Future So Bright, Gotta Wear Shades: Lens Tint May Affect Social Perception of Head-Worn Displays

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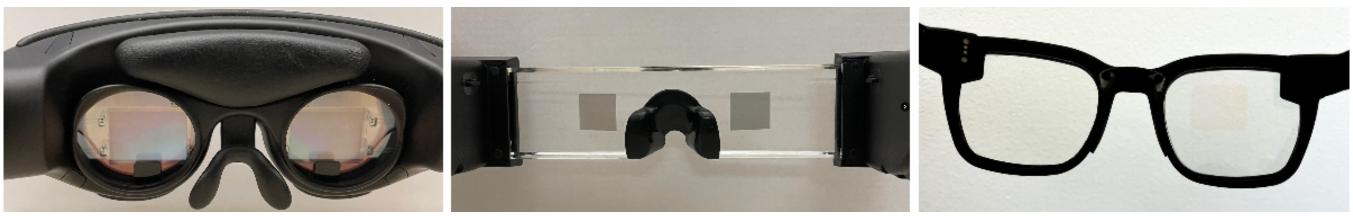

Figure 1: Tinting lenses disguises embedded optical combiners in head worn displays, making them less distracting to the user and less noticeable to conversational partners. The Magic Leap 1 (left) darkens the entire lens to try to match the transmissivity of the optical combiner (seen here as a square in the center of the round lens). Consequently, the user appears to be wearing sunglasses, which may be disconcerting to conversational partners, especially when indoors. When the display is off, the optical combiner in the Epson Moverio (center) has between 40-50% less transmittance than the rest of the lens, resulting in a distracting grey rectangle in front of the user's eyes. The optical combiner in the Vuzix Z100 (right) has high transmissivity (at the expense of display brightness) but can still be noticed by bystanders. Tinting the lens would help hide the combiner and possibly be less distracting to the user and bystanders.

ABSTRACT

Social perception of head worn displays (HWD) can be a barrier to usage. Some designers are attempting to create HWDs that could be mistaken for normal eyeglasses. However, hiding optical combiners in a eyeglass lens is difficult. One option is to tint the lens to match the tranmissivity of the combiner. The darker the shade, the more easily the optics can be hidden.

However, how dark can the lenses be before they are perceived poorly by conversational partners, especially indoors? We present two studies with a total of 36 participants observing conversations with actors wearing 100%, 75%, 50%, and 25% transmissive lenses. The results suggest that even 25% opacity may be too much tint for the eyeglasses to be considered unremarkable.

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CCS CONCEPTS

• **Human-centered computing → User studies**; **Ubiquitous and mobile computing design and evaluation methods**; *Accessibility technologies*; **Mixed / augmented reality**.

KEYWORDS

Head worn display, social acceptability, optics, user-centered design

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1 INTRODUCTION

Head-worn displays (HWDs) present a promising opportunity for augmenting human capabilities.

Research identifies the sharp uptake of HWDs, specifically in healthcare and industry environments over the past 5 years, indicating the fruitfulness of their practicality in the workplace [15]. Researchers have also identified the benefits HWDs can bring to everyday life for individuals with disabilities. For example, HWDs can provide real-time speech-to-text captioning to aid those with hearing loss or deafness [11, 12]. However, people with disabilities often do not want to use technology that looks unusual and may call attention to their disability [3, 8, 14, 16]. Even workers on assembly lines are concerned with how others will perceive their use of a HWD [1].

Social perception, defined as an individual's judgment and inferences about some target, plays a pivotal role in the mainstream acceptance of a HWD. The collective perception about an object or event from a group determines the object/event's "social acceptability," reflecting how much deviation there is from the group's established norm. As defined by the American Psychological Association [17], social acceptance means the absence of social disapproval. We agree with Koelle et al.'s [7] conclusions that accessory-like shapes and familiar styles are recognized as the best way to integrate wearable technology on a grand scale. Glasses are at once a corrective device, a fashion statement, and a common accessory; thus, they have an excellent chance of gaining social adoption.

However, previous HWDs include conspicuous, abnormal physical design features. Most HWDs feature large frames, chunky shapes, and/or distracting reflections displayed across the lenses. Most use optical combiners embedded in lenses which make the lenses appear odd to bystanders and, when the display is off, are distracting to the user themselves. Existing smartglasses may address this problem by attempting a uniform lens color (Magic Leap 1), may ignore the issue altogether (Epson Moverio product line), or may create a combiner that is as transparent as possible (Vuzix Z100 - shown left to right in Fig. 1). As products such as the Vuzix Z100 more resemble normal eyeglasses, there will be an increasing desire to hide optical combiners. One method is to tint the rest of the eyeglasses lens to match the transmissivity of the combiner.

