NotifEye: Using Interactive Glasses to Deal with Notifications while Walking in Public

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ABSTRACT

In this paper we explore the use of interactive eyewear in public. We introduce *NotifEye,* an application that allows a person to receive social network notifications on interactive glasses while walking on a busy street. The prototype uses a minimalistic user interface (UI) for interactive glasses to help people focus their attention on their surroundings and supports discreet interaction by using a finger rub pad to take action on incoming notifications. We studied pragmatic and hedonic aspects of the prototype during a pedestrian navigation task in a city center. We found that, despite the potential risk of overwhelming people with information, participants were able to keep track of their surroundings as they dealt with incoming notifications. Participants also positively valued the use of a discreet device to provide input for interactive glasses. Finally, participants reflected on their (evolving) perception of interactive glasses, indicating that glasses should become smaller, more comfortable to wear, and somewhat of a fashion accessory.

Author Keywords

Wearable Computing; Head-Mounted Displays; Interactive Eyewear; Discreet Interaction; In The Wild Studies.

ACM Classification Keywords

H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

INTRODUCTION

Computers are getting smaller, more powerful, and closer to our bodies. Computers have transitioned from being in a large room (e.g., ENIAC), to our desks (e.g., PCs), to a bag (e.g., laptops), and to our pockets (e.g., mobile phones). A common question these days is where will this trend towards miniaturization take us next. On the one hand, tablets (e.g., Surface or iPad) seem to have favored a larger and more comfortable format that allows complex tasks such as typing, while still providing the freedom and availability of a portable device. On the other hand, wearable computers (e.g., the Pebble watch or Galaxy Gear) have continued the trend towards ever-smaller computers, ones that can be worn on our wrists or other parts of the body. Products such as the Epson Moverio or Google Glass are exploring the possibilities that interactive glasses could soon offer to the general public.

Bumping into street signs and other people while walking on a busy sidewalk is a common problem when people are also trying to check their email or update their Facebook status from their mobile phones [30]. Interactive glasses have the potential to provide timely information (i.e., notifications) while still allowing people to pay attention to and keep an eye on other pedestrians on the sidewalk. However, such a scenario raises three key interrelated questions: do the notifications presented on the interactive glasses affect the person's ability to keep track of the environment [42] while walking on the street? How would people provide input to interactive glasses [26]? And finally, how does the social context [15] affect different aspects of the interaction both for the one wearing the interactive glasses and the passers-by?

We present the design and evaluation of *NotifEye,* which allows a person to use interactive glasses to receive and take action on incoming social network notifications while walking on a busy street. *NotifEye* uses a minimal UI for interactive glasses to help people focus their attention on their surroundings and supports discreet interaction using a finger rub pad to provide input. In a series of *in situ* evaluations of *NotifEye* based on phenomenology, participants reported being able to keep track of their surroundings as they dealt with incoming notifications. Participants also positively valued the use of a discreet input device to interact with glasses. Finally, participants reflected on social acceptability and their (evolving) perception of using interactive glasses in public.

The rest of this paper is structured as follows. We begin by reviewing the relevant related work. Then, we describe the design principles and interaction techniques of *NotifEye* in detail. Finally, we report the results of the evaluation, followed by discussion and conclusions.

RELATED WORK

A large body of prior work has influenced the design of *NotifEye*. We have identified three main related-work areas: wearable computing interaction, mobile notifications, and social acceptability.

ACE '14, November 11 - 14 2014, Funchal, Portugal

ACM 978-1-4503-2945-3/14/11...$15.00
http://dx.doi.org/10.1145/2663806.2663824

Wearable Computing Interaction

Over the past 30 years, wearable computing researchers have been exploring how to contextualize computers in such a way that humans and the computers they use become inextricably intertwined [1,3,7,28,29]. Humanistic Intelligence arises when the human being becomes part of the feedback loop of a computational process, a reciprocal relationship where the computer and the human use each other as one of its peripherals [28]. The continued progress of Moore's Law now means that what would have been considered a super computer at the dawn of much wearable computing work (around 1997) can now fit into maybe a few dozen cubic centimeters or less. Wearable computing hardware has transitioned from large and heavy backpacks [45] to small computers worn on parts of the body such as Symbols's WSS 1000 [42]. Gemperle *et al.* [14] studied and defined the places on the human body where solid and flexible forms can rest without interfering with *dynamic wearability*, or the interaction between the human body and the wearable object in motion. A large body of work has been dedicated to studying ways to interact with head-mounted displays (HMDs) and interactive glasses. Some of these interaction techniques, while originally conceived for interaction with mobile phones, are also relevant to interactive glasses. These include pointing, typing, gesturing [4,8,32], as well as speech and touching the frame as in Google Glass.

With *NotifEye,* we propose discreet interaction techniques for interactive glasses by using a rub pad placed on people's index finger to provide input to the glasses.

