In-the-Wild Experiences with an Interactive Glanceable AR System for Everyday Use

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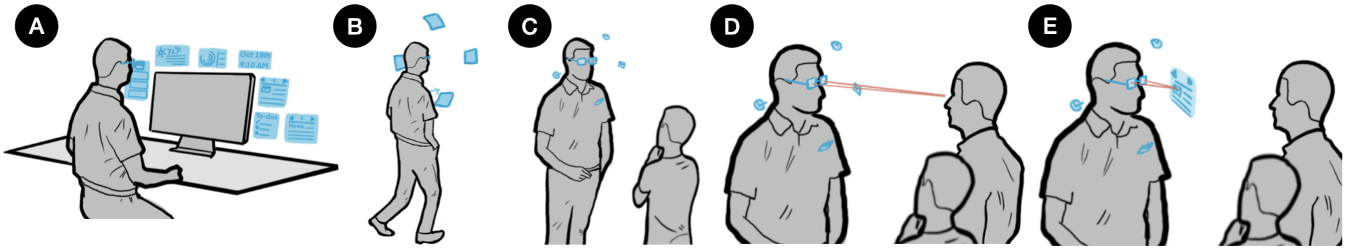

Figure 1: Usage scenarios for the interactive Glanceable AR system: (a) AR apps that are world-fixed to a physical monitor; (b) Body-fixed AR apps with the Head-Glance (HG) interface for mobile use; and (c) Body-fixed AR app icons which can be activated as needed during a social conversation. (d-e) A demonstration of the fixation-glance technique based on gaze vergence depth; if the user fixates on a conversation partner behind the AR app icon, the icon remains minimized, but verging on the icon causes it to expand, revealing app information.

ABSTRACT

Augmented reality head-worn displays (AR HWDs) of the near future will be worn all day every day, delivering information to users anywhere and anytime. Recent research has explored how information can be presented on AR HWDs to facilitate easy acquisition without intruding on the user's physical tasks. However, it remains unclear what users would like to do beyond passive viewing of information, and what are the best ways to interact with everyday content displayed in AR HWDs. To address this gap, our research focuses on the implementation of a functional prototype that leverages the concept of Glanceable AR while incorporating various interaction capabilities for users to take quick actions on their personal information. Instead of being overwhelmed and continuously attentive to virtual information, our system centers around the idea that virtual information should stay invisible and unobtrusive when not needed but is quickly accessible and interactable. Through an in-the-wild study involving three AR experts, our findings shed light on how to design interactions in AR HWDs to support everyday tasks, as well as how people perceive using feature-rich Glanceable AR interfaces during social encounters.

CCS CONCEPTS

• **Human-centered computing** → **Interaction techniques**; **Empirical studies in interaction design**; **Mixed / augmented reality**.

KEYWORDS

interaction technique, adaptive interface, glanceable information, head-worn augmented reality, in-the-wild user study

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1 INTRODUCTION

Recent advancements in display technology and hardware are making augmented reality head-worn displays (AR HWDs) increasingly lightweight and powerful. In the near future, they could have a close-to-eyeglasses form factor and be worn all-day, overlaying information anywhere and anytime to assist users' everyday tasks.

Recently, Grubert et al. proposed the term "pervasive AR", in which they believe that, unlike conventional AR experiences that used to be sporadic and special-purpose, future AR interfaces need to be continuous, omnipresent, and universal to support users anytime and anywhere [15]. However, AR content has the potential to hinder real-world activities. By being pervasive and always available, interfaces can become intrusive, overwhelming, distracting, and occlude essential elements in the user's physical surroundings. As Grubert suggested, the pervasive AR vision requires the

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design of "appropriate information display and interaction, which is unobtrusive, not distracting, and is relevant and safe to use [15]."

Motivated by this, more recent work began to investigate how to display information in AR in non-distracting, non-intrusive, easy-to-access, and easy-to-understand ways [7, 21, 26, 28, 31]. Glanceable AR, proposed by Lu et al., is a paradigm that aims to enhance the unobtrusiveness of information displayed in AR without sacrificing its accessibility [26]. In Glanceable AR, virtual information is secondary and placed outside the user's central vision, and can be prioritized whenever needed.

Building upon the concept, a series of works have validated the usability of Glanceable AR in both controlled laboratory studies and in-the-wild evaluations [10, 24]. However, there are two gaps. First, existing work primarily used AR HWDs as information display and consumption devices. If AR HWDs are to be truly versatile, users need to not only check information but also take quick action on the information when desired. Examples include deleting an email after receiving it, finding the location of the next meeting after obtaining an event notification, or opening a news article after seeing its headline. Thus, we ask how much interaction with Glanceable AR content users would desire, and how they would like these interactions to occur. Second, existing work evaluated Glanceable AR in mostly single-user scenarios. We still need to understand how users would perceive using an unobtrusive AR system while having social encounters with co-present others.