This study explores the social acceptability of tinting glasses-style HWDs. We conduct both in-person and remote within-subjects studies to investigate the correlation between four transmissivity levels and social desirability.

2 RELATED WORK

A lack of communication solutions has lead to D/deaf and hard of hearing (DHH) individuals to have difficulty with group conversation with hearing people, particularly within the everyday office [4]. Commonly employed strategies to address this issue are either too conspicuous, such as the use of a note-taker, or unsatisfactory, such as relying on a written summary [2]. Companies deploying technological products for this purpose have encountered many other challenges, including the lag of captions and insufficient details about social context [9]. For instance, real-time captioning applications on smartphones, using automatic speech recognition, may help with individual tasks, but prove futile in group settings due to an inability to accommodate multiple speakers [2].

Research has, however, shown a definite preference for captioning within the DHH community, especially when text captions are presented next to their respective speakers [2]. Thus, HWDs provide strong benefits for captioning. The remaining concern, conspicuousness, relates to the HWD itself. A user may wish to appear as natural as possible, and a device that is too abnormal will garner unwanted attention, defeating the very purpose of wearing one. This problem is the basis of our dilemma: how can we develop a functional HWD which still looks unremarkable?

2.1 Understanding Social Acceptability of Wearables

Wearable augmented reality products garnered widespread attention around 2014, mostly due to headlines made by Google Glass and Epson's smartglasses [13]. However, public use of the products faced a number of hurdles relating to what might be considered socially acceptable. However, "acceptable" is a loose term and the "public" is a broad category. To refine the bounds of the definition of social acceptability, Marion Koelle [6] measured it as a combination of ratings from four categories: social image and identity, social norms and ethics, embarrassment and stigma, and utility and justification. The success of wearable technology (termed "wearables") considers not only the task for which they are used, but how they are used and how they look. The ideal wearable blends seamlessly with the status quo, complete with familiar, accessory-like features [7]. Hence, we believe that glasses are the best form upon which to build a wearable. Companies have shown that it is indeed possible to fit smartglasses with state-of-the-art technology, but previous attempts have disregarded other equally important variables. In fact, there is an undeniable disparity between recommendations for acceptable designs put forth and empirical confirmations of their success [7]. We intended to help bridge this gap by choosing and optimizing one specific design feature of a glasses-style HWD. The following section discusses the selected feature - transmission of the lenses - and its importance.

2.2 Human factors issues with Glass-style HWDs

Historically, the lack of consideration of user-centered design styles has been the demise of many HWDs. Clint Zeagler's study [18] examining the impact of functional, technical, and social considerations on the design of wearables identified that Google Glass's front-facing camera design roused public misunderstanding and questions about privacy. Peddie [13] expands upon this, citing the Glass's one-eye, off-angled display called attention to the glasses themselves.

So far, little research has been conducted to shed light on the ideal design of a HWD for the general public which does not compromise functionality. We propose a user-centered process that isolates and studies each design component of a HWD that could hinder social acceptability. For this study, we concentrate on the lenses of the glasses.

There are many factors in the lenses of HWDs that warrant improvement, one such we have dubbed as the "gray square." As seen in Fig. 1, many HWDs sport a dark spot embedded in the lens. This detail is the optical combiner that reflects the display into the user's eye. It can be a source of distraction and discomfort for users (those wearing the HWD) and viewers (those seeing the HWD in use). Those who are not familiar with HWDs may misunderstand the square's purpose. To mitigate this issue, we focus on reducing the contrast between the glass lens itself and the "gray square." The most straightforward approach is to find a level of lens opacity that masks the gray square and appears "normal" to bystanders. The darker the tinting of the lens, the easier it is to hide an optical combiner. However, just as many might consider a person wearing sunglasses inside to be rude for not allowing eye contact, HWD display wearers may find opprobrium if the tint is too dark on their glasses.

3 METHOD

The framework for the current methodology was based on previous work [10] that determined when evaluating the acceptability of HWDs, subjects viewing a video demonstration correlate well with viewing a live demonstration.

Accordingly, we settled on a within-subjects design where each participant watches four video demonstrations, with each demonstration featuring a HWD with a different transmission level. We decided to space the levels in 25% increments to cover a wide range of transmission: 100% (standard lens, completely clear, to be used as a baseline), 75%, 50%, and 25%. There were 3 primary components of our testing; the HWD prototype, video demonstration, and follow-up questionnaire.