Mobile Notifications

Another issue with wearable computing is attention [42]. Our human short-term memory can hold a limited number of chunks of information (i.e., seven plus or minus two). Wearable computing systems can easily overwhelm users with data, leading to information overload. Researchers have been studying the role of interruptions from incoming notifications in mobile contexts. Fischer *et al.* [11], have studied how the content of a given notification and when this notification is delivered affects people's willingness to be interrupted *in situ*. They found that content had a significant effect on people's gut reaction, making people more receptive to content they have expressed interest in, while time of delivery had no effect as they were studying an asynchronous medium (i.e., SMS). In a subsequent study [12], they tried to identify opportune moments to deliver notifications. They found that people were more responsive to interruptions that took place at the end of an episode of mobile interaction (i.e., calling or reading an SMS). Ho and Intille [17] took a different approach and tried to predict receptiveness to getting messages (i.e., reminders and non-caller ID phone calls) by scheduling interruptions and matching them with physical activity transitions (i.e., sitting, standing and walking). They found that messages delivered during transitions were more positively received than when delivered at random times. Costanza *et al*. [8,9] studied ways of delivering notifications on peripheral displays (i.e., LEDs embedded in a pair of ordinary glasses) by manipulating the speed and brightness of the stimuli. They found that the level of disruption and the visibility of cues can be controlled through their brightness and velocity (i.e., fast and bright notifications are noticed quicker). They also found that tasks of very high workload might make some of the cues not noticeable at all due to the visual field narrowing phenomenon. Another approach to notification is the use of an intelligent system, for instance based on context information and machine learning, to let the computer decide whether or not to interrupt the user when an incoming call or message arrives [17, 18, 19]. In general, McFarlane [31] identified four methods for managing interruptions spanning the systems described above: *immediate*, *scheduled* (interruptions happen at defined intervals), *negotiated* (user determines when to attend), and *mediated* (an intelligent system might determine when best to interrupt).

With *NotifEye,* we present notifications to people on interactive glasses with a limited field of view positioned in the user's foveal vision and study whether these affect their ability to keep track of the environment while trying to complete a pedestrian navigation task. In our approach, we leave the decision to the user as to when and how to react to the received notifications.

Social Acceptability

Goffman [15] says people make decisions on social acceptability of their actions by gathering information about their current surroundings and using their existing knowledge. Therefore, interactions set in public places must be designed to account for the presence of spectators or passers-by [38]. Rico and Brewster [40] evaluated the social acceptability of gestures for mobile interfaces. When performing gestures in public, participants reported being aware of the audience around them and that some of them were watching them. In particular, subtle gestures that feel similar to everyday actions were preferred. In a related study, Williamson *et al.* [46] found that people were more frequently and also more comfortable gesturing on the street than on public transport, as any unwanted attention from strangers would more quickly pass by. Using Reeves *et al.*'s [38] gesture classification, Montero *et al.* [33] found that secretive gestures, where both the manipulation and the effect are hidden, were highly socially acceptable for private and public contexts.

By conducting the study of *NotifEye* in public, we explore how the social context affects different aspects of the interaction both for the one wearing interactive glasses and the passers-by.

DESIGN OF NOTIFEYE

Based on the relevant literature described in the previous section, we decided to design and implement the *NotifEye* prototype that: 1) allows a person to receive and take action on incoming social network notifications while walking on a busy street, 2) uses a minimal UI for interactive glasses to help people focus on their surroundings, and 3) supports discreet interaction using a finger rub pad to provide input.

Dealing with Incoming Notifications while Walking

Attention becomes scarce as information becomes plentiful [30], especially in a mobile usage context [22,35,37]. Bumping into street signs and other people while walking on a busy sidewalk is a common problem when people are also trying to check their email or update their Facebook status from their mobile phones. Interactive glasses have the potential to provide timely information (i.e., notifications) while still allowing people to pay attention to and keep an eye on other pedestrians on the sidewalk.

We keep the interaction simple by providing a limited set of options for a person to deal with incoming notifications (i.e., open, close or discard). Replying by typing from the glasses would require heavy user input and is therefore not allowed. People might also prefer to stop walking and take their mobile phone out to reply to an incoming message.

Minimalistic UI Elements to Focus on the Surroundings

Careful UI design is needed when presenting information on interactive glasses so that it interferes as little as possible with the primary task (e.g., walking) [34]. In particular, the use of transitions, animations, fonts, shapes and colors that are specifically designed and targeted for a wearable display avoids creating unnecessary distractions [29].

We take a minimalistic approach to presenting information on interactive glasses by allowing people to subtly see virtual notifications overlaid on top of the physical reality (display-fixed [10] rather than aligned with the world). A minimal user interface consisting of small butterflies carrying notifications flying across the user's view, as a form of ambient visualization, allows people to focus their attention on their surroundings.

Discreet Interaction to Provide User Input

In order for wearable input devices to be adopted in everyday and public situations, they should be as natural and conceptually unnoticeable as possible [39]. Such an input device should be designed for subtle use [2,8,26]. The device should preferably be small, operate eyes-free using small movements, allow for one-handed use, and be readily available [2]. We also avoid highly visible hand gestures that imply waving [32], touching the glasses (e.g., Glass), or looking at one's own hands through the display [45].

