Detecting User Experience and Emotional Change in Mixed Reality Technologies

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***Abstract*—** In light of the original report on mixed reality (virtual and augmented reality) studies, this reproducible work aims to re-examine user experience in three selected virtual environments, namely, head-mounted display (HMD), mobile VR and mobile AR. Based on user's emotional feedback, our research helps to cross-check current design guidelines for creating Virtual Reality (VR) and Augmented Reality (AR) contents and producing their technical and physical support (e.g. software performance and hardware comfortability). We propose a combination use of semi-structured interview and questionnaire that allows us to dive into participants' emotional and behavioral change and mental effort in relation to specific interactive elements and user tasks. Also, we encourage participants to give their comments on what specific techniques (e.g. haptic feedback) can upgrade the newest mixed reality applications. To sum, this project intends to not only reevaluate the preceding Mixed Reality research in terms of their methodological approaches and result accountability but contribute to an improvement of immersive devices in a user-centric view.
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Keywords—AR, VR, MR, UX, Interaction design, Reproducible work, User studies

I. INTRODUCTION

Reproducibility is highly valued in science-majored academia as it is a tool to verify and reevaluate previous findings. Defined by [7], reproducibility is a key characteristic of one successful scientific study – it is the ability to "recompute data analytic results given by existing data analysis pipeline". We brought this idea into user-experience (UX) research where a huge debate is often discussed – "Are usability evaluation reproducible?" [8]. In his review on a group of comparative user experience (CUE) studies [8], it is concluded that usability tests should be defined and applied to a course of standard procedures so as to gain the maximum benefit from individual usability practices.

On the basis of the initial mixed reality research [4], our reproducible project focused on two aspects: firstly, we would like to explore how existing design guidelines for virtual content are being implemented in selected portable VR and AR technologies and how non-professional users treat such technology-enhanced customer experience; secondly, we would like to compare our findings to the foundation report as it is valuable to re-examine and comprehend the current user research in mixed reality design field. Defined by [12], mixed reality, a context-dependent concept (therefore there is so single definition), can be taken as the reality-virtuality continuum that comprises AR and VR technologies and their combination use. As for [4], mixed reality is the technical and digital equipment that offers synthetically interactive and engaging immersive environments. Along with the new wave technological development in millennial, mixed reality is widely implemented in different fields such as entertainment, education, retail and healthcare [3]. Such technique is often embodied in a physical hardware support such as a headset that allows users to place their heads and look around objects in the virtual space. For example, Google cardboard offers an affordable consumer service for VR fans – it provides a low-cost paper-based headwear that enables a stereoscopic sight-viewing experience with an additional help from smartphones [10]. More advanced VR options such as Microsoft HoloLens and Oculus Quest promise users a better interactive experience by a mixture of hand and head movements - a combination of hand controller or gestures with virtual contents. In contrast, the main purpose of AR technologies is slightly different from VR that it imports and visualizes digital objects and information into the user's physical world to facilitate real-time interaction and thereby is often seen as technologies with more reality [6]. In the case of mobile AR, it usually involves the addition of virtual elements to the real environments via a smartphone's Lidar camera. Example mobile AR applications such as IKEA Place [15] enables users to place and arrange furniture based on their real living conditions.

That said, MR researchers stated that although low-cost MR technologies are still in the early stage of development, they have received many users and scholar's attention as this technological innovation is shaping and modifying human communication and interaction [2]. To offer an insight into current MR technologies and thereby provide suggestions for this field, we followed the steps in the initial report of AR and VR devices and reproduce a small-scaled inter-device research on low-cost and portable mixed reality equipment, namely, HMD (Oculus Quest), mobile VR (Google Cardboard) and mobile AR (IKEA Place). We reinvestigated significant user-experience components in MR devices suggested in Greenfeld's experiment [4]. In the end, we compared our primary findings to their results to find similarities and differences. As said, our ultimate goal is to contribute to the MR design industry by providing a comprehensive analysis of user attitudes towards current technologies.

