of the paper include: (1) explorations of user acceptance and perceptions of applying AR HWDs with a glanceable interface for everyday tasks; (2) design and implementation of a working Glanceable AR system for everyday uses; and (3) evaluations of the interface through an unsupervised in-the-wild study that explored authentic everyday use cases.

2 Related Work

2.1 General-purpose AR interfaces

The majority of existing AR applications are designed for special-purpose use cases such as training simulations [17] and knowledge work [21, 30]. However, AR systems, especially AR HWDs, have long been envisioned as general-purpose computers to assist people's everyday tasks. Back in 2002, Feiner said that future AR HWDs will become "much like telephones and PCs," and display information "that we expect to see both at work and at play" [16]. With the advancements in AR systems in recent years, we are coming closer to this envisioned future. Google Glass was an early attempt to apply wearable HWDs to general-purpose everyday use cases [44]. Recently, more smart AR glasses have been announced. For example, the nreal mixed reality glasses come with built-in 6 Degree of Freedom (DoF) tracking and hand tracking capabilities, with a form factor similar to a pair of conventional eyeglasses.

However, realizing the Pervasive AR vision requires not only work on improving the capabilities and form factor of the display, but also research on how to design effective information display strategies to make AR HWDs feasible for general-purpose everyday uses. In this research, we attempt to fill the gaps by proposing a general-purpose AR interface, and evaluating it in authentic everyday use cases.

2.2 Information acquisition with AR HWDs

Strategies for virtual information display in the literature can be categorized as world-fixed, object-fixed, head-fixed, body-fixed or device-fixed [5, 29]. In AR specifically, world-fixed, display-fixed and body-fixed are popular layouts to register virtual windows [15]. ARWin was a desktop workspace augmented by virtual calendar, weather and web browsers [14]. This information was world-fixed to physical surfaces around the desktop. Starner and Billinghurst proposed a spatial display metaphor, in which virtual windows were body-fixed to a cylinder surrounding the user [2]. They found the approach was faster in locating information than presenting all information at one position. Lages and Bowman evaluated an adaptive walking interface for AR HWDs. Their interface could switch between world-fixed and body-fixed layouts based on user input. Their result emphasized that it is important to prevent virtual information from blocking real-world objects or environment that is of interest to the users. Lu et al. explored display-fixed and body-fixed interfaces for accessing information through glancing at the periphery [31]. Their results shed light on peripheral information display for convenient access and continuous awareness of information. In this research, we expand on the work of Lu et al., and explore the potential of world-fixed and body-fixed layouts for displaying information through AR HWDs in everyday scenarios.

2.3 In-the-wild studies in VR/AR research

The term "in the wild" in HCI research refers to performing studies with users in uncontrolled environments rather than in the laboratory [8]. Steed et al. proved the viability of in-the-wild virtual reality (VR) experiments with unsupervised users [45]. Field studies, as a methodology of conducting in-the-wild research, collect data in users' contexts. Compared to traditional user studies that take place in a lab with structured and artificial tasks, field studies can be more powerful to "understand the end user's natural behavior in the context of his or her everyday environment [12]." Existing research proved the viability of field studies to obtain quality feedback from users in real-world tasks and environments with AR systems [27, 28, 34, 39].

In this research, we conducted an in-the-wild study to explore applications of AR HWDs in common everyday scenarios. To relate to participants' contexts, our prototype displays participant's own data from Google services. To our knowledge, there are no in-the-wild studies that explore the use of AR HWDs for general-purpose everyday uses with users' own data. Our study is the first in-the-wild study that reveals these use cases in an unsupervised manner to understand genuine user perceptions and requirements.

2.4 Evaluations of promising AR systems

Envisionments of promising technologies are common in the HCI community. Understanding acceptance, preferences and requirements of intended users are crucial prior to actual implementations to save cost and effort. Previous research has mainly applied three methodologies: (1) Distribution of online surveys to obtain feedback from a broad population. For example, Popovici and Vatavu obtained feedback from 172 participants on interactions and scenarios for an envisioned AR television [38]. (2) Employment of visual prototypes to convey design ideas. In the same study, Popovici and Vatavu described use cases of AR television via video prototypes and illustrations [38]. Häkkilä et al. conveyed the concept of Augmented Reality windows for cars via video see-through displays [22]. (3) Field studies to understand real-world user acceptance and requirements. For example, Ventä-Olkkonen et al. explored the concept of a AR city via field studies and conceptual prototypes [46]. This research shows field studies as an approach to reveal real-world use cases for non-existing technologies. In our research, we employ similar approaches to distribute and evaluate our idea of using Glanceable AR for everyday scenarios and tasks.

3 Study 1 - Perceptions of Video Prototype

3.1 The video prototype

To convey our design ideas in distributable form, we developed a video prototype[4] that illustrates some envisioned scenarios of using Glanceable AR in common everyday situations. We showcase three scenarios in the prototype (Fig. 2): (1) working in front of a desktop computer; (2) taking a walk outdoors; and (3) cooking according to a recipe. The reasons we chose these scenarios are twofold: (1) they are common and are good representatives of sitting, standing, walking conditions requiring and not requiring hands; (2)

[4]https://youtu.be/qsDVDP7wA-E

they all prioritize focus on the real-world environment or objects, in which accessing digital information on separate devices could be intrusive and distracting. The video prototype walks through the three scenarios one by one with an actor wearing a Magic Leap One AR headset. The prototype uses a Wizard-of-Oz approach [13] for interaction. In the following section, we will explain the core elements we embedded in the prototype, and the design rationale behind them.

3.2 Design rationale

3.2.1 Glanceability

As its name implies, glanceability is a major design principle of Glanceable AR [31]. According to Matthews et al., visual displays have the quality of being *Glanceable* if they enable users to understand information quickly with low cognitive effort [32].

Widgets are common in mobile phone and desktop computer interfaces [47]. They continuously run in the background [4], and allow users to quickly glance at information without opening an app. In everyday AR scenarios, widgets could be a feasible form of presenting multiple pieces of information simultaneously and continuously to users. They are compact so they take a small proportion of the field of view, and they are easy to access and understand with a quick glance. Grubert et al. found that AR widgets could be feasible while interacting with physical displays [19]. Based on our review, there is limited research that explores the potential integration of widgets into AR systems for general-purpose information display. As such, we showed nine widgets in the video prototype that people use frequently, including Weather, Timer, News, Calendar, To-do List, Music, Fitness, Recipe and Email. To avoid distracting or disrupting user's tasks in the real world, following the design principles of Glanceable AR, these widgets are positioned at the periphery to be unobtrusive, but can be accessed via a glance whenever needed.