We constructed the "HWD" prototype using four standard, clear prescriptionless reading glasses, identical to each other. The choice of standard reading glasses as a proxy for an actual head worn display was made to isolate transparency as the only nonstandard aspect. The sole distinguishing factor among the four prototypes was the opacity of the lenses. To create opacity, we printed ink on transparency film sheets and attached the sheets to the glasses using transparent adhesive tape. Each pair of lenses had a different amount of ink in the film. For 100% transmission (i.e., no opacity) we used an inkless sheet, and for 75%, 50%, and 25% transmission, each had more ink than the previous, respectively. Most importantly, we used an Avantes UV-Vis Fiber Optic Spectrometer to ensure the transmission of light through the lenses was precisely the level we desired. As we were worried about about internal reflections between the layers of film, tape, and lens, we measured light transmission from both directions (see Fig. 2) to be sure of consistency.

We created a demonstration video to present to participants which captures a third-person perspective of two actors sharing a casual conversation during their work break (see Figure 3). (Note that filming from the conversational partner's perspective proved too distracting, as the social cues of the conversation dominate the viewer's perception.) The setting of the video was chosen to be an indoor breakroom to evaluate acceptability under the highest scrutiny, as wearing shades outside is already deemed acceptable. The actors faced each other and the camera was placed to the side and slightly behind Actor 1, who wears no glasses, so that Actor 2, the actor wearing the HWD, is more centered. We shot this video four times, each with Actor 2 wearing a different pair of the glasses. Other than the glasses used, all videos are identical, each being 13 seconds long (determined by the need to maintain participant engagement while capturing a concise, representative social interaction).

We created four identical questionnaires, distinguishing them only on the researcher's side by the transmission level (100% (i.e., no opacity), 75%, 50%, or 25%) that the participant was responding to. Each questionnaire contained eight 5-point Likert-style questions (strongly agree, agree, neither agree nor disagree, disagree, strongly disagree) and one final free response where participants could elaborate upon their answers (see Figure 5). The questionnaire assesses aspects of social desirability, written with positive and negative connotations. Questions were presented in the survey in a random order.

Participants provided their consent using an ethics board-approved protocol. After watching each video, participants responded to the corresponding questionnaire to record their perception of the glasses featured.

The results from demonstrations of the 100%-transmittance lenses are used as a baseline.

3.1 In-Person Study

Our in-person study had 20 participants who self-reported as male (8), female (11), or non-binary/third gender (1), with an average age of 21.3 (SD=5.06). 19 of the participants are students at a major technical university and one is a software engineer. Participants were randomly divided into four equal groups. All participants watched the same four video demonstrations but in different orders determined by their group, using Latin square ordering (1243, 2314, 3421, 4132) to prevent order bias. A maximum of two subjects participated at one time, accompanied by the researcher to ensure the protocol was followed. To control the environment, all studies were conducted in the same private conference room, and all videos were viewed on the same television, with the same resolution and distance from the screen. Participants signed consent forms and were given a briefing of the experiment routine before using their phones to scan a QR-code linking to the welcome page of the questionnaire for their respective video order. They were instructed not to view any survey questions before viewing the corresponding video. The researcher paused each video as soon as they ended and participants were given as much time as they wished to complete the questionnaire. We hypothesized that there would be a difference in social perception scores between the standard 100% transmission lenses and each of the three other conditions.

3.2 Remote Study

Given that researchers have found good correlation between the results of live demonstrations and recorded videos of HWD use in similar experiments [10], we then replicated our study remotely to further test our hypotheses with 16 participants who self-reported as female (9), male (6), or preferred not to say (1) with an average age of 24.375 (SD=4.41). The participants' occupations ranged from student and software engineer to varying fields in the medical industry. 15 viewed videos from a laptop and one from a big screen TV. We again divided participants into four groups and using Latin square ordering to control for order effects. We created a Qualtrics survey, complete with a welcome page, consent form, and instructions, and sent the link to participants. After the first video was the corresponding questionnaire on the next page, and so on. Participants were instructed to watch each video only once and the ability to go to a previous page was disabled. Each questionnaire contained an additional question that confirmed whether participants watched the video once, free of distractions. Participants completed the survey on their laptops to keep viewing conditions consistent. We hypothesized that there would be a difference in social perception scores between the standard 100% transmission lenses and each of the three other conditions. We also hypothesized