In this work, we attempted to fill these gaps by extending the Glanceable AR paradigm. We implemented a practical high-fidelity prototype that allows both the display of interaction with personal information in AR. Our system draws insights from calm technology, peripheral awareness, and the Glanceable AR concepts. Different from how current digital content consumes and demands the user's attention continuously, we propose that virtual information should stay unobtrusive in the background, but is easily accessible and interactable whenever needed. We further integrated three techniques to trigger these interactions, including gaze-based dwell, gaze-vergence, and eye blinks. We collected over 10 hours of in-the-wild system usage by three experts and analyzed user behaviors and usage patterns.

Our results demonstrate how interactions could take place in everyday use of AR HWDs, how users prefer different interaction options, and how users perceive using the Glanceable AR approach while moving around and having face-to-face conversations with others. Our findings provide valuable insights on designing systems that support everyday viewing and interaction needs with personal information in AR HWDs, both in single-user and social situations.

2 RELATED WORK

Researchers in the field shed light on the future of AR decades ago. Back in 2002, Feiner mentioned that he believed the future of AR would "become much like telephone and PCs ... the overlaid information will become what we expect to see at work and at play [11]." In 2010, Want wrote that "AR could become an indispensable tool of the future in much the same way we have come to rely on the cell phone today [43]." AR devices have been bulky and heavy, with limited display capabilities. As such, significant research has explored the applications of AR in special-purpose uses, such as education/training[19, 44] and surgery [12, 38]. More recently, with hardware advancements, AR and mixed reality (MR) HWDs have become capable of supporting tasks that frequently occur in our daily lives, such as information acquisition/monitoring [22, 26], productivity [3, 4, 9, 23, 30], collaboration [14, 20, 33], and entertainment [17, 29, 34]. Recent devices offer precise tracking of head/hand/eyes, bright high-resolution displays, and reasonable comfort and field of view (FOV), all of which can be used to deliver relevant information to users when needed in a variety of situations[1,2].

However, realizing the pervasive AR future requires advancements not only in hardware, but also in user interface designs. Since AR HWDs can display information pervasively anywhere and anytime without the constraints of other mobile devices, if not designed carefully, AR content can quickly take over the real world and become intrusive to people's reality and their physical tasks. This has been seen as an important challenge in AR, with researchers seeking information display methods that empower quick access while avoiding distractions, information overload, and occlusions between virtual and real objects [2, 13, 28].

Motivated by this, recent work started to investigate how to present information in AR in ways that are unobtrusive and accessible to users. For example, Lu et al. proposed Glanceable AR, a concept in which virtual content is placed in the periphery to stay unobtrusive [24–26]. Orlosky et al. proposed HaloContent, an interface which allows non-invasive presentation of AR content while avoiding occlusions [28]. Cai et al. proposed ParaGlassMenu, an AR interface in which virtual content is fixed around a conversation partner's face for quick input [8]. Davari et al. studied an interface which adapts its spatial position and transparency during social conversations [10].

However, three directions remain underexplored in the literature: (1) As Abowd and Mynatt mentioned, different from typical laboratory studies, computing activities that happen in our daily lives rarely have a clear beginning/end, so we must expect interruptions and concurrent operation of other tasks [1]. Such characteristics make actual field deployment and evaluations of promising systems critical, to understand genuine user perceptions and needs in their actual everyday contexts. However, there has been a lack of in-the-wild evaluations in the context of everyday AR information access. (2) According to the technology adoption model (TAM), in order for users to accept and use a new technology, it needs to not only be perceived as useful but also to produce high levels of intention by users to adopt it [42]. Social influence is a crucial component of such intention. However, there has been a lack of studies that explore the use of proposed interfaces during both informal and formal social encounters that occur everyday; (3) There has been a lack of a standalone proof-of-concept prototype which integrates design ideas into one system. This would help understand user perceptions of a proposed system as a whole rather than partially on separate design components.

In this work, we addressed all these gaps by implementing and deploying an integrated and functioning prototype that took inspiration from recent research. Our system displays users' personal

[1]Apple Vision Pro: https://www.apple.com/apple-vision-pro/
[2]Magic Leap: https://www.magicleap.com/en-us/

Table 1: Interactive features provided with each Glanceable AR app.