3.2.2 Interface design

Four types of interface design choices were shown in the video prototype: gaze, follow mode, voice&hand gestures, and notifications.
Gaze: To allow for an adaptive information display, we demonstrated a gaze-contingent metaphor [18]. The amount of information in the widgets is dynamically managed depending on the direction the user is looking. The widgets are normally displayed in low detail to minimize the space they occupy, however, once gazed at, they expand and show more information. For example, the weather widget shows current weather and temperature by default, but it expands to show a weather forecast for the next few hours when looked at. We demonstrated the gaze interactions with the actor gazing at the email, calendar, fitness and weather widgets.
Follow Mode: The widgets incorporate two modes: stationary mode and follow mode. Adopting the design of existing glanceable and peripheral displays, the widgets are in stationary mode by default and are world-fixed. Following the "Fixed to Users" design principle of Glanceable AR, the widgets can enter follow mode to be body-fixed and follow the users around to enable information access on the go [31]. For stationary scenarios such as working in front of a computer monitor, the widgets are placed at the edge of the monitor to avoid distractions. For moving scenarios such as cooking and exercising, the head-glance (HG) interface was applied [31], in which the widgets are placed outside the periphery of the user to ensure clear forward vision, but can be accessed quickly by turning the head. In the video, we demonstrated both stationary (see Fig. 2(a)) and mobile use cases (see Fig. 2(b)).
Voice & Hand Gestures: We illustrated two other input modalities in the video prototype. Voice could be useful when hands are occupied for other tasks, while hand gestures could be useful when voice is not convenient in a given scenario. The actor uses voice to set a timer, play music, and trigger the widgets to follow him. He uses hand gestures to browse the music library while exercising outside.

Figure 2: Two scenes from the video prototype: (a) stationary use case in which all widgets are located at the edge of a physical monitor; (b) follow mode with head glance (HG) interface in which the fitness, weather and music widgets follow the user and stay outside the periphery.

Notifications: Notification system are crucial for personal computing devices. Existing mobile devices mainly apply auditory and tactile cues to notify users of certain events [23]. Unlike traditional mobile devices in which digital content is constrained to the physical device, in AR content can be displayed around the user in the 3D environment. As such, notifications in AR HWDs should not only deliver information, but also the location of the virtual content so users can be spatially aware of the piece of content that is drawing attention. Costanza et al. found that changing the brightness and speed of visual stimuli at the periphery could be an effective strategy to deliver notifications in HWDs [11]. Similarly, in our prototype, we display the icon of a widget and an arrow in the periphery and alter the brightness to notify users. The arrow points towards the widget that is delivering the notification so that users can easily find the widget in the physical space.

3.3 Research Goals

In the first study, our goal was to obtain feedback from a broad sample of the general population about the Glanceable AR design shown in our video prototype, and to understand their perceptions of using it in different scenarios, compared to the ways they accomplish those tasks now. We aimed to answer the following four research questions:
RQ1.1 How do users perceive the quality of user experience of the Glanceable AR prototype in everyday use cases?
RQ1.2 What are the perceived benefits/drawbacks of using AR systems like this?
RQ1.3 What are the scenarios that users perceive as beneficial when using our Glanceable AR approach?
RQ1.4 What are the pros and cons that users perceive for using Glanceable AR as compared to existing personal computing devices (e.g., smartphones, tablets, and smartwatches)?

3.4 Experiment

3.4.1 Online Survey and Procedure

We developed an online survey to gather data about people's perceptions of the video prototype. The study, which was approved by our university ethics board, was voluntary/unpaid and consisted of six steps. Participants were first asked to read and agree to the consent information presented at the beginning of the survey, Second, they were asked to provide their background information. Third, they were asked to watch the video prototype. After they finished watching, fourth, they were asked to fill out the System Usability Scale (SUS) and a shortened version of the User Experience Questionnaires (UEQ) on overall and individual features of the interface [7, 43]. Although such questionnaires are typically used following a participant's actual interaction with an interface, we expected that they would still give us information about participants' perceptions of expected usability and user experience (UX) after watching the video. We restrict our claims to such perceptions and do not make any claims about actual usability and UX from this questionnaire data. Fifth, they were asked to imagine using

the Glanceable AR interface in real life, and compare it with existing devices that they frequently use in terms of *ease of access* and *distraction* for six tasks listed below:
Task 1: Check information while stationary.
Task 2: Check information while moving.
Task 3: Check information while hands are occupied.
Task 4: Interact with widgets while stationary.
Task 5: Interact with widgets while moving
Task 6: Interact with widgets while hands are occupied
Finally, they were asked to give comments on what they liked or disliked, and how the interface is better or worse as compared to existing devices they normally use. At the conclusion of the survey, they were asked to leave their email address if they would like to be contacted for an additional 20-minute interview. In the interview, we asked them to explain their comments in the questionnaire and provide further suggestions.

In order to evaluate only the Glanceable AR interface design, we asked participants to ignore the form factor of the Magic Leap headset in their SUS and UEQ responses. The survey took around 30 minutes to complete. It was distributed across multiple online communities, including Reddit, Twitter, Linkedin, Facebook and university mailing lists.

3.4.2 Participants

We received 123 responses for our survey, among which 60 responses (48.78%) were abandoned due to incompleteness and low quality. 63 complete responses were recorded successfully in the end. The respondents (14 females, 49 males) were between 20 and 69 years old (M = 32.90, SD = 11.25). Although gender balance was desired, we did not fully achieve this since participants self-selected to participate. Thirty-one of them self-identified as experienced with AR. Respondents came from various backgrounds, including college students (19), lecturers/researchers/professors/postdocs (11), developers/engineers/designers (9) and consultants/advisors/analysts (4). Participants were from all over the world; the most frequent countries of residence were USA (24), China (8), Italy (5), Germany (4) and France (3). Almost all (62) of the participants said they used mobile phones everyday. Participants also used personal computers (60), tablets (34), smartwatches (23), and virtual assistants (21). Eight respondents participated in the additional interview.

3.5 Results

We conducted a series of analyses on our results. The Shapiro-Wilk test was applied to test the normality of the quantitative data we obtained. Non-parametric tests (i.e., the Mann-Whitney U test and the Wilcoxon signed-rank test) were conducted for non-normally distributed data. The r statistic was reported as a measurement of effect size [36, 40]. According to Cohen's classification [10], $0.1 \leq r < 0.3$, $0.3 \leq r < 0.5$, and $r \geq 0.5$ would be considered as small, medium and large effects respectively. We used an α level of 0.05 in all significance tests. In the results figures, pairs that are significantly different are marked with * when $p \leq .05$, ** when $p \leq .01$, and *** when $p \leq .001$.