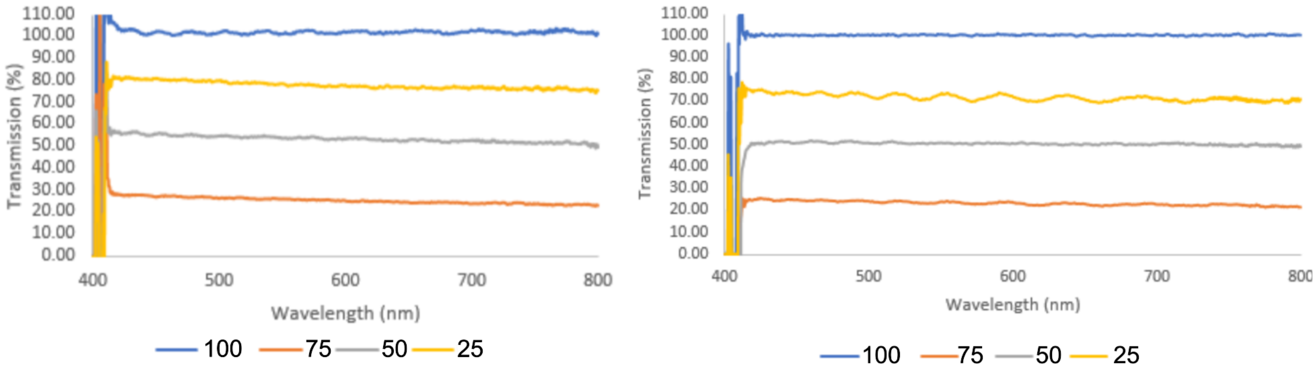

Figure 2: Spectrograph readings. Left: light traveling through lens glass then film. Right: light traveling though film then glass.

Figure 3: Video demonstrations. From top: 100%, 75%, 50%, 25% transmissivity.

that were would be no significant difference between the results collected from the in-person study and the remote study.

4 RESULTS

We evaluated the acceptability of each transmission level by analyzing the Likert-scale data obtained from the questionnaires.

To determine the aggregate acceptability of each transmission level, we calculated a composite "acceptability score." Following from Kelly et al's [5] methods for quantifying results when studying social acceptability, each Likert-scale response weight (ranging from -2 (strongly disagree) to +2 (strongly agree)) was multiplied by -1 or +1, depending on the connotation of the question (negative or positive, respectively). For example, a response of "strongly disagree" to the prompt "these glasses seem distracting to me" receives a weighted score of -2 * -1 = 2. Averaging the eight weighted scores per questionnaire produced the acceptability score (of that questionnaire). This method resulted in an 80-point data set (20 participants * 4 questionnaires per participant) for the in-person study and a 64-point data set (16 participants * 4 questionnaires per participant) for the remote study.

4.1 In-Person

We ran a one-way within-subjects ANOVA on the in-person acceptability rates. There was a significant effect of the amount of transmissivity using the Greenhouse-Geisser epsilon to compensate for a lack of sphericity: F(2.453, 46.616) = 15.909, p<0.001, η^2 = 0.456. A significant linear tread emerged, F(1, 19) = 41.868, p < 0.001, η^2 = 0.688 with acceptability decreasing as transmissivity decreased. Linearly independent pairwise comparisons (GLM in SPSS) on estimated marginal means revealed a statistical significance between 100% and the three other levels (75% p=0.011, 50% p = 0.009, and 25% p < 0.001). In post-hoc testing, the difference in 50% and 25% transmissivity reached statistical significance (p < 0.001). Bonferroni correction was used to adjust for multiple comparisons. See Figure 4.

4.2 Remote

We used the same method to analyze the remote study data. There was a significant effect of the amount of transmissivity using the Greenhouse-Geisser epsilon to compensate for a lack of sphericity: F(2.453, 37.238) = 5.197, p=0.007, η^2 = 0.257. A significant linear tread emerged, F(1, 15) = 10.47, p = 0.006, η^2 = 0.411 with acceptability decreasing as transmissivity decreased. Linearly independent pairwise comparisons (GLM in SPSS) on estimated marginal means revealed a statistical significance between 100% and the two lowest levels (50% p = 0.029, and 25% p = 0.032). Bonferroni correction was used to adjust for multiple comparisons. See Figure 4.