Application	Interactive Features
Email	Navigate/open/delete/star emails
Calendar	Navigate/open events
News	Refresh/open articles
Clock	Set timer/alarm
Tasks	Check/uncheck to-do items
Weather	-
Activity	-

information as interactive Glanceable AR apps. With an in-the-wild user study, we collected over ten hours of use from three AR experts and produced novel insights on the proposed interactions and uses in social contexts.

3 SYSTEM DESIGN

In order to explore everyday uses of AR HWDs for personal information access, we implement a prototype on the Magic Leap One AR display. The optical see-through characteristic of it allows the users to clearly see the real world and conduct everyday physical tasks at ease such as reading texts on physical monitors. It also provides good eye and hand tracking, and can be worn comfortably for over an hour.

We design and provide seven popular apps into our prototype (seen in Figure 2). They include Calendar, Email, and Activity (apps that displayed information linked with the user's own Google account); Weather, Clock, and News (apps that display the current weather forecast, time and news articles based on the user's actual location); and Tasks (an app that shows to-do lists based on a Google Sheet).

3.1 Glanceablility

To avoid distracting or disrupting users' tasks in the real world, following the design principles of Glanceable AR, these apps are positioned at the periphery, to stay unobtrusive, but can be accessed via a glance whenever needed. To enhance the glancing experience, we implemented a "gaze-hover" feature. UIs on apps that are interactable are enlarged upon being gazed at, which makes them easier to gaze and serves as indicators that users could trigger potential interactions on them (see Figure 4 (a)).

3.2 Supporting both stationary and mobile use

To support seated stationary use cases, the position and location of the AR apps could be freely customized via raycasting with a handheld controller. By pointing the controller at an app, then clicking and holding the trigger button, the apps could be freely dragged around in space. They could also be scaled via the touchpad.

To support mobile use, we enhanced the mobility of the AR content by integrating the Head-Glance interface (HG), in which AR apps are fixed to the user's torso and stay outside of the central FOV of the AR display [24, 26] (see Figure 1 (b)). Each app has a "follow mode", which is triggered by selecting the follow button on the side menu (see Figure 4 (c)). Upon selection, the app would be attached to the user's body torso and stay outside of the centrak vision. Users could turn their head independently of their body in order to access the virtual information. Users wear the controller in a custom-designed belt in order to allow for body tracking independent of head tracking. To avoid potential distractions or information overload, the users can have four apps following them at a time by maximum, allocated to top, down, left, right positions.

3.3 Fixation Glance and Blink for activations

In mobile settings, even placed outside the central view, body-referenced apps can still be intrusive due to the dynamic nature of the physical surroundings. To further improve the unobtrusiveness of HG, we include the option for the users to further minimize the body-referenced apps as icons and activate them upon request (see Figure 1 (c-e)). We implemente Fixation-Glance (FG) and Blink techniques for activating the AR apps [25]. Using FG, users need to look at an app and converge their gaze to the depth of the icon to make the app expand and show more content (see Figure 1 (e)). As such, if users are looking at the real world behind the body-referenced icon, the content would not appear to avoid blocking the user's view (see Figure 1 (d)). Recent work also strongly favored Blink as an interaction method [27], notably for rapid activation of AR content with high social acceptance [25]. As a result, we implement Blink as an alternative to FG to activate applications (see Figure 5). Users gaze at a given icon and blink their eyes twice to expand it. The icon of the AR app wiggles as visual feedback when blinks were successfully detected. By default, the Fixation Glance technique was enabled for activating targets.

3.4 Supporting interactive features

To incorporate interactive features into the AR apps, we started by brainstorming and filtering through a list of interactive features. We narrow it down to a subset of promising features, focusing on quick and simple interactions that are frequently needed right after an information acquisition behavior (e.g., delete an email after reviewing it; check attendees and locations of an upcoming calendar event). Different from prior work in Glanceable AR or other general-purpose AR systems, we include navigation features in the Email, Calendar and News apps (see Figure 4 (a)). Users are able to navigate through multiple pages of emails, calendar events, and news articles through gaze-based dwell or blink interactions. In the Email app, users are able to trash an email or star an email after reading it (see Figure 4 (b)). For the Clock app, users can set a timer or an alarm. For the Tasks app, users can mark a task as completed / incomplete. As such, five out of the seven applications allow functions beyond viewing and consuming information (see Table 1).