3.5.1 Perceived user experience

The SUS scores of the video prototype ranged from 15.00 to 95.00 with a mean score of 67.14 (SD = 16.53), which is between 'OK' and 'Good' [1]. The Mann-Whitney U test yielded no difference for SUS score between experienced and inexperienced AR respondents ($U = -485.5, Z = .145, p = .885$). Fig. 3 (a) shows the results of the overall UEQ together with UEQ ratings (for both pragmatic and hedonic scales) for the following six features: (1) glance-stationary: glancing at the AR widgets while stationary to acquire information; (2) glance-mobile: glancing at the AR widgets while moving to acquire information; (3) gaze: gazing at the widget for higher detail; (4) follow mode: attaching widgets to the user for mobile use; (5)

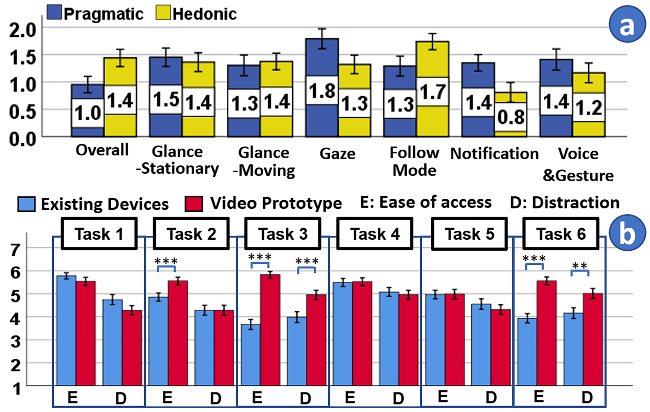

Figure 3: (a) UEQ results for both overall and separate features shown in the video prototype; (b) ratings of ease of access and distraction for six tasks (higher ratings mean easier access and lower distraction) ($\pm S.E.$).

Benefits	Drawbacks	Wish-to-haves	Scenarios
Hands-Free(30)	Form factor(28)	Customization(16)	Navigation(15)
Convenient(27)	Voice input (20)	Phone call(9)	Shopping(9)
Awareness(19)	Distracting(19)	Messaging(7)	Assembling(5)
Non-intrusive(13)	Overwhelming(18)	-	-
Always accessible(8)	Invasive(12)	-	-
Real-time Data (5)	Occlusion (8)	-	-
-	Addiction (5)	-	-

Table 1: Most frequently occurring codes and their frequencies in four categories: benefits of the interface, drawbacks of the interface, wish-to-have features, and other scenarios in which the interface could be useful.

notification: delivering notifications through blinking icons at the periphery pointing to the source and (6) Voice&Gesture: using voice input or hand gestures to control the widgets being gazed at. All of the average ratings were greater than 0.8, which is considered positive. When asked if they would want to use the interface on a daily basis if the form factor of the display was similar to a pair of eyeglasses, 36 participants gave a positive response (57.14%), 18 respondents (28.57%) selected unsure, and 9 participants (14.29%) gave a negative response.

Fig. 3 (b) shows the mean ratings for Task 1 - Task 6 in terms of ease of access and distraction. Wilcoxon signed-rank tests showed that participants rated the video prototype as being significantly easier to acquire information as compared to the existing devices they normally use for Task 2 ($Z = 3.335, p = .001, r = .297$), Task 3 ($Z = 5.796, p < .001, r = .516$), and Task 6 ($Z = 4.933, p < .001, r = .439$). The approaches shown in the video prototype were also rated as significantly less distracting compared to existing devices for Task 3 ($Z = 3.428, p = .001, r = .305$) and Task 6 ($Z = 3.013, p = .003, r = .268$). The Mann-Whitney U test shows that for Task 1, respondents inexperienced with AR considered the video prototype as easier for accessing information, as compared to respondents experienced with AR ($U = 337.5, Z = 2.262, p = .024, r = .285$).

3.5.2 Qualitative results

We used the qualitative analysis software AQUAD 8 to perform qualitative coding on approximately 391 lines of text from comments in the surveys and interview scripts [41]. We categorized and grouped the codes, and listed the most frequently-mentioned ones together with the frequency of occurrence in Table 1.

As for perceived benefits of the video prototype compared to existing devices, codes such as *hands-free, convenient, awareness of information, non-intrusive, always accessible,* and *real-time data* appear most frequently. Participants commented: *Information is always accessible*; *I like not being distracted*; *you can still maintain awareness of what is going on around you*, and *it makes it easier to access information when your hands are occupied.*

The most commonly mentioned potential drawback of the interface, because the actor was wearing the Magic Leap One headset, was the form factor of the display. A participant commented *glasses must be really small and stylish before being considered viable*. Participants also disliked voice interactions shown in the prototype as it could disturb others in a shared space, which is consistent with existing literature. Other than form factor and voice, *distracting, overwhelming, invasive, occluding the real-world* were also mentioned by several participants. They commented *the content could still block my vision when I'm looking to the side (at the real world)*, *I think the apps would actually get in the way too often*, and *I worry about the increase in the number of distractions it would bring, and how it could potentially take away my vision*. Five participants felt worried that the interface could cause *addiction* to virtual content due to its ease of access and always-on nature, which could limit their interactions with the real world: *I already feel like I spend too much time checking emails ... I'm afraid that wearing such a device might lead to an over stimulation from the technology*, and *I think having stuff floating around all the time might be distracting and make me even more addicted to the internet*.

For wish-to-have functions that were not demonstrated in the video prototype, *customizing the virtual content (widgets)* appeared the most, including location in space and notification levels. *Phone calls, messaging and watching videos* were also brought out by respondents. As for other scenarios that users would like to use the interface in, *navigation* was mentioned by the most participants. Fourteen participants also mentioned having a shopping list/instruction tutorials at the periphery while hands are busy during shopping/assembling furniture could be potential use cases.

3.6 Discussion

In this section, we will summarize and discuss our findings based on the **RQ**s.

RQ1.1: The pragmatic and hedonic UEQ ratings were positive (>0.8) both overall and for separate features, among which the gaze and follow mode features obtained especially high scores, indicating that people expect them to be practical and pleasant to use. Over half of the respondents affirmed that they would like to use the interface everyday, which provides further evidence for the potential of Glanceable AR for everyday use cases.