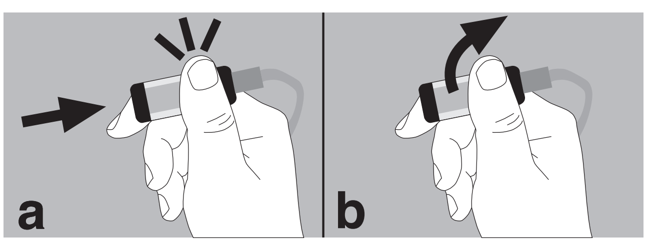

Figure 1. (a) Swiping and holding the finger on the rub pad to open a notification, and (b) lifting the finger to close it.

Figure 2. The *NotifEye* UI shown on the glasses' display. A blue butterfly for an incoming Twitter notification (left) and an open orange butterfly showing a *NotifEye* message (right).

We use discreet interaction using a rub pad placed on people's index finger as the main means to provide user input to the interactive glasses. People are able to make small subtle movements with their fingers, similar to when snapping their fingers, counting coins, or rolling a marble.

INTERACTION

Receiving Notifications

To receive a new notification, a person must be wearing the interactive glasses and must have shared their social network credentials (e.g., Twitter or Facebook). When a new notification arrives, a butterfly carrying the incoming message slowly fades in as it starts flying from one part of the screen to another, gently flapping its wings. The butterfly moves across the display for 10 seconds until it gracefully fades away if the person has decided to not act upon the notification. The choice of a butterfly to carry notifications was meant to feel refreshing, while still being something that can simply be ignored. The butterflies can vary in color to provide visual cues as to which social network the incoming notification belongs to, or to indicate other types of messages (SMSs, email, etc.).

Opening a Notification

To open an incoming notification, the person must use the finger rub pad (Figure 1) and match the direction of the butterfly's flight, which results in displaying the message or contents of the notification (simulated view in Figure 2, right). If the butterfly is flying from left to right on the glasses' display, then the person must swipe the finger rub pad with their thumb in that same direction to reveal the message. Up to six incoming notifications can be displayed and acted upon at a given time (i.e., three in each direction). We match the speed of flight to the speed of swiping that the person provides on the finger rub pad in three different ranges (slow: >800ms; medium: 500-800ms; fast: <500ms). When the opening gesture is triggered, the message appears on the display by means of a fade in as the butterfly slowly flaps its wings in place (Figure 1, right). The expressiveness of the finger rub pad (e.g., soft vs. hard flicks) and alternative ways to provide feedback on it (e.g., electrotactile feedback) were further explored with the help of the Playful Experiences (PLEX) Cards [23].

Reading a Message

Using the metaphor of catching butterflies, once the person has opened the notification they must hold the message (or butterfly) in their hand by keeping their thumb down on the rub pad (Figure 1a). The butterfly and the opened message it carries remain visible on the display for as long as there is contact between the thumb and the rub pad.

Closing a Message

To close a message, the person lets the butterfly go by removing their thumb from the finger rub pad (Figure 1b). The butterfly will gracefully fly away and continue along its previous flight path. This gives the person a chance to reopen the message by swiping and holding again, if needed.

Discarding a Message

To discard a message, the person must press and hold their thumb anywhere on the rub pad for two seconds. As a result, any butterflies currently present in the display will modify their flight path and quickly fly towards the nearest edge of the display. This animation provides a distinct feedback to the wearer about the current state of the interaction, which is especially needed when crossing the street. This is the only mechanism provided by the prototype to control the delivery of information. Similar to Costanza *et al.* [9], we let users make the decision if and how to react to incoming notifications rather than timing their delivery or filtering them based on context.

EVALUATION

In order to assess, a) whether people can cope with incoming notifications while walking in the street, b) the appropriateness of the proposed interaction techniques for interactive glasses, and c) how the social context affects the interaction, we invited people to experience the *NotifEye* prototype during a pedestrian navigation task in the wild. We collected qualitative data both during the navigation task and later during semi-structured interviews. Quantitative data was collected at the end of the task by means of a validated questionnaire.

Participants

The evaluation was conducted with 13 participants who actively use Twitter, Facebook, or both. The participants were chosen to represent a variety of user types, including parents, students, and professionals. The participants varied in gender (7 female, 6 male), age (between 24 and 51), handedness (12 right, 1 left), and background (5 technical, 8 non-technical). All participants owned a mobile phone and were familiar with other touch devices (e.g., iPad), although their attitude towards the use of such devices varied greatly (i.e., from *"I use it everywhere, even in the toilet"* to *"I'm trying to avoid smartphones"*). Most of them (9/13) regularly checked social network updates from their phones in various mobile situations. They had no prior experience with interactive glasses. Some wore prescription glasses (5/13) or contact lenses (3/13) during the evaluation. They were all familiar with the Tampere downtown area.