4.3 By-Question Analysis

Post-hoc, we conducted a question-by-question analysis to identify if any particular question strongly rejected the positive correlation between transmission and acceptability observed in the aggregate analysis. As the transmission level was decreased, the acceptability scores generally became lower as well, and studying questions individually could justify their exclusion from future studies. Keeping data from the two studies separate, we grouped each response by question and plotted averages against transmission level. The final graph indicated the acceptability for that question at each

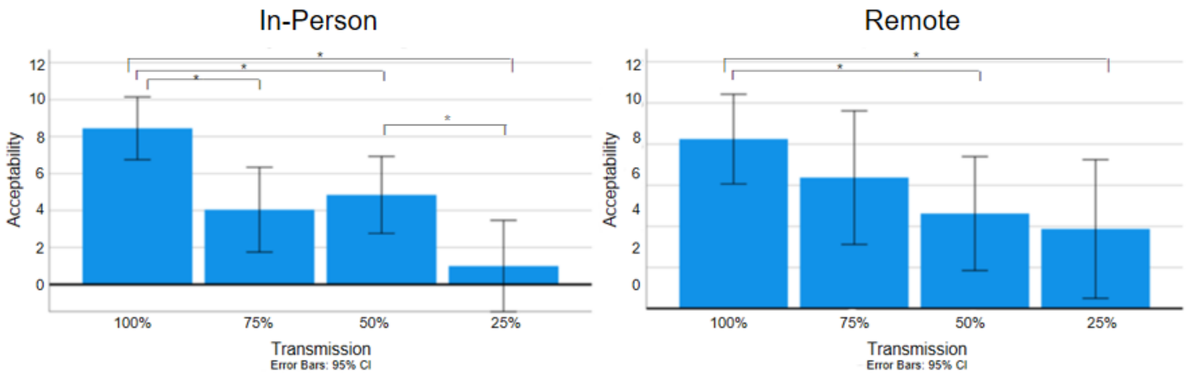

Figure 4: Mean Acceptability Scores for In-Person and Remote Studies. A * indicates a pairwise difference that reaches statistical significance. Error bars indicate standard error for 95% confidence interval.

transmission level. For questions with a negative connotation, the resulting graph was flipped to maintain the same skill. Figure 5 shows the compilation of the eight questions across the two studies. (In-person and remote studies were placed on the same graph as separate clusters to help identify a reason for statistical significance between the two.) While most clusters showed a positive correlation between transmission and acceptability, some did not. Our next section discusses factors contributing to these discrepancies.

5 DISCUSSION

The baseline 100% transmission (clear) glasses met our expectations: across every question in every study, the standard glasses had the highest acceptability; the darkest lenses (25% transmission) consistently ranked as the least acceptable.

The studies suggest that even 25% opacity (75% transmissivity) may be too much shade to avoid social opprobrium. Unlike the in-person study, the remote study did not reach the level of statistical significance in the difference in mean scores for 100% and 75% transmissivity, potentially due to the lower number of participants and the higher variance in scoring observed. Even so, the acceptability score trended down surprisingly quickly in both studies.

Notably, questions aligned with the general trend of acceptability decreasing as transmission decreased. The question "I would like to wear these glasses."(Q8) exemplifies this correlation with a nearly perfect linear decline in acceptability with each 25% reduction in transmission. This evidence solidifies the assumption that, ideally, lenses should be as transparent as possible. A similar trend occurred for Q2, "I would feel uncomfortable standing by the person wearing the glasses," particularly for the remote portion. Comfort, in the context of this question, began to fall as lenses became darker.

Q7 ("The glasses worn in this video were fashionable.") and Q8 ("I would like to wear these glasses.") had exclusively negative acceptability scores (with the exception of one 0.1) indicating that the style and appearance of the glasses reflects one's inclination to use them. We must consider that the glasses used for the demonstration purposes were standard, wire-framed reading glasses, and were thus not particularly "fashionable," especially among college students. The participants' perception of the glasses as unfashionable can account for their reluctance to wear them. A more objective measure of the acceptability of the physical appearance might be achieved by a re-phrased question such as "I or somebody I know would use these glasses for vision correction." The question with the highest average acceptability was Q5, "This interaction seemed normal to me." This result may suggest the abnormality of the lenses did not impact the social context enough to deem it strange.

6 LIMITATIONS AND FUTURE WORK

While this study offers valuable insights about the social perception of lens tint in HWDs, we continue to seek improvements. First, the subjective nature of the questionnaire introduces the potential for extra variability among responses. In turn, findings on fashionability and desirability may reflect individual preference rather than execution of objective design criteria. Additionally, considering the impact screen size could have on perception, display modes should ideally be standardized between all studies.