RQ1.2: It was interesting to us that respondents held contradictory opinions on the benefits and drawbacks of the interface. Some of them considered it non-intrusive and convenient, while others considered the interface distracting and overwhelming. One potential reason for this could be the limited expressivity of the video prototype. In the interview, two participants commented: *it is hard to tell how distracting notifications are just from the videos*, and *I think the apps would actually get in the way too often, but I'd have to test out the system on my own to see if my hypothesis is correct*. This could also be reflected by the wide range of SUS scores, and that 28% of participants felt unsure about whether they would want to use the system frequently. Without actually experiencing the interface, the opinions of participants could be incomplete or even biased by their own understanding of the video. As such, although the prototype obtained a positive response in general, evaluations of actual use are needed to validate the user experience of Glanceable AR.

RQ1.3 & RQ1.4: As shown in Table 1, the most compelling scenarios to participants were those where the hands are occupied with tasks in the real world. The ratings on the tasks also show that compared to existing devices, participants considered the Glanceable AR interfaces significantly more convenient and less distracting in scenarios when hands are occupied. As shown in Fig. 3(b), checking information while moving with Glanceable AR was also considered more convenient as compared to existing devices.

To summarize the first study, we conveyed the idea of Glanceable AR to a sample of participants of varied ages and backgrounds through a video prototype and obtained their feedback. Our results show that participants feel relatively positive about Glanceable AR in general, but some improvements should be made to the prototype, and issues such as distraction and occlusion cannot be fully understood with the video. The usability and acceptance of the Glanceable AR interfaces need to be explored through direct user experience.

4 Study 2 - Authentic Use of Working Prototype

4.1 Working Prototype

To explore authentic uses of Glanceable AR interfaces, we implemented a working prototype on the Magic Leap One AR headset. Similar to the video prototype, the working system incorporated seven widgets: Email, Calendar, Fitness, Tasks, News, Weather, and Clock. Using this prototype, we conducted a second study to explore the user acceptance, requirements and experience of using a Glanceable AR interface in the wild. Compared to most AR user studies, this study was unique in several respects: (1) participants used the prototype for a minimum of 2.5 hours in authentic everyday use cases; (2) the sessions were unsupervised with a minimal level of outside control; and (3) users' own data were integrated into the working prototype to allow practical uses.

Personal & Real-world data: All widgets were linked with real-world or personal data sources. The Gmail, Calendar, Fitness, and Tasks widgets were linked with the user's personal Google account. The Gmail widget displayed the latest or incoming email from the user's Gmail inbox. The calendar widget displayed three calendar events, the current, previous and next event from the user's Google calendar. The Fitness widget displayed personal data from Google Fit, which includes calorie consumption, daily walked steps, and active minutes, and could be linked to sensors in personal fitness tracking devices. The Tasks widget displayed to-do lists the user entered in a google sheet. To implement these features, we asked participants to give permission for our application to access data associated with their Google account, and compiled a personal version of the application for each participant with an access token generated by Google. We did not collect participants' account names or passwords, nor did we have access to log in to their Google accounts. We deleted the access tokens as soon as we finished deployments, and we deleted the personalized versions of our application as soon as participants finished the study. Participants could remove the access they granted to the AR application to access their google information at any time in their Google account settings.

The News, Weather and Clock widgets displayed real-world information. For example, the News widget displayed random news headlines from the user's region. The Weather widget displayed real-world weather conditions, temperature and a five-hour forecast. The clock widget displayed current local time, and also provide alarm and countdown timer functionality.

Notification: Given the contradictory feedback about notifications from the first study, we decide to keep the feature in the working prototype to study it further. When a notification happened, the icon of the notifying widget appeared and blinked at the edge of the FoV of the display. The icon pointed towards the location of the widget so users could easily locate it. We integrated notification systems in all seven widgets. A notification was delivered for the following conditions: (1) Gmail: when a new email arrived in the inbox; (2) Calendar: when an event was approaching; (3) Fitness: when daily goals were completed; (4) Tasks: when the deadline of a task was approaching; (5) News: when the widget obtained a new news story; (6) Weather: when rain was forecast in the next hour; and (7) Clock: When a timer expired or alarm was triggered.

4.1.1 Improvements

Gaze: Given the positive feedback on gaze from the first study, we kept the gaze-contingent metaphor for the working prototype. For all the widgets, gazing at the widget would either expand the widget

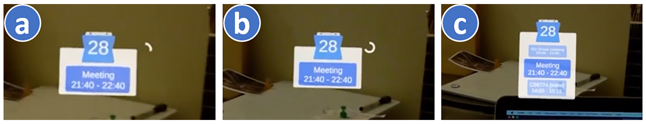

Figure 4: Gaze-contingent interaction with dwell: (a) user starts to gaze at the calendar; (b) user keeps gazing at the calendar with the progress circle filling up; (c) after one second, the calendar expands with more detail.

to show more detail, or trigger some interaction. For example, the weather widget displayed current temperature and weather condition by default, but expanded with weather forecasts when gazed at. We added a one-second dwell time to avoid the "Midas touch effect [26]." A progress circle would appear on the side of the widget to represent the dwell time (see Fig. 4). As such, the user could always perform a quick glance to look at the low-detail information, and gaze for a longer time only if they needed more information from a widget.

Follow Mode with Head Glance+: In Section 3.2.2, we introduced the head glance interface as the primary method of on-the-go information access. However, as pointed out by respondents in the survey, even if the widgets are placed outside the periphery to be glanced at via head rotation, occlusion issues could still happen when users intend to turn their heads to look at the real world instead of the widgets. As such, we developed a new technique that we call head glance plus (HG+) (see Fig. 5). In HG+, widgets were represented as small visual targets, and the full widget only appeared if user was looking in the direction *and* at the depth of the target. The Magic Leap's dual eye trackers were used to determine both gaze direction and vergence depth. As such, if the system detected that the user was looking behind (or in front of) the target, the widget would not appear, to avoid occluding people's vision. Existing research has explored applying gaze depth for virtual object selection and manipulations [37]. Hirzle et al. explored applications of gaze depth to enable x-ray vision in HMDs [25]. To our knowledge, there is little research on applying gaze depth for information acquisition. We see HG+ as a promising strategy to enable a more unobtrusive information display compared to HG. In the second study, we integrated HG+ into the working prototype.