II. METHOD AND APPROACH

A. *Participant's Background and Experimental Design*

In consideration of practicability and availability of research timeline and mixed reality devices, this study decided to downsize the test group advised by the original report. This reproducible research recruited participants (n=13) through the main experimenter's personal contact such as personal invitation via social media. In brief, 54% of candidates are self-identified as male (n=7) and 46% are female (n=6). Their age varied from 22 to 31 (mean=25) with a majority between 23-25 years. Regarding their previous experience with mixed reality technologies, 62% users had only one-time or less than one-time test play with HMD devices and mobile AR. Oppositely, majority of participants (around 54%) played twice or more mobile VR equipment. All participants are currently registered students at postgraduate level from Queen Mary University of London and Loughborough University London with diverse educational background – business, medical and bioscience, sport science, law and computer science.

During the test play, each user was expected to complete tasks from three mixed reality devices including mobile AR (IEKA Place app [15]), mobile VR (Within VR app [13] plus Google cardboard support [14]) and HMD (Oculus quest 2 [16]). Every experiment lasted around 30 to 40 minutes in total (subject to participant and conductor) and comprised three sub-experiments (one mixed reality device per sub-experiment). Participants were given enough time break in-between every subtest that helped to finish up the target questionnaire and clam down their feelings. In total, we designed three separate surveys and three separate sub-test that follow the similar structure. The semi-structured interview (around 20-minute long) was conducted on a later phase, which aimed to collect user's opinions on potential usage of mixed reality technologies. Also, it aimed to gather user's inter-device experiences and their attitude towards the broad field of interaction design.

B. *Questionnaire and Semi-structured Interviews*

Inspired by the first-hand research, our study focused on three categories to evaluate an immersive technology, namely, ergonomics, user emotional response and mental effort. We highlighted the interaction patterns between participants and mixed reality technologies rather than engaging content that one device could afford. Unlike the original report where main investigators filmed all participant's movement, this study mainly relied on note-taking and self-reporting during and after a testing experiment. This approach allowed for a locomotion analysis from two points of view (i.e. user and observer) and led to a cross-checked empirical confirmation. As for the questionnaire, our study used pre-defined answers documented in various forms such as Likert Scale and multiple choices. This design considered efficiency and effectiveness of demonstrating our expected results. Open answers were allowed during the semi-structured interviews where user's subjective insights and attitudes towards mixed reality's format (i.e. the technique) and content (i.e. the visual material) were encouraged by elaborative and explanatory questions. Through the mixed approach of interviews and surveys, we looked into the following aspects:

- Ergonomics section investigated software and hardware's comfortability and easiness when experiencing one device. This was majorly conducted through questionnaire.
- Emotional feedback examined user perceived emotional change during one experiment. This section was guided by an experimenter that participant should pay special attention to the virtual and physical environments when using one device. We used structured-interview questions and questionnaire to research this topic.
- Mental effort evaluated how much effort the user put during the test play. This includes the effort for (1) understanding a task, (2) following an instruction presented by one device and (3) completing the task in that virtual environment. The survey was developed on the basis of the NASA Task Load Index (NASA-TLX). This index is a multi-dimensional scale that helps to understand workload estimates from certain operators when users are performing a task or afterwards [5].

C. *Propotype and User Tasks*

We thoroughly selected mixed reality content regarding the device availability and capability, similarity of story narration across platforms, possibility of user reaction and interaction patterns, and replicability of the original research. We aimed to not only test user's inter-device performance but a comparison between this study's result and the first-hand resource. Therefore, as for mobile VR, we chose to display the story "Do Not Touch!" provided by Within application [13]. With Google cardboard [14], a hardware support, this mobile VR allowed users to watch a series of comedy-like stories that happened in an art museum – "catch me if you can" between visitors, historical figures in the paintings and security guards. It encouraged users to perform complex movements to be engaged in the narration. For the HMD Oculus Quest 2, we selected the in-built demo game "Mission: ISS" [16] where participants were welcomed to a spaceship to experience on-board zero-gravity astronaut's life. We instructed users to choose "explore mode" which included multiple locomotion tasks such as spacewalking, touching and arranging items and switching points of field. The decision took account into an often-mentioned issue in HMD technologies: motion sickness [11]. Previous studies [11] showed that factors such as exposure time, VR content, complexity of hardware and software and user characteristics were more or less associated with VR sickness. After our delicate panel test, we found this game can offer smooth visual stimulation (controller-based movement) and thereby largely enhanced the comfortability.