3.4.1 Lowering the cost of manual interactions. We attempt to minimize the use of the hand or hand-held controller, given that hands are frequently occupied by other tasks in our daily lives. In our system, a controller was only needed for the initial placement of AR applications in the physical space (future systems would likely use bare-hand interaction for this purpose, but the hardware we use does not fully support such interactions). App placement is automatically restored if the space is recognized, so it only needed to be done once for uses in the same space. Hands are used for rapidly

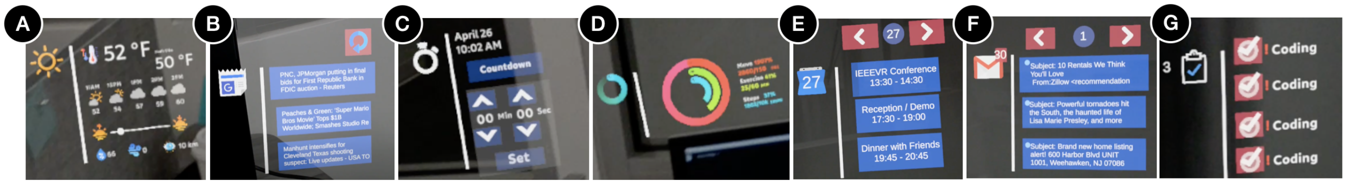

Figure 2: An overview of the seven applications integrated in the interactive Glanceable AR system: (a) Weather; (b) News; (c) Clock; (d) Activity; (e) Calendar; (f) Email; and (g) Task.

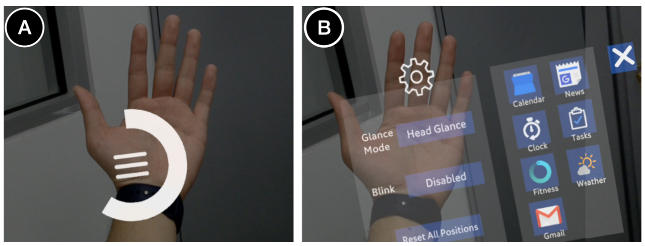

Figure 3: Hand menu. The user raises their hand to trigger the menu, then interacts with menu items via gaze-based dwell/blink interactions.

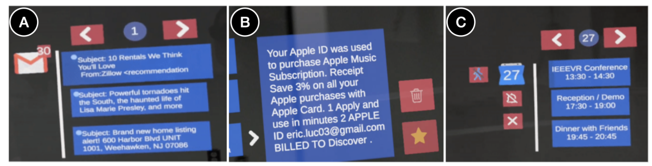

Figure 4: (a) Design of the Email, Calendar, and News apps. Gazing at an interactive item (e.g., an email subject) would enlarge it, making it easier to glance at. (b) Interactive features included *Trash* and *Star* buttons; (c) Each app has a built-in menu with three features: follow (left), mute (middle) and close (bottom).

Figure 5: Design of the Follow feature. (a) In minimized mode, an icon represents the minimized application; (b) A wiggling animation was used to indicate successful detection of user blinks; (c) After two consecutive blinks, the app was activated. A visual indicator indicates the placement of the app relative to the body.

summoning a menu. After the user raises their hand and faces their palm towards the headset camera, a menu appears alongside the palm (see Figure 3 (a-b)). In this menu, users can toggle the visibility of each AR application, switch between HG and FG-based interaction methods, and enable/disable blink-based confirmation (see the following section) through gaze-based interactions. Functions that are universally applicable for each application, such as toggling follow mode, mute, and close, were moved to a universal menu that appears after the user gazes at the icon of each application (see Figure 4 (c)) to further reduce the required uses of hand and controllers.

3.4.2 Blinking as a confirmatory input. Furthermore, we attempt to integrate Blink not only as a method of activation, but also as a confirmatory input as an alternative to the traditional dwell interaction. After enabling blinking mode, users can utilize blink as a replacement for dwell to prevent "Midas Touch" [16]. For example, instead of dwelling on an email title to confirm intent on viewing the body of the email, users can blink their eyes twice while looking toward the email subject. As such, users can take their time reading the email's subject, not worrying about it being opened unintentionally after the dwell timer runs out. Through this approach, we want to study the pros and cons of using Blink more universally as a confirmation interaction. For both Dwell and Blink, a progress bar appears on the UI as visual feedback. By default, Dwell interactions was enabled to prevent Midas Touch. Users needed to enable Blink through the hand menu.

3.4.3 Closing/Muting apps. Participants are allowed to close or mute any app using buttons attached to each app (see Figure 4). Such features were noted as desirable in prior work [24]. Participants can have better control by only having the needed and relevant apps opened. The system also provides notification features. When a new email comes in, a calendar event is approaching, a timer/alarm runs out, a new news article is collected, and when it is about to rain, the system notifies the users by showing an icon at the edge of the FOV, guiding the users to look at the corresponding app that has updated information. Users are allowed to disable (mute) notifications on a per-app basis using the hand menu. By default, all the apps were opened and not muted when the system just started.