Customization: As the top wish-to-have function in the list, we decided to include customization in our prototype. Survey respondents wanted customization of widget positions and level of notification. As such, in the working prototype, we allowed users to place and scale the widgets freely (see Fig. 6(a)). For follow mode, users could specify which location in the periphery they wanted to assign each widget. We also allowed users to customize notifications in a separate menu (see Fig. 6(b)), for example, how far in advance they would like a calendar event to give a notification. Also, users could mute any of the seven widgets if they did not want to receive notifications from them, and could customize the category of news items. Users could freely switch between HG and HG+ for mobile use. To ensure robust control, we did not use voice or hand gestures. All customizations were achieved through the Magic Leap One controller via ray-casting [6]. Users kept the controller in a 3D-printed case attached to a belt; this allowed us to track torso orientation to enable head glancing, and also kept the controller conveniently available for customization when needed.

4.2 Research Goals

In the second study, our goal was to evaluate Glanceable AR in authentic everyday scenarios in an unsupervised manner to understand user acceptance and perceptions. We aimed to answer the following three research questions:

RQ2.1 How do users perceive the quality of user experience of the Glanceable AR system in authentic everyday use cases as compared to existing personal computing devices (e.g., smartphones, tablets, and smartwatches)?

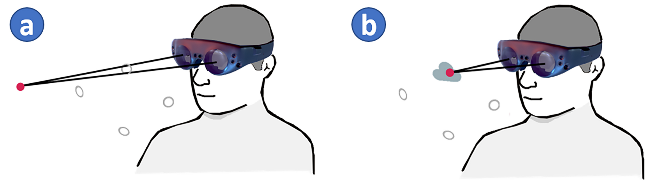

Figure 5: An illustration of head glance plus: (a) widgets are represented as small targets to avoid occluding the user's view when the user is looking at the real-world environment behind the target; (b) when the user converges their gaze at the depth of the target, the widget expands and appears.

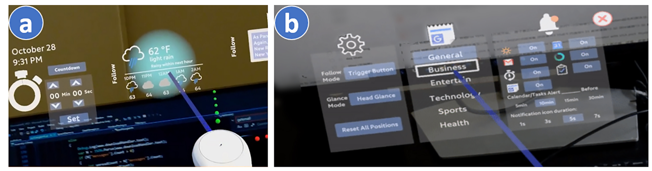

Figure 6: (a) Using raycasting to select and move widgets; (b) Adjusting news category and notification levels in the main menu.

RQ2.2 What are the common user behaviors and patterns when using the Glanceable AR system?

RQ2.3 When using the Glanceable AR system, for what scenarios is it considered beneficial or unfavorable?

4.3 Participants

We recruited six participants (two female) between 23 and 29 years old (M=25.33, SD=2.58). Participants were all college students. Three participants self-identified as experienced with AR. All participants used Google services (including Gmail and Google calendar) frequently for everyday work. All participants reported that they used mobile phones and PCs every day, while some used virtual assistants (4), tablets (2) and smartwatches (1). Four participants participated in the study locally on campus, and two participants participated in the study remotely. For local participants, a Magic Leap One AR headset was provided for them to take home for the duration of the study. Remote participants needed to have access to a Magic Leap One headset to be able to participate.

4.4 Experiment Procedures

The experiment, which was approved by our university ethics board, was divided into four phases. In the first phase, participants were asked to read and sign the digital consent form remotely. In the second phase, an online tutorial session was provided to participants to walk through the hardware, calibration processes, and the Glanceable AR interface. The length of this phase ranged from 80 to 120 minutes, depending on how experienced participants were with the hardware. In the next phase, participants were asked to freely use the interface in everyday scenarios for at least five sessions of at least 30 minutes over the course of three days, and to fill out a diary survey immediately after completing each session. In the diary, we asked about the time period, scenarios of use, layouts of widgets, and perceived user experience in that session. In the fourth phase, participants were asked to complete a post-study survey (SUS and full version UEQ), and participate in a 40-minute final interview, which was audio-recorded. After all study sessions were complete, participants were compensated with $70 USD.

4.5 Results

4.5.1 Usage sessions and scenarios

We lost three sessions of log data accidentally during data transfer. Thus, 27 sessions were recorded successfully, yielding a total of 936.61 minutes (15.61 hours) usage time. Various scenarios of use were reported by participants in the diaries, including working in front of a computer (reported in 16 sessions); cooking/eating (7

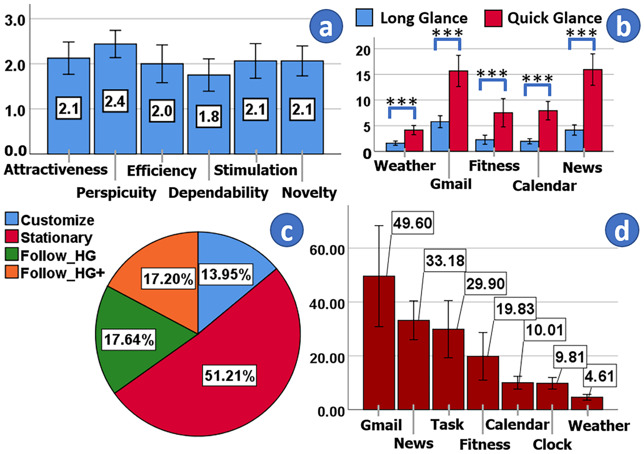

Figure 7: (a) UEQ results for study 2; (b) average frequency of glancing at each widget, red indicates a quick glance less than a second and blue indicates a long glance over one second to expand the widgets; (c) percentage of time participants spent in each mode on average for each session; (d) duration in seconds participants spent gazing at each widget on average for each session ($\pm S.E.$).

sessions); watching TV (5 sessions); playing games (3 sessions); attending a remote classes or meeting (3 sessions); talking on the phone (2 sessions); cleaning/doing laundry (1 session) and brainstorming on a whiteboard (1 session).

4.5.2 Overall user experience

The SUS scores ranged from 62.5 to 97.5, with a mean score of 90 from AR experts and 73.33 from non-experts, yielding an overall mean score of of 81.67 (SD = 15.54), which is very positive. Fig. 7(a) shows the mean ratings for the six UEQ subcategories. Based on a benchmark published in 2017, all six categories obtained better results than 90% of existing studies [42].

4.5.3 User behaviors

Fig. 7(b) shows the average frequency of quick and long glances at the widgets. The Wilcoxon signed-rank tests showed that participants performed quick glances significantly more often than long glances for Weather ($Z = 3.937, p < .001, r = .535$), Gmail ($Z = 4.464, p < .001, r = .607$), Fitness ($Z = 4.027, p < .001, r = .548$), Calendar ($Z = 4.110, p < .001, r = .559$), and News ($Z = 4.254, p < .001, r = .579$) widgets. As shown in Fig. 7(c), on average participants spent 13.95% of their time customizing the application, 34.84% of time in follow mode (split equally between HG and HG+), and 51.21% of their time in stationary mode in which all widgets are world-fixed. Fig. 7(d) shows that participants spent the largest amount of time gazing at the Gmail and News widgets, followed by Tasks, Fitness, Calendar, Clock and Weather. The average amount of time spent gazing at widgets in a session was 156.94 seconds, or just over 2.5 minutes out of each 30-minute session.