Figure 3. The evaluation route took participants across two parks connected by a bridge, into the main road where they got the task, until they almost reached the railway station.

Route

The city center of Tampere was picked to put people in a familiar place and frame of mind, one that shapes their expectations without saturating their attention [30]. The entire route (Figure 3) consisted of shared pedestrian and bicycle trails. The first part of the navigation task was designed to allow participants to slowly get used to walking while dealing with the incoming notifications on the interactive glasses. This part of the route included crossing a bridge over the river, walking past a pub terrace, near a children's playground until reaching the main road.

The second part of the navigation task was designed to create a more demanding situation. Participants were asked to walk on a busy street, find a bus stop, and retrieve information about a specific bus. In this situation, walking, safety, looking for the bus stop, and dealing with incoming notifications on the interactive glasses all compete for attention [35]. This part of the route went through Tampere's main road, a busy shopping street that connects the central square and the railway station. Participants had to cross three one-way streets with traffic lights at each intersection, which were rather quiet in terms of traffic. There were large differences in the number of pedestrians (between 45-106) and cyclists (between 3-32) that participants encountered along the route, mainly due to the time of day (10:00-20:30) and the changing weather (sunny-rain).

Procedure

Each 80-minute session consisted of four parts: introduction, training, task, and semi-structured interview. First, the participant arrived at Laikunlava, an open-air stage by the Library Park (Figure 3), where the experimenter greeted the participant, collected background information from them, and provided a description of the study (10 min).

Next, the participant was trained on using the finger rub pad and the interactive glasses by performing 20 trials, i.e., opening 10 notifications in each direction (10 min).

Third, a two-part navigation task started (30 min). The first part of the task was read aloud to the participant and consisted of walking along a predefined route until reaching the main road while dealing with incoming notifications. They were told to feel free to open as many or as few notifications (i.e., blue butterflies) as they wanted. They were also informed to keep an eye on incoming orange butterflies (simulated view in Figure 2, right), which would contain instructions for them (i.e., the second part of the task). The participant kept their mobile phone in their pocket throughout the task and could attend to it if they felt the need to. The experimenter walked a couple of meters behind the participant (Figure 4, right) to ensure the participant's safety (e.g., make sure fast approaching bicycles from behind would not hit them), and to record the interaction using a small GoPro video camera attached to the shoulder strap of his backpack. An observer followed them a few meters further back, taking notes and photos. If the participant reached the main road and had somehow missed the orange butterfly containing the second part of the task, the experimenter would read it aloud to them. The second part of the task was to *walk down the main road towards the railway station and find when the next bus number 13 is coming* by scanning the electronic signs at bus stops along the way. The observer's main task here was safety, making sure the participant would not be hit by an oncoming car when crossing the road. Jaywalking was otherwise allowed. There were no unsafe situations. Once the task was successfully completed, participant and experimenter walked back to the starting point to measure the participant's preferred walking pace [6]. The idea was to get a sense whether the task had slowed the participant down and, if yes, by how much.

Once back at the starting point, the participant was asked to fill-out the AttrakDiff [16] questionnaire, which measures both pragmatic and hedonic aspects of interactive products along four dimensions. Pragmatic quality (PQ) refers to the product's ability to support the achievement of behavioral goals (i.e., usability). Hedonic quality refers to the users' self: *stimulation* (HQ-S) is the product's ability to stimulate and enable personal growth (i.e., personal goals and aspirations), and *identification* (HQ-I), is the product's ability to address the need of expressing one's self through objects one owns (i.e., social aspects of product ownership). Both HQ-S and HQ-I have been found to contribute to perceived attractiveness (ATT), which describes a global value of the product based on the quality perception. Participants indicate their perception of the product by rating 28 pairs of opposite adjectives that relate to the four dimensions on a 7-point scale (-3 to 3). The single evaluation variant of AttrakDiff was used (similar to [24,25]).

Finally, semi-structured interviews were conducted at Laikunlava where participants were asked a consistent number of open-ended questions, prompting them to reflect back on the experience of interacting with the prototype (30 min). All sessions, including the semi-structured interviews, were recorded on video. Participants were given two movie tickets each to compensate them for their time.

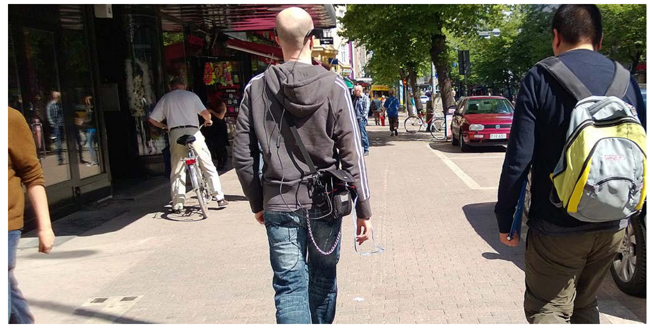

Figure 4. Evaluation setup. A participant walks on a street wearing the glasses as he deals with notifications (center), while a researcher follows a couple of meters behind (right).