4 EXPERIMENT

To evaluate our interactive Glanceable AR prototype design, and to gain insight into future real-world use of Glanceable AR for everyday use cases, we performed an ecologically-valid in-the-wild study.

4.1 Research Questions

We aimed to answer the following research questions:

- **RQ1.** What features and design elements make a Glanceable AR system practical for everyday uses?

- **RQ2.** How do users perceive using a feature-rich Glanceable AR system for accessing, managing and interacting with AR apps?
- **RQ3.** How do different interaction techniques compare to each other?
- **RQ4.** How do users perceive using a feature-rich Glanceable AR system during social encounters with others?

4.2 Participants

We recruited three participants (1F/2M) from the local university (Mean age = 34). The small sample size was due to the requirements of the hardware and the multi-session nature of this study. We want to make sure each participant spent enough time using the system. All participants self-identified as experts in AR and used Google services for daily work. We recruited AR experts to gather more design insights on the system from experienced users (who will likely be the major users of AR HWDs in the future with the proliferation of the hardware), and to reduce the amount of required training to become familiar with the interactions and input. All participants used a smartphone, smartwatch, PC, and virtual assistant regularly.

4.3 Experiment Procedure

The study was divided into five phases. In the first phase, participants were asked to complete a background questionnaire and grant the AR application access to their personal Google account. In the second phase, an onsite tutorial session was provided to participants to walk through the hardware, calibration processes, the mobile app, and the Glanceable AR interface. In the third phase, participants were asked to use the AR HWD freely for at least six sessions of at least 30 minutes and to fill out a diary survey immediately after completing each session. We chose 30 minutes empirically because it was a suitable time to wear the Magic Leap One AR headset without experiencing discomfort or notable fatigue, so participants could ignore hardware constraints as much as possible in their experiences. In the diary survey, we asked participants about the time period, scenarios of use, layout of the AR apps, which interactions they tried, and the overall perceived user experience in that session. In the fourth phase, after all sessions were finished, participants were asked to complete two post-study surveys, including the System Usability Scale (SUS) [6] and full version UEQ [18] questionnaires. In the last phase, we conducted a half-hour final interview with participants to ask in detail about their experiences of using the Glanceable AR prototype.

5 QUANTITATIVE RESULTS

5.1 Usage sessions

We collected data from a total of 20 sessions, covering 624.52 minutes of use (10.41 hours). Participants used the prototype under a variety of scenarios (sometimes multiple scenarios in a single session), including working in a laboratory/office (13 sessions), in a class/meeting (5 sessions), having conversations with someone (5 sessions), and walking around (2 sessions).

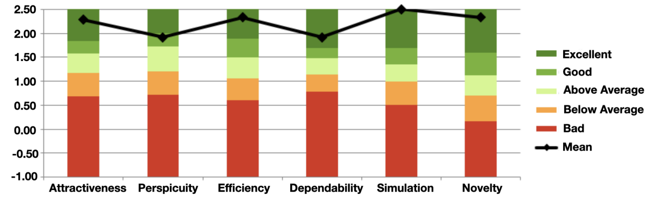

Figure 6: The average UEQ scores and the benchmark results.

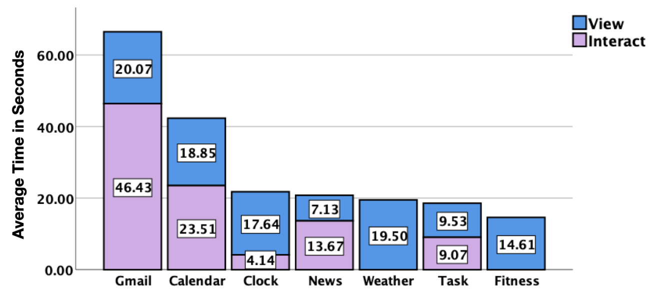

Figure 7: The average time in seconds that participants spent viewing/interacting with each of the AR apps per session.

5.2 Usability Ratings

The interactive Glanceable AR system obtained an average SUS score of 75 (Good) (SD = 2.5) from the three AR experts. Figure 6 illustrates the average UEQ sores compared to the benchmark scores. Other than perspicuity (M = 1.92 - Good), all the other categories received excellent ratings in the range of the 10% best results [36]. At the beginning of each diary entry, we asked participants to rate the quality of their user experience for the previous session. All ratings were above average (≥ 5 in a 1-10 scale) with a mean rating of 7.58.