Regarding mobile AR, we utilized IEKA Place, a lifestyle AR application developed by IKEA [15]. This app allowed for a virtual environment where users can place and arrange true-to-scale furniture after scanning the physical playground. In the experiment, the user was asked to follow its AR instruction and drag and drop their preferred items based on the size of test room. To sum up, all three technologies steered participants to (1) walk and look around, (2) observe virtual scenes and (3) interact with object in specified virtual environments.

III. EROGOMICS

Similar to the initial study [4], we used the same scale from "strongly disagree" (0) to "strongly agree" (5) (see Fig. 1, 2, 3). Surprisingly our results on comfort were different on the 13 participants: Google Cardboard (mobile VR) was the most comfortable device with an overall mean score of 3.60. 46.2% of the participants selected "agree" and 23.1% chose "strongly agree" regarding the space and 53.8% agreed with

FOV comfort. Mobile augmented reality received an average value of 3.51. HMD (Oculus Quest 2) ranked third with a mean of 3.47 and 15.4% of the participants chose “disagree” and 30%” neutral”.

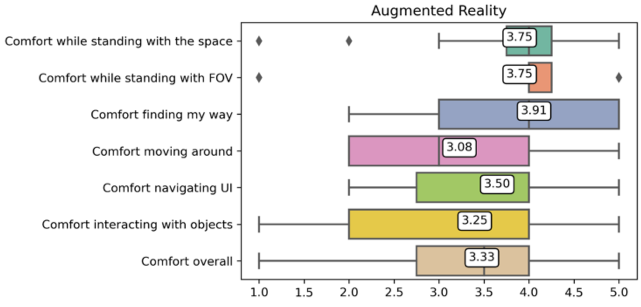

Fig. 1. Ergonomics: AR

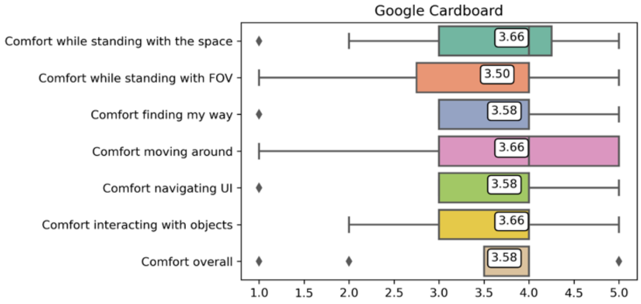

Fig. 2. Ergonomics: Mobile VR

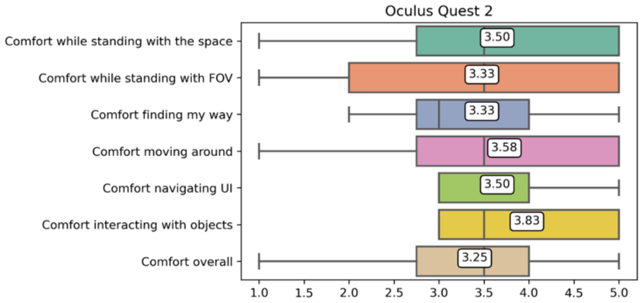

Fig. 3. Ergonomics: HMD Box Plot

A. Exploring and Looking Around the Enviroment

For exploration while standing, mobile Augmented Reality was the most comfortable with a mean of 3.75. This means that the participants felt very well with the space and the FOV (61.5% of the participants chose “agree”). The HMD had the worst score on this test with the largest interquartile range (IQR) with 38.5% of the participants disagreement and 30.8% strongly agreement in terms of comfort using FOV. It is something interesting because Oculus Quest 2 is the most advanced HMD for now.

B. Walking and Navigating the Enviroment

All the devices were globally appreciated, however the participants selected Augmented Reality as the best device with 3.91 for mean value in comfort finding their way (30.8% strongly agreed) against 3.33 mean value for the HMD (with 30.8% neutral and 30.8% disagree) and finally in between Google Cardboard has the smallest IQR and a mean value of 3.58.The HMD experiment was not in a natural environment (outer space) and probably added some biases in the report. As [9] stated that HMD interface can propose improved presence in collaborative mode and satisfying experiences. Moving around was perceived really easily with the cardboard (light weight) with a mean score of 3.66 (30.8% agree and 30.8% strongly agree). Augmented Reality is considered as the worst with 3.08 as mean value and 38.5% disagreed with comfort when moving around. The HMD is located in between even with 3.58 as mean value and 38.5% of the participants strongly agreed with comfort while moving around the environment.