Implementation

We implemented *NotifEye*[1] using the commercially available Epson Moverio BT-100 see-through interactive display running Android, a Google Nexus 4 smartphone, an Arduino Mega ADK microcontroller board and a custom finger-worn touch sensitive input device, the finger rub pad. Overall the resulting system is compact, with all the above components except for the interactive display and the finger rub pad fitting into a small-sized camera bag with room to spare (Figure 4, center), and light-weight (240g for the interactive glasses, 35g for the finger rub pad and less than 500g for the camera bag and its contents).

The touch sensitive surface of the rub pad is made up of a grid of 4 by 2 capacitive electrodes covering a total surface area of 4 cm by 1.5 cm. Strips of tape were placed at both extremes of the touch sensitive area to provide tactile cues to people about the location of their thumb with respect to the finger rub pad. The Arduino board, powered by an external battery, connects to the rub pad and reads the touch intensity level for each electrode as a numeric value using the I2C interface. The microcontroller is also connected to the Nexus 4 smartphone through a USB cable.

Software in the Nexus 4 reads the raw touch intensity values, from which the location of finger touch is calculated for both axes using weighted average calculation of the touch intensity values. Since the resulting touch point's coordinates are floating point numbers relative to the physical dimensions of the touch area, touch point calculation is reliable even in the axis where there are only two touch sensors, allowing more gesture possibilities in the future. Gestures (e.g., swipe and hold), including their speed and direction, are detected from the calculated touch points. For instance, a gesture is considered a swipe when the touch point changes more than a predefined threshold along an axis. The threshold value has been experimentally determined to minimize misrecognition of gesture input. If the user holds their finger for a predetermined period (800 ms) of time after a swipe gesture has been detected, it is considered as swipe and hold. In addition, the application in

[1] *NotifEye* video. youtube.com/watch?v=3w2CUoTfnEo

the Nexus 4 provides the swipe event data to an application running in the Moverio through a wireless TCP connection. In order to keep delays as short as possible, a minimal binary transfer protocol is used. The application is also responsible for receiving Twitter notifications through the cellular network. To provide a steady stream of tweets (i.e., around 1 or 2 per minute), a Twitter account following 83 other accounts was set up. Those other accounts covered updates on news (e.g., BBC), companies (e.g., Microsoft), technology (e.g., Engadget), business (e.g., The Wall Street Journal), politicians (e.g., Alexander Stubb), sports (e.g., BBCSport) and local weather (e.g., Ilmatieteen Laitos).

Finally, the application running on the Moverio visualizes the received notifications by drawing butterflies flying across the display against a black background (which is perceived as transparent). The Moverio's 960 by 540 pixel display has a field of view of 23 degrees projected to both eyes, with the resulting virtual image positioned in the user's foveal vision, perceived as an 80-inch image from a distance of 5 meters. Considering the long daylight hours in Finland at the time of the year when the study was conducted (i.e., sunrise at 3:45 and sunset at 23:05), the Moverio's removable lens shades were on all the time and the display brightness was set to maximum to allow proper visibility of the UI elements.

Analysis

Affinity diagramming [20] was used to analyze the data from both the observations of use and the semi-structured interviews. Two researchers independently made notes as they watched the videos for each of the 13 participants. The same two researchers collaboratively analyzed the qualitative data through several interpretation rounds. The affinity diagram supported categorization and visualization of the main themes emerging from the data. These themes form the core of our results section.

RESULTS

In the following sections we describe the main results of the *NotifEye* evaluation. First, we present how people dealt with incoming notifications while walking. Second, we look at people's interactions with the glasses. Finally, we examine people's reactions to using the prototype in public.

Dealing with Incoming Notifications while Walking

In general, almost all participants (12/13) positively valued the idea of receiving notifications on interactive glasses. The use of butterflies to represent incoming messages was surprising and fun to them, and fitted nicely within the city environment: *"It's really nice that the butterfly comes flying because it comes with a message. It's nice to open the message through the butterfly."* (P10) *"I don't [use] push notifications. […] But this way, it was nice to get the butterfly and try to catch them."* (P1) On stimulation (HQ-S), the second of the two hedonic dimensions of AttrakDiff (Figure 5), the prototype is located in the average region, which means people think it is inventive and creative. This rating is mostly connected to the minimalistic UI design.

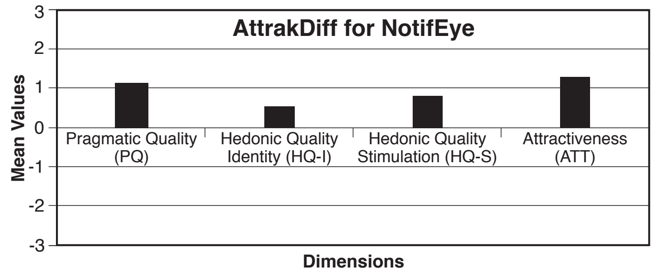

Figure 5. Mean values along the four AttrakDiff dimensions.