4.5.4 Arrangement strategies

Based on our playback of data from the logs of all 27 sessions, we observed three patterns that participants used to arrange the widgets when they were stationary.

The first common strategy we observed was that participants liked to arrange the widgets around a physical object that was their primary focus. For example, for the 22 sessions that involved participants working in front of a desktop monitor, attending a meeting/class, or watching TV, 16 (72.73%) of the sessions demonstrated strong patterns of arranging the widgets on the edge of the computer monitor, laptop screen, or TV, (as in Fig. 2 (a)). Participants commented that: *I like putting the widgets close to my monitor. I just look slightly beyond the monitor, and they are there;* and *having them around my monitor makes me feel my screen is extended, I do not need to have email window open on my monitor, which saves my screen space.*

The second common strategy we observed was clustering and placing widgets depending on the perceived frequency of use in the session. In the playback of 11 sessions (40.74%), we observed that participants grouped the widgets. A participant commented *it's like when you organize your desk, you move some things closer to you and some things further away depending on how important they are to your task.*

The third strategy, which was interesting but uncommon, was attaching widgets to different locations around the house. We did not collect any information about participants' environment due to privacy concerns. However, a combination of the interview, the diary entries for each session, and the playback allowed us to confirm that widgets were placed in different locations/rooms in a house by two out of the participants. One participant commented: *I tried to position the widgets as if they were at different locations in my house, and I really liked it*; and the other mentioned *I place the weather widget at my door near my keys, so as in situations where I will leave my house, I can quick glance and know if it is going to rain*.

4.5.5 Interview comments

Perceived user experience: The interface received positive feedback from all participants. Participants commented that: *I liked it a lot! I think it is really convenient*, *if it is not that the display hurts my nose, I would really like to use it for longer time* and *I liked that I check the information proactively by turning my head, instead of something pops out on my monitor*. All participants gave positive comments about the gaze-contingent interaction and customization of widgets locations and notification levels. When asked if they were willing to use the interface on a daily basis if the form factor of the display was similar to a normal pair of eyeglasses, all participants gave a positive response.

Perceived distractions: All participants considered the Glanceable AR interface less distracting and disruptive to their primary tasks, compared to existing devices such as smart phones and personal computers. Participants commented: *I can easily check information without picking up and unlocking my phone, but they also stay out of the way when I don't want them.* When asked if they thought the interface was distracting in some scenarios, three participants said they did not consider the interface distracting at all. They commented: *since I can customize their locations, I just put them slightly outside of my view* , and *when I find a widget gets into the way too often, I just mute it in the menu.* The other three participants commented that for the widgets that they do not want to use, even though they are placed far away, they could still get in the view: *It would be great if I can make a widget disappear, or only see the ones that I need.* Two participants mentioned the level of distraction varied depending on the context of use. They commented: *when I am relaxing, I don't wanna read my emails, the notifications from it kinda distract me.* As for notifications, four participants thought having a blinking icon at the periphery was acceptable, while the other two thought that the blinking behavior drew too much attention.

Virtual content addiction: A number of respondents in the first study worried that when information becomes more easily accessible through AR glasses, they might become more addicted to digital information. As such, we asked all participants if they thought they checked information in the widgets more frequently than they would normally do with their phones. Five participants gave a positive response. One commented: *yeah I definitely checked the news and weather more than I would normally do* However, two participants who were inexperienced with AR thought there was a novelty effect. They commented: *they look cool and I think that is why I looked more frequently*. We also asked if participants were worried about virtual content addiction in AR based on their experience of using this interface. Four participants gave negative responses based on the current interface, but all of them said that addiction would be a concern if more widgets were supported. One participant said: *I cannot browse internet, watch videos, or check social media, but if I can, I could definitely see myself addicted with the glasses.*

Follow mode and HG+: All participants were positive about follow mode. Participants commented: *I like having the widget around me but not on my face*, and *it allows me to keep getting information when I am moving*. Three participants mentioned that with the HG interface, widgets sometimes blocked the real-world environment. Three participants reported that they used HG+ frequently, and all of them considered it more convenient and less obtrusive than the HG technique. One participant commented: *it feels magical that I can see through the dots without making the widget appear*, and *It is definitely less distracting than the other technique (HG)*. The other three participants reported that they did not use HG+ frequently due to inconsistent eye tracking.

Favored scenarios: All participants said that Glanceable AR provided benefits when working in front of the computer. Three participants reported that the interface allows them to decide quickly what to do without context-switching. One participant said: *when I get a email, I can quickly glance at the subject and see if it is important. If it is, I quickly go to my computer and reply to the email. In the most cases that it's not, I just ignore it and go back to work, and it takes less than two seconds for me to decide.* Cooking was mentioned by four participants as a useful scenario. One said: *in one session when I was cooking my hands are dirty, and I do not have my phone with me, then an important email comes in, I might miss that email without the display.* As for scenarios they did not try but think the interface could be useful, three of them mentioned having a notes widget during a presentation. Two participants mentioned walking outside with the email widget to avoid missing important emails.

4.6 Discussion

In this section, we will discuss our results based on the **RQ**s.

RQ2.1: In the second study, we were able to confirm the positive quality of user experience of Glanceable AR in authentic everyday scenarios. The interface received excellent SUS and UEQ ratings, and participants expressed willingness to use the interface every day (ignoring the form factor of the display). Given the limitations in form factor of the Magic Leap One headset, the fact that we still received 126.61 minutes more usage time than required from participants also demonstrated the positive usability of Glanceable AR. The major benefits pointed out by participants were that it was less distracting and disruptive to their focus in the real world, as a quick glance requires less context-switching than pulling out a separate device. Having information out of the way but always accessible made the Glanceable AR approach able to handle common unstructured events in everyday life, such as checking email, news, and weather without taking too much of users' attention or cognitive effort. However, participants also wanted more interactions with the widgets beyond simple information access. Some of them wanted to reply to emails directly in the widgets or create a calendar event by voice. Incorporating a higher level of interaction in Glanceable AR could contribute to a more useful experience, but might also lessen some of the benefits described above. The always-on property of the interface also received some criticisms. It could still be distracting in scenarios when users want to be relaxed and isolated from digital information. Having an option to turn off the display completely might be helpful.