This study suggests opportunities for future investigations, such as whether anti-reflective coatings or polarization may affect acceptability. There is much to explore concerning the utility of the questions mentioned above as well as other methods of gauging acceptability of physical appearance.

The scalability of online surveys simplifies gathering a large sample size, facilitating the exploration of questions such as the impact of cultural bias on acceptability, or how various factors of the demonstration bias the results (say, a male wearer). Conducting private interviews with participants to discuss their responses after the study could provide insight beyond quantitative measurements. We plan to re-conduct this study using increments between 100 and 75% transmission to better determine the amount of allowable tint.

7 CONCLUSION

Our research showed that lens transmissivity correlates with social perception of glasses-style head-worn displays (HWDs). We aim to create a HWD that blends in with normal eyeglasses. However, even 25% opacity may cause a significant drop in acceptability scores over baseline. Future work is needed to pinpoint what level of tint

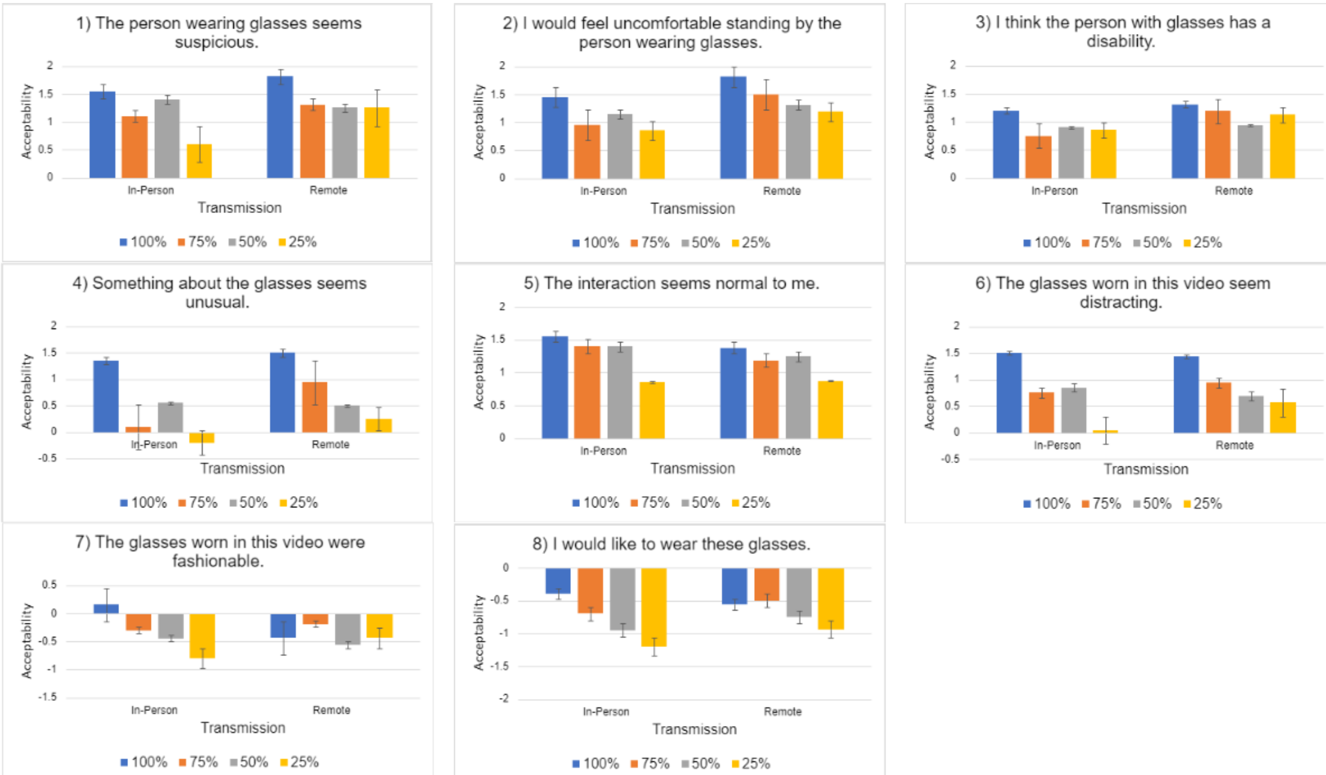

Figure 5: By-Question Analysis.

is acceptable for HWDs so that designers can more easily embed displays that are both useful and usable.

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