Most participants (11/13) focused on the practical aspects of such an application, saying that it allows them to receive information in a convenient manner and it could free their hands up to do other things, thus saving time: *"It's more practical when you go out because, if you are busy walking, then you don't need to do some extra effort."* (P7) *"[With this], I would then be able to do other stuff, like being with the kids or cleaning."* (P10) On the AttrakDiff questionnaire (Figure 5), the prototype was rated high on the pragmatic quality (PQ) dimension, indicating that it supports people's goals and they see a practical use for it. Along these lines, participants reflected on how interactive glasses have the potential to provide similar functionality and services as smartphones (e.g., call, messaging, camera, Skype, news, weather, reminders, currency rates). While this finding is not new, to our knowledge, no studies conducted *in situ* and with users who are unfamiliar with wearable computing have naturally reported this potential evolution of mobile phones towards interactive glasses. This suggests that people (and technology) may be ready for the wearable computing vision [43] to become a reality.

All participants (13/13) agreed they were able to keep track of their surroundings as they walked down a busy street while using the interactive glasses. Participants were mostly aware of what was happening around them, kept a steady walking pace, and did not feel their personal safety was ever at stake: *"I could keep track of traffic and people. […] I didn't feel like I was in danger."* (P5) *"I could see the cars and the red lights. […] Security is good."* (P8) Most participants (9/13) said the reason they were able to keep track was partly thanks to the small amount of information and the minimalistic way it was presented on the glasses. They felt the UI elements did not interfere with what they were seeing or doing: *"What is going on (on the glasses) makes sense and [I'm still] able to concentrate on the surrounding environment."* (P11) *"It was really easy to use [the glasses while walking in public], it wasn't annoying my view."* (P13) However, some participants (5/13) mentioned they had to pay extra attention and be more cautious than usual when they walked down the street while using the glasses. For most of these participants (4/5), this was due to the current design of the Moverio glasses, which blocks a portion of the participant's peripheral view: *"You have to be slightly more careful because of the frames [on the sides] to keep track of people and cars. They block [part of what you see]."* (P12) But for a couple of them

(2/13), moving objects on the display were (potentially) distracting: *"I had to be really careful with walking and with the red lights because I didn't want to get distracted by the messages [flying around]"* (P10) *"I was able to keep track of traffic and people but it did distract me clearly."* (P6) A Paired Two Sample t-test showed a significant difference between the time taken performing the task and the time taken walking back following the same route at the preferred walking pace of the participants ($t=4.09$, $d.f.=11$; $P<0.05$) (Figure 6). Due to unfavorable weather conditions, we could not complete the walk back with P3 and hence the rest of the session (i.e., filling in the questionnaire and the semi-structured interview) was conducted in a nearby café. We observed a couple of participants who often slowed down or even came to a full stop when a new notification appeared on the glasses' display, thus having a direct impact on the average completion time for the task.

The majority of the participants (10/13) explicitly commented on the image quality provided by the glasses, saying it was crisp and clear. This allowed them to see the UI elements adequately: *"Most of the times it was very easy to see the butterflies."* (P2) As this last comment suggests, a few participants (4/13) occasionally had difficulties seeing the butterflies and messages displayed on the glasses, mainly in sunny, bright conditions. Similar to [21], these participants developed a strategy where they would turn their head towards a dark background to better see the information shown on the glasses: *"I had to look towards darker surfaces, [such as] the grass or a tree, because towards the sky or [bright red] bricks, […] I couldn't read well."* (P1) This is in line with [13] where they found that information presented against plain backgrounds, such as a concrete wall, was less difficult to discern than information displayed against visually busy backdrops, such as a brick wall [21]. Another strategy used by one of these participants was to use her hand to shield the display from the sun. Two participants further requested for display contents to be stabilized to compensate for the up and down movement of the glasses while walking: *"It was a little bit difficult to read because you are looking at something while walking and the glasses are following your head so [the image] is moving a little bit."* (P9)

Supporting Discreet Interaction for Interactive Glasses

All participants (13/13) were able to successfully open and read incoming notifications using the proposed interaction techniques. Their general feeling was that the interaction techniques were natural and easy to understand: *"It felt really natural to do this [swipe] movement. […] You learn it very quickly. It's really intuitive."* (P10) *"It was very easy to understand."* (P1) On the AttrakDiff questionnaire (Figure 5), the prototype is located in the above-average region on the attractiveness (ATT) dimension and thus the overall impression of the prototype is very attractive, especially in the way input is provided to the interactive glasses. These high ratings indicate that the participants perceive this feature as motivating and pleasant.

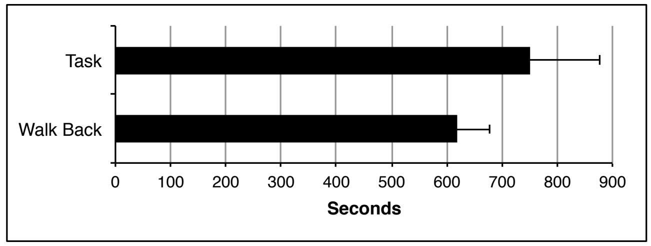

Figure 6. Completion times.