5.3 Usage Behaviors

During each thirty-minute session, we measured the total time participants used each app, defined as the time in which their gaze direction intersected with the app in stationary mode, when the app was activated and being gazed at in mobile uses, or when they actively interacted with the app). On average, participants used AR apps for 204.12 seconds (see Figure 7), including 66.50 seconds viewing/interacting with the Email app, followed by Calendar (42.35 seconds), Clock (21.78 seconds), News (20.79 seconds), Weather (19.50 seconds), Task (18.59 seconds), and Fitness (14.61 seconds). Participants spent 22.02 seconds opening/closing/muting apps. Participants initiated and completed 20.2 interactions with the AR applications in each session.

The strategies participants used for arranging the AR applications included: (1) placing AR applications around the edge of a physical monitor (P1, P2, P3); (2) arranging AR applications by categories (P1, P2, P3); (3) placing AR applications around a physical desk (P2 & P3); and (4) placing the relevant apps in easy to access locations and either closing the irrelevant apps or placing them further away in locations that are not visible (P1 & P2).

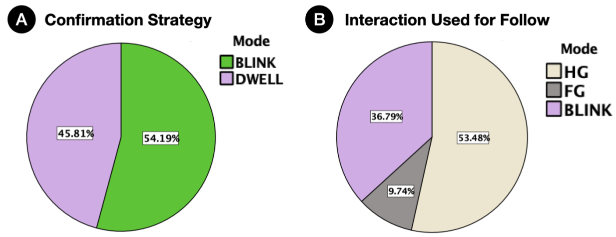

Figure 8: (a) The percentage of time in which users used Blink vs. Dwell as a confirmatory input; (b) percentage of time users used each interactions for glancing at the AR apps during mobile use cases.

5.4 Stationary Uses - Blink vs. Dwell

When the prototype was used in a stationary setting, users could choose either Blink or Dwell as the confirmatory input to trigger certain interactions (e.g., delete email, set a timer). Our results show that in the 502.86 minutes (80.52%) of using the prototype without moving around, participants used Blink for 272.49 minutes (54.19%), which is more than Dwell (230.37 minutes, 45.81%) (see Figure 8 (a)). Participants commented: "If I am trying to read an email, I don't want it selecting that email, like I wish that there is some way to let the system know that ... I want to interact with it. For that reason, with Blink, I can look at information without activating it, and if I want to interact with it, I just blink my eye twice (P1);" and "It works every time ... it was cool, and it was easier for me to access my apps [with Blink] (P2)."

5.5 Mobile Uses - HG vs. FG vs. Blink

Throughout the 20 sessions, participants spent 121.66 minutes (19.48%) using the follow mode with at least one application following them (15.85% with one app, 19.60% with two apps, 26.65% with three apps, and 37.90% with four apps). Among the 121.66 minutes of follow mode use, 65.06 minutes (53.48%) used the HG interface, 11.85 minutes (9.74%) used FG as the activation technique, and 44.76 minutes (36.79%) used Blink as the activation technique (see Figure 8 (b)).

5.6 Open/Closing/Muting Apps

We found that that 67.66% of the time, participants did not close any apps. Then, 6.9% / 6.51% / 18.74% of the time, participants closed 1 / 2 / 3 apps accordingly. The time that participants closed more than three apps were below 0.2%.

When it comes to muting the notifications of apps, 87.09% of the time participants did not mute any apps, and 12.88% of the time participants muted 1 app. The total percentage of time that participants muted more than 1 app is below 0.03%. The most frequently muted app was the news app, which was muted for a total of 30.63 minutes across all sessions.

6 QUALITATIVE RESULTS & DISCUSSION

In this study, we implemented a functioning prototype of an interactive Glanceable AR system. In general, our results demonstrated the positive impact of using AR in everyday life while being supportive, non-distracting, and easy to use, even with the limitations of current hardware. Our prototype received high usability ratings from our expert users. Participants considered the approach novel, attractive, efficient, dependable, stimulating, and helpful. When asked whether they would like to use such a system daily if the form factor of the AR display were ideal, all three participants responded positively.

6.1 Perceived Distractions

All participants mentioned that they like the non-distracting and focusing characteristics of our system: "I did not find the apps at all distracting (P1);" "Unlike when I normally work on my computer, I could .. have just the one main thing that I was working on, and then I can keep my calendar, email, and to-do list, and the clock using the AR apps (P2);" and "It helps me to focus on my main screen, and also being able to access all the apps at the same time without having to leave my main screen out of my field of vision (P3)." The most successful scenario of using the interactive Glanceable AR system was when users had a primary task that needed attention, in which they would customize the locations of the AR apps to be around the periphery of the area of primary visual attention (for example, when users were working in front of a desktop computer, having a class, or talking to someone). In such cases, they could quickly access information with a glance whenever needed and quickly return to their primary tasks with little to no context switching.