RQ2.2 & RQ2.3: We found that users performed quick glances more often than long glances. This indicates that participants were able to understand information in the widget and make decisions quickly within a short duration. The scenarios that users perceive as the most beneficial for Glanceable AR were very similar to what we showed in the video prototype in the first study. When viewing a primary physical display, participants demonstrated patterns of placing widgets around the physical monitor or clustering them by usage frequency. We found it very interesting that some participants developed the strategy of enlarging and placing the widgets all around the house to bind the widgets with the context of rooms. Combining Glanceable AR with context-sensitivity, it could be possible to enable a more adaptive and unobtrusive information display.

Overall, our findings demonstrate that the Glanceable AR approach has great potential for everyday information access tasks. Our interface provides design inspiration for future implementations of Glanceable AR interfaces. Based on the feedback from participants, we would suggest incorporating gaze-contingent interaction features to maximize unobtrusiveness; integrating a follow feature for on-the-go access to widgets; empowering customization of locations, scales, and notification levels of widgets; and allowing users to dim the display completely when they do not want to be disturbed. We have confidence in the validity of our findings since they were obtained in unsupervised real-world settings in authentic scenarios.

5 Limitations and Future Work

There are several limitations of our work. In the first study, our sample was not gender-balanced, which could have affected the results to some degree. Second, participants' responses after watching the video prototype might not reflect their opinions of actually using the interface. We addressed this limitation with study 2. Third, the participants of the second study were all college students, which could contribute to working in front of a computer being the most frequent scenario of using the interface. Future work could be conducted to recruit more participants with diverse backgrounds to evaluate the approach. Fourth, our prototype mainly displayed information to users. Future work could explore how different levels of interactions with the widgets could affect user experience in everyday scenarios. Fifth, several participants were not in the habit of using some of the widgets in their daily lives (e.g., three participants did not use the Google fit service), which made the interface less useful to them. Sixth, participants only used the interface indoors in home or office environments. Further research could explore the user experience of Glanceable AR outdoors. Seventh, interactions with the widgets including positioning and customization were achieved through a controller. The hand-held nature of the controller could make it challenging to be applied to everyday use cases. Future research could explore voice, hand gestures or gaze as potential input modalities. Finally, we did not collect any data about the environmental features that participants used the interface in. Future research could explore how environmental features (location, space, public/private) would influence patterns of using the interface.

6 Conclusions

In this research, we explored Glanceable AR as an approach for pervasive, general-purpose information display with future AR HWDs. In our first study, we demonstrated potential everyday scenarios of using Glanceable AR in a video prototype and obtained feedback from sixty-three participants in a survey. In the second study, we implemented a working application and studied real-world authentic use by six participants. To our knowledge, this was the first in-the-wild AR study that explored AR HWDs for general-purpose everyday use cases. Our results shed light on the design of future general-purpose interfaces for AR HWDs that are not distracting and easy to access at the same time. We found strong evidence for the potential of the Glanceable AR approach to support the everyday information access needs of average users once always-on AR glasses are widely available.

Acknowledgments

We thank the study participants and anonymous reviewers. This work has been supported by the Office of Naval Research.

REFERENCES

[1] A. Bangor, P. T. Kortum, and J. T. Miller. An empirical evaluation of the system usability scale. *Intl. Journal of Human–Computer Interaction*, 24(6):574–594, 2008.

[2] M. Billinghurst and T. Starner. Wearable devices: new ways to manage information. *Computer*, 32(1):57–64, 1999.

[3] T. Blascheck, L. Besançon, A. Bezerianos, B. Lee, and P. Isenberg. Glanceable visualization: Studies of data comparison performance on smartwatches. *IEEE transactions on visualization and computer graphics*, 25(1):630–640, 2018.

[4] P. Bolliger and B. Ostermaier. Koubachi: A mobile phone widget to enable affective communication with indoor plants. *Mobile Interaction with the Real World (MIRW 2007)*, p. 63, 2007.

[5] D. Bowman, E. Kruijff, J. J. LaViola Jr, and I. P. Poupyrev. *3D User interfaces: theory and practice, CourseSmart eTextbook*. Addison-Wesley, 2004.

[6] D. A. Bowman and L. F. Hodges. An evaluation of techniques for grabbing and manipulating remote objects in immersive virtual environments. In *Proceedings of the 1997 symposium on Interactive 3D graphics*, pp. 35–ff, 1997.

[7] J. Brooke. Sus: a "quick and dirty'usability. *Usability evaluation in industry*, p. 189, 1996.

[8] B. Brown, S. Reeves, and S. Sherwood. Into the wild: challenges and opportunities for field trial methods. In *Proceedings of the SIGCHI conference on human factors in computing systems*, pp. 1657–1666, 2011.

[9] J. Cadiz, G. Venolia, G. Jancke, and A. Gupta. Sideshow: Providing peripheral awareness of important information. 2001.

[10] J. Cohen. *Statistical power analysis for the behavioral sciences*. Academic press, 2013.

[11] E. Costanza, S. A. Inverso, E. Pavlov, R. Allen, and P. Maes. Eye-q: Eyeglass peripheral display for subtle intimate notifications. In *Proceedings of the 8th conference on Human-computer interaction with mobile devices and services*, pp. 211–218, 2006.

[12] C. Courage and K. Baxter. *Understanding your users: A practical guide to user requirements methods, tools, and techniques*. Gulf Professional Publishing, 2005.

[13] N. Dahlbäck, A. Jönsson, and L. Ahrenberg. Wizard of oz studies: why and how. In *Proceedings of the 1st international conference on Intelligent user interfaces*, pp. 193–200, 1993.

[14] S. Di Verdi, D. Nurmi, and T. Hollerer. Arwin-a desktop augmented reality window manager. In *The Second IEEE and ACM International Symposium on Mixed and Augmented Reality, 2003. Proceedings.*, pp. 298–299. IEEE, 2003.

[15] S. Feiner, B. MacIntyre, M. Haupt, and E. Solomon. Windows on the world: 2d windows for 3d augmented reality. In *Proceedings of the 6th annual ACM symposium on User interface software and technology*, pp. 145–155, 1993.

[16] S. K. Feiner. Augmented reality: A new way of seeing. *Scientific American*, 286(4):48–55, 2002.

[17] N. Gavish, T. Gutiérrez, S. Webel, J. Rodríguez, M. Peveri, U. Bockholt, and F. Tecchia. Evaluating virtual reality and augmented reality training for industrial maintenance and assembly tasks. *Interactive Learning Environments*, 23(6):778–798, 2015.