The use of the finger rub pad played a big role in people's ability to quickly and subtly interact with the glasses. Participants unanimously (13/13) said that the small discreet device allowed them to walk normally, keeping their arms extended next to their body in a comfortable position and swinging naturally: *"Having the ring [i.e., finger rub pad] is much nicer, your hands are there where they are supposed to be."* (P2) *"It's really good because then you can just keep your hands down."* (P9) Moreover, most participants (12/13) explicitly said they could perform small finger gestures that others do not pick up on, which is important when interacting in public: *"The finger rub pad is very small and people probably don't notice I'm doing things with it, so in that sense, it was nice for the situation."* (P2) However, we observed that some participants (4/13) were looking down under the glasses to check where they were swiping. Participants missed some sort of tactile cue or feedback to feel the edges of the swipe area and/or to feel that they are swiping in the right place: *"Now I had to look down under [the glasses] to check if I was touching the right surface."* (P5) *"If you could somehow feel where [the finger rub pad] stops so you don't have to check."* (P5) A few participants (3/13) said the ultimate solution would be to rub one finger against the other, with no device in between: *"It would be nice if you [could] do it with your finger [then] you would feel your own finger."* (P1) While discreet interaction was favored, the finger rub pad would have to be smaller, wireless, provide tactile feedback, or ultimately allow people to directly rub their fingers one against the other to provide input to the interactive glasses.

Other Ways to Interact with Glasses

Participants also expressed their opinions on other potential ways to interact with interactive glasses in public, i.e., gestures, speech and touching the frames of the glasses. Most of them (9/13) were clearly against performing large visible gestures in public places as they thought it was too physical and would make them look weird: *"No gesturing in open spaces. I don't want to get arrested."* (P1) *"It would make you look like a crazy person."* (P6) One participant nicely summarized how others felt about doing gestures in the air to control interactive glasses in public: *"There's a limit somewhere here (draws a horizontal line across his chest). If you have to lift your arm above that line, then it's too physical."* (P12) These findings are inline with Rico and Brewster [40]. Regarding voicing speech commands, a similar number of participants (9/13) discarded it as a viable option saying it would be inappropriate in public, potentially annoying, and that it would make them feel stupid: *"I find [speech] quite annoying [in public]."* (P3) *"I feel stupid if I say something [to myself], even if I'm alone at home. If [the glasses] would use speech probably I wouldn't use it at all."* (P12) Nearly half of the participants (6/13) said they would rather avoid touching the glasses for interaction, especially if it has to be done frequently (i.e., concerns about potential fatigue). Drawing a parallel with performing gestures in the air, participants said touching the glasses would be both too visible and unnatural: *"Touching the [frames of the] glasses once per minute would be too much."* (P2) *"It feels like too big of a gesture."* (P12) On the other hand, some participants (5/13) thought that touching the frame might go unnoticed for others in public, which would be a good thing: *"Maybe if you touch your glasses nobody notices what you are doing."* (P13) Finally, teeth clenching and the use of gaze [44] were mentioned by a couple of participants as other ways to interact with glasses in a discreet fashion.

Participants also mentioned other external interaction devices to be used alongside interactive glasses. Watch-like devices worn on the wrist [27] and touch areas incorporated into clothing (i.e., interactions around the pocket area [41]) were mentioned as alternative ways to provide input to the interactive glasses: *"Maybe a watch kind of [device] and you would [swipe] there."* (P11) *"Maybe something in my pocket as normally I have my hands in the pocket."* (P13)

Wearing Interactive Glasses in Public

Finally, we discuss people's current perception of publicly using interactive glasses in general. At the start of the interaction, most participants (8/13) felt self-conscious about wearing (and using) the interactive glasses in public. They specifically said it had felt strange and weird to them to be using such a device in a social context: *"You felt a little bit like a fool just because of the size of the thing."* (P11) In their current form, the interactive glasses stand out and are clearly noticeable. As part of feeling self-conscious, participants also speculated that passers-by were probably wondering what they were doing with those interactive glasses on: *"Some people were watching and they were thinking 'what are they doing?'"* (P7) Passers-by's most common reactions were to: a) ignore the participant, b) look, giggle, and continue along their path (Figure 7a), c) similar to the previous but react surprised or confused (Figure 7b), d) try to avoid crossing the participant's path (Figure 7c). As P4 walked by a group of six people sitting at one end of the bridge, one of them shouted at him: *"Lucifer, bring the light!"* This shows that interactive glasses currently feel strange not only to the participants, but also to those around them. However, participants' perception of wearing the glasses in public changed over the course of the evaluation. Almost all participants (12/13) said they noticed that people were staring at them, but they got used to it and did not mind about it anymore: *"I did notice some people looking at me but it wasn't intimidating or anything."* (P2)

Figure 7. Passers-by's reactions. (a) Look, giggle, and continue walking, (b) similar to the previous but react surprised or confused, and (c) avoid crossing the participant's path.