6.2 Interactive Features

When asked about their perceptions of the interactive features of the applications, all three participants considered them easy to use, helpful, and non-distracting. Participants commented: "When I get an email, I can quickly glance and delete it if it is not important (P1);" "I used the trash feature a few times, which was nice because I did not have to open up my email client to do that (P2);" "I really like the fact that we can interact with those apps ... the possibility that we can interact with the apps and like see things and trash emails and everything ... make it easier in such a way that I do not have to go to my computer. [I can] interact with the things I see just in AR (P3)."

Our prototype featured significantly more interactivity than prior similar systems (e.g., [22, 24]). This interactivity was deemed useful and did not seem to reduce the unobtrusiveness of the AR apps. In contrast, participants commented that the interactivity feature allowed them to further perform quick actions without using a secondary device or web application, which kept their workspace clean and focused. Participants also mentioned that they would like more applications and features. However, this may come with more distractions, similar to what our mobile phones offer nowadays.

Meanwhile, participants also wished for more features and app support: "If we can have some pre-defined answers like Gmail has, like thank you, sounds great, if I can blink on them to send, it would be super helpful (P3);" "I wish I can have a music control app to switch songs." Participants may also be overloaded with interaction possibilities, as well as the perception and cognition costs to make an interaction decision. Design choices need to be carefully considered to strike a balance between the level of interactivity and the potential distraction and obtrusiveness levels.

6.3 Social encounters with Glanceable AR

In this study, we collected diary entries detailing scenarios when participants were having face-to-face conversations with others wearing the AR HWDs with the AR applications following them around. Participants commented that they felt the Glanceable AR system was socially friendly: "Normally, it would be considered rude to check your phone while talking with someone. However, with this system, I was able to check the email as it was coming in without seeming rude (P1);" "While having conversations with people, it's way nicer to use the Glanceable apps for quick checks (of email, time, calendar) compared to taking out my phone or even looking at my watch. If I had used my phone/watch the same amount as the Glanceable apps, people would have been annoyed with me, or thought I wasn't paying attention to them (P2)." This further evidenced the advantages of unobtrusive interfaces in AR HWDs. The unnoticeability and easy accessibility made it viable to support social conversations without being as in the way as mobile phones and smartwatches. However, some potential issues were also mentioned: "I probably checked my email too much during the conversations, and so I wasn't as completely present as I should have been (P2);" and "since the [conversation partner] cannot see my eyes ... it might be difficult for her to assess my reactions and emotions. Also, there's always a possibility that I get distracted by a new notification (P3)." Due to hardware limitations, users found it hard to keep eye contact with the conversation partner. On the downside of high accessibility, users may feel tempted to be drawn away by the presence of the AR apps around them. A solution to this, as mentioned by P3, is to enable the users to access different modes, such as work mode, productivity mode, and meeting mode, each of which have unique settings for app and notification visibility, to avoid irrelevant apps from appearing and consuming users' attention unnecessarily.

6.4 Confirmatory inputs for stationary and mobile uses

Participants used Blink more than Dwell when stationary, and used Blink more than FG when mobile. The fact that both Dwell and FG were the default interaction techniques when a new session started, but Blink still outperformed them in terms of usage time proved the popularity of the Blink technique. The primary reason for favoring Blink, as mentioned earlier, was due to its ability to fully distinguish the intent of viewing from the intent of interacting: "there are times where I just want to look at the displayed information without trying to activate the various components. I wish there was a discrete way that I could tell the system that I am ready to interact via eye gaze. The blink condition sort of gets close to this (P1)."

Although Blink appears to be a more favorable option, participants also experienced difficulties using Blink due to tracking issues: "the current implementation of Blink is not highly reliable for me, so I often had to try multiple times to activate something (P2)." During Blink, when users' eyes were half-closed, the eye-tracking results jittered, which caused issues when the visual targets were small. Better tracking algorithms will be needed to stabilize the gaze cursor for Blink to be more robust and usable in everyday scenarios. In our studies, participants did not report fatigue while using the Blink technique. In previous research, blink interaction has been explored as a text-entry input for motor-impaired populations [37]. In their evaluations, participants reported slightly higher than average visual fatigue. This indicates that frequent prolonged use of blink interaction could cause eye strain. Future interfaces should be mindful of that by reducing the required blink interactions within a short duration.