[18] J. H. Goldberg and J. C. Schryver. Eye-gaze-contingent control of the computer interface: Methodology and example for zoom detection. *Behavior research methods, instruments, & computers*, 27(3):338–350, 1995.

[19] J. Grubert, M. Heinisch, A. Quigley, and D. Schmalstieg. Multifi: Multi fidelity interaction with displays on and around the body. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*, pp. 3933–3942, 2015.

[20] J. Grubert, T. Langlotz, S. Zollmann, and H. Regenbrecht. Towards pervasive augmented reality: Context-awareness in augmented reality. *IEEE transactions on visualization and computer graphics*, 23(6):1706–1724, 2016.

[21] J. Guo, D. Weng, Z. Zhang, H. Jiang, Y. Liu, Y. Wang, and H. B.-L. Duh. Mixed reality office system based on maslow's hierarchy of needs: Towards the long-term immersion in virtual environments. In *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 224–235. IEEE, 2019.

[22] J. Häkkilä, A. Colley, and J. Rantakari. Exploring mixed reality window concept for car passengers. In *Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, pp. 1–4, 2014.

[23] R. Hansson, P. Ljungstrand, and J. Redström. Subtle and public notification cues for mobile devices. In *International Conference on Ubiquitous Computing*, pp. 240–246. Springer, 2001.

[24] J. M. Heiner, S. E. Hudson, and K. Tanaka. The information percolator: ambient information display in a decorative object. In *Proceedings of the 12th annual ACM symposium on User interface software and technology*, pp. 141–148, 1999.

[25] T. Hirzle, J. Gugenheimer, F. Geiselhart, A. Bulling, and E. Rukzio. A design space for gaze interaction on head-mounted displays. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pp. 1–12, 2019.

[26] R. J. Jacob. Eye movement-based human-computer interaction techniques: Toward non-command interfaces. *Advances in human-computer interaction*, 4:151–190, 1993.

[27] P. E. Kourouthanassis, C. Boletsis, and G. Lekakos. Demystifying the design of mobile augmented reality applications. *Multimedia Tools and Applications*, 74(3):1045–1066, 2015.

[28] J. LaViola, B. Williamson, C. Brooks, S. Veazanchin, R. Sottilare, and P. Garrity. Using augmented reality to tutor military tasks in the wild. In *Proceedings of the Interservice/Industry Training Simulation & Education Conference, Orlando, Florida*, 2015.

[29] J. J. LaViola Jr, E. Kruijff, R. P. McMahan, D. Bowman, and I. P. Poupyrev. *3D user interfaces: theory and practice*. Addison-Wesley Professional, 2017.

[30] Z. Li, M. Annett, K. Hinckley, K. Singh, and D. Wigdor. Holodoc: Enabling mixed reality workspaces that harness physical and digital content. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, pp. 1–14, 2019.

[31] F. Lu, S. Davari, L. Lisle, Y. Li, and D. A. Bowman. Glanceable ar: Evaluating information access methods for head-worn augmented reality. In *2020 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, pp. 930–939. IEEE, 2020.

[32] T. Matthews. Designing and evaluating glanceable peripheral displays. In *Proceedings of the 6th conference on Designing Interactive systems*, pp. 343–345, 2006.

[33] T. Miller and J. Stasko. The infocanvas: information conveyance through personalized, expressive art. In *CHI'01 Extended Abstracts on Human Factors in Computing Systems*, pp. 305–306, 2001.

[34] A. Morrison, A. Oulasvirta, P. Peltonen, S. Lemmela, G. Jacucci, G. Reitmayr, J. Näsänen, and A. Juustila. Like bees around the hive: a comparative study of a mobile augmented reality map. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pp. 1889–1898, 2009.

[35] A. Neshati, Y. Sakamoto, L. C. Leboe-McGowan, J. Leboe-McGowan, M. Serrano, and P. Irani. G-sparks: Glanceable sparklines on smartwatches. In *Graphics Interface*, pp. 23–1, 2019.

[36] J. Pallant. Survival manual. *A step by step guide to data analysis using SPSS*, 2011.

[37] T. Pfeiffer, M. E. Latoschik, and I. Wachsmuth. Evaluation of binocular eye trackers and algorithms for 3d gaze interaction in virtual reality environments. *JVRB-Journal of Virtual Reality and Broadcasting*, 5(16), 2008.

[38] I. Popovici and R.-D. Vatavu. Understanding users' preferences for augmented reality television. In *2019 IEEE International Symposium on Mixed and Augmented Reality (ISMAR)*, pp. 269–278. IEEE, 2019.

[39] K. Rehrl, E. Häusler, R. Steinmann, S. Leitinger, D. Bell, and M. Weber. Pedestrian navigation with augmented reality, voice and digital map: results from a field study assessing performance and user experience. In *Advances in Location-Based Services*, pp. 3–20. Springer, 2012.

[40] R. Rosenthal, H. Cooper, and L. Hedges. Parametric measures of effect size. *The handbook of research synthesis*, 621(2):231–244, 1994.

[41] J. Saldaña. *The coding manual for qualitative researchers*. Sage, 2015.

[42] M. Schrepp, A. Hinderks, and J. Thomaschewski. Construction of a benchmark for the user experience questionnaire (ueq). *IJIMAI*,

4(4):40–44, 2017.

[43] M. Schrepp, A. Hinderks, and J. Thomaschewski. Design and evaluation of a short version of the user experience questionnaire (ueq-s). *IJIMAI*, 4(6):103–108, 2017.

[44] T. Starner. Project glass: An extension of the self. *IEEE Pervasive Computing*, 12(2):14–16, 2013.

[45] A. Steed, S. Frlston, M. M. Lopez, J. Drummond, Y. Pan, and D. Swapp. An 'in the wild'experiment on presence and embodiment using consumer virtual reality equipment. *IEEE transactions on visualization and computer graphics*, 22(4):1406–1414, 2016.

[46] L. Ventä-Olkkonen, M. Posti, O. Koskenranta, and J. Häkkilä. Investigating the balance between virtuality and reality in mobile mixed reality ui design: user perception of an augmented city. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational*, pp. 137–146, 2014.

[47] L. Vising. Mobile widget architecture, 2008.

[48] C. Wisneski, H. Ishii, A. Dahley, M. Gorbet, S. Brave, B. Ullmer, and P. Yarin. Ambient displays: Turning architectural space into an interface between people and digital information. In *International Workshop on Cooperative Buildings*, pp. 22–32. Springer, 1998.