A few participants (5/13) said they could see interactive glasses becoming less of a curiosity and more of a norm in the future. However, for that to happen, interactive glasses would have to become smaller and more comfortable to wear: *"I wouldn't want to know about the glasses at all. If I have them on me they would be integrated into these (points at his glasses)."* (P4) Finally, two participants said the glasses should become a fashion accessory: *"I would use it depending on how it would be finally shaped for a consumer like me."* (P3) On identity (HQ-I), the first hedonic quality of the AttrakDiff questionnaire (Figure 5), the prototype is rated the lowest of the four scales, which means that the Moverio glasses we used are not premium or stylish enough for people to fully identify with them.

DISCUSSION

Presenting Notifications on Interactive Glasses

In designing *NotifEye,* we deliberately limited complexity and started with small steps to gain an understanding of what people are able to cope with in terms of information coming through the glasses while walking on a busy street. Our study results suggest that people would be able to deal with larger amounts of and more complex information. We base this claim on people's requests for more functionality in the prototype (e.g., adding extra information to the butterflies, making butterflies context aware, adding the possibility to customize the butterfly, being able to receive other types of messages or calls, etc.). While people were able to seamlessly process simultaneous and unrelated motions (both from the UI and the environment), the few reports of potential distraction caused by moving objects (i.e., butterflies) on the display call for further investigation on the type of motion and animation acceptable for interactive glasses. Bartram *et al.* [5] found that icons on a computer screen with simple motion (called *moticons*) are effective indicators for notification, and are in fact better detected and identified than color and shape codes, possibly offering an additional way to consider for encoding information for notifications. Another possible way to compensate for some of the distraction caused by moving objects on the display would be to track the user's head and adopt a world-fixed [10] presentation of the UI elements, thereby giving the user the ability to gently move the head.

In bright sunny conditions, the quality and brightness of the display are crucial to be able to see and discern the virtual image without needing to resort to mitigation strategies (e.g., looking at dark areas, shielding). Such environmental conditions also have implications on the color choice for UI elements, which may appear altered or washed out [36].

Using Personal Content

As part of our study design, participants were not dealing with time-critical, important, or personally valuable information. There were two main reasons for not using participants' personal Twitter accounts: to keep a regular flow of incoming tweets and privacy. First, the amount of Twitter accounts that participants followed varied greatly. As a result, the number and frequency of incoming tweets would have heavily depended on how many Twitter accounts they followed and how active those accounts were. By having a single Twitter account for all participants, we were able to ensure a similar number of Tweets coming towards them through the glasses (i.e., not too few and not too many). As mentioned earlier, this was also affected by the time of the day when the test was conducted where some Twitter accounts overseas would be silent at the time of testing due to time differences (i.e., night). For some participants that did not (actively) use Twitter, the orange butterflies containing *NotifEye*-related instructions further acted as a potential incoming notification from another social network (i.e., Facebook) thus allowing them to grasp the idea of displaying other types of notifications on interactive. Second, for privacy reasons, by not using personal Twitter accounts we avoided collecting specific participant data (i.e., followers and following accounts), or content (i.e., posts or timeline). Using a common Twitter account, we simply logged incoming tweets with an associated time stamp.

Understanding Social Acceptability

One of our original goals with *NotifEye* was to study how the social context affects different aspects of the interaction both for the one wearing the interactive glasses and the passers-by. Social arrangements must be carefully planned when studying social acceptability as different factors of the experimental setup can influence the results. In our case, what it means to: 1) wear large interactive glasses when walking in a city center, 2) while being followed around by two researchers, 3) who are capturing everything on video and photographs. All these factors could have made the bystanders feel curious about and more likely to stare at the participant, who in turn feels increasingly self-conscious. As mentioned earlier, ensuring an oncoming bicycle or car would not hit the participant when crossing the road was one of our main concerns. However, we must come up with better ways to (visually) capture the general surroundings and the specific interactions that the participant makes (e.g., on the rub pad). In addition, we must also be able to capture the perceptions of passers-by by explicitly asking them about their particular experience, without disrupting the ongoing task for the participant.

CONCLUSION

NotifEye allows a person to receive and take action on incoming social network notifications while walking on a busy street. During the evaluation of *NotifEye,* participants indicated that receiving minimalistic notifications through interactive glasses combined with a discreet interaction device ensured that the information and the interaction did not distract from or interfere with what they were seeing or doing (i.e., walking). Participants also reflected on the social acceptability of using interactive glasses in public, identifying size, comfort and fashion as the main current issues. Makers and designers of wearable technologies should take hedonic, pragmatic, and social acceptability aspects as important considerations in their designs. Future work includes further quantifying both how people handle notifications (i.e., accepted, ignored, dismissed, etc.) and use the rub pad (i.e., response time, false positives, etc.).

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