An alternative to Dwell/Blink is a technique called Vergence Matching, proposed by Sidenmark et al. in a recent work [39]. Instead of using gaze vergence for content activation, the work proposes correlating changes of gaze vergence depth with movement patterns of the visual target in the depth dimension for target selections. However, as the authors suggests, the technique may cause visual discomfort, and the ability to control eye vergence movements varies from person to person. Beyond gaze-only interactions, research has demonstrated the potential of leveraging other input modalities. For example, Pfeuffer et al. proposed using a pinch gesture to confirm gaze selections [32]. This combination was also recently introduced in the Apple Vision Pro MR headset. Sidenmark et al. proposed using head-based or hand-based pointing in conjunction with gaze in error-prone or challenging selection scenarios [40, 41]. Although integrating other modalities could help clearly separating viewing and interacting, it may induce extra physical fatigue on the users, and it requires multiple input modalities to be simultaneously available. More research is needed to explore lightweight and efficient input and interactions for future AR HWDs.

6.5 Generalization to other AR devices

We believe the system implemented in this work and our lessons learned could be generalized to other AR/MR devices on the market, as well as future devices, that aim to be part of users' everyday workflow. Our system was implemented and tested on the Magic Leap One (ML1) AR headset. We believe the system can be easily replicated on other available AR and MR devices on the market, the majority of which possess better graphical and computational power than the ML1, and have similar specs in other areas such as FOV and resolution.

We should ask, however, whether any limitations of the ML1 affected our findings, and whether our findings will still apply to future AR headsets without such limitations. The ML1 and other current devices may need re-calibration while used in scenarios involving wide-area locomotion or with insufficient lighting. However, the current prototype was designed to use follow mode while walking, which does not require precise absolute tracking, so we do not believe this affected our results. Our system also requires extra hardware to track the user's body torso in relation to the AR HWD. Potential alternatives include using computer vision methods (e.g., head-mounted fish-eye cameras [35, 45]) and commercial motion capture devices[3]. While our approach was certainly inconvenient and would be undesirable for all-day use, it was not mentioned by

[3]Sony mocopi: https://www.sony.net/Products/mocopi-dev/en/

participants as a negative part of the user experience in these short sessions. Finally, the ML1's FOV is relatively small compared to virtual reality (VR) HWDs. If future AR devices have much larger FOVs, this could make techniques like HG *less* usable, since placing content in the periphery would mean placing it much farther from the center of the user's forward-facing view, requiring users to rotate their heads significantly more to view AR content. Future work will need to explore how Glanceable AR principles should be applied in wide-FOV AR HWDs; we could study this now in VR headsets using the MR simulation approach [5].

In general, our results favors the design and implementation of a feature-rich Glanceable AR system. In the system, users' personal information is non-distracting, easily accessible, easily understandable, and easily interactable. Different interaction techniques were implemented for users to not only view their information, but also act upon these information rapidly. Our results shed light on the future in which users are empowered to retain control over their realities while taking advantage of the display modalities of AR HWDs anywhere and anytime, in both single-user and social scenarios.

7 LIMITATIONS AND FUTURE WORK

There are several limitations of our work. First, although all experts, our study involved a small pool of participants. Future work could be conducted to recruit more participants to evaluate the approach. Second, interactions with the apps, including positioning and customization, were achieved through a controller. The handheld nature of the controller could make it challenging to be applied to everyday use cases. Future research could explore voice, hand gestures, and gaze as potential input modalities. Third, the study was conducted within the duration of three to five days. We used this duration due to physical and environmental constraints. We acknowledge that a longer term of use (e.g., 3 weeks or 3 months) may bring different insights to our results, allowing investigations on our system with more granularity, and revealing how user perceptions and behaviors evolve cross-sessions. Future studies could evaluate longitudinal uses of the interactive Glanceable AR approach in everyday scenarios.

8 CONCLUSIONS

In this work, we implemented a general-purpose AR system for everyday information acquisition tasks, in which personal information is displayed as interactive AR apps. Through an in-the-wild deployment with three AR experts, our results demonstrated the positive usability of our design. Participants enjoyed using our system, appreciated the interactive features embedded with the AR apps to perform quick actions such as trashing emails and mark to-do lists, and liked using the app during social encounters with other people. Our results favored eye blinks as an interaction technique and confirmatory input as an alternative solution to dwell for solving Midas Touch. Different from traditional digital experiences that continuously draw users' attention, our results shed light on how to develop AR systems that support everyday information acquisition tasks unobtrusively, allow users to take quick actions on-demand, both in stationary and on-the-go settings, with and without the presence of other people.

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