C. User Interface and Interaction with Objects

Regarding user interface, Mobile VR has the best mean value with 3.58 and 53.8% of participants agreed with the easiness of the interactive elements. HMD and Augmented Reality have the same mean value of 3.50 but 61.5% were neutral and 30.8 agreed for HMD against 53.8% agreed and 30.8% neutral for Augmented Reality. The Mobile VR doesn’t have controllers compared to HMD but only a button on the side for interaction and Augmented Reality and no physical way to interact. This greatly affected the report of object interactions. HMD has a mean value of 3.83 and 30.8% of participants strongly agreed with comfort in this task, which is against 3.25 for Augmented Reality (23.1% neutral and 23.1% disagree) and the mobile VR(mean = 3.66, 46.2% agree with the comfort statement.)

IV. Emotional Feedback

A. Exploring and Looking Around the Enviroment

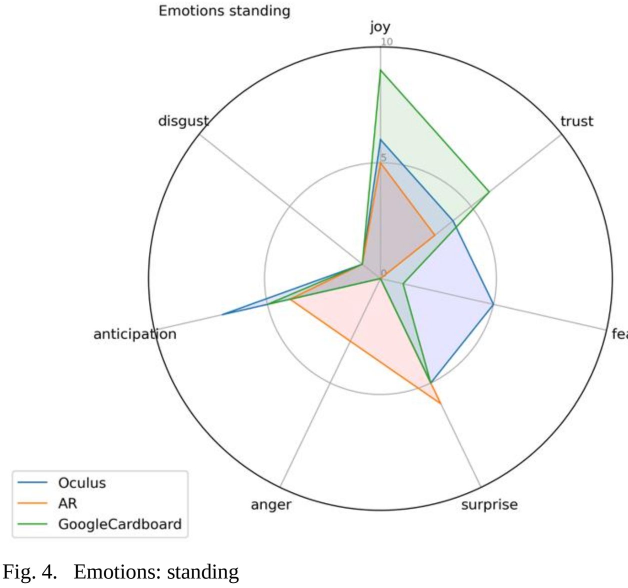

Fig. 4. Emotions: standing

Regarding the emotional responses while standing, we can notice (see Fig. 4) that even if there is a large intersection, the nature of the main emotions comparing each device is slightly different: mobile VR brought more joy (46.2%) and trust from the participants, HMD more fear and anticipation (53.8%) and mobile Augmented Reality more surprise (46.2%). Regarding joy, this can be explained with the type of content. The media on Cardboard was a “comedy” and here again the content brought some biases. Such an idea can also be applied to fear that the content is a first outer space experience as an astronaut in orbit: the user has a high probability to feel some fear.

B. Walking and Navigating the Enviroment

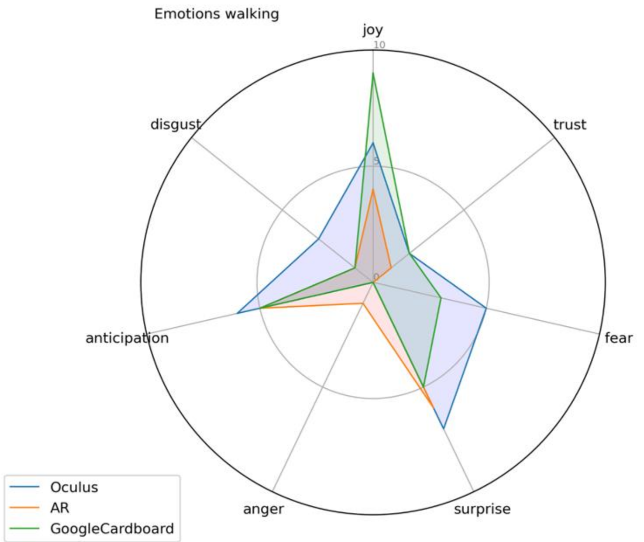

Fig. 5. Emotions: walking

When we asked the user to walk under our guidance, mobile VR again brought a lot of Joy (69.2%) and an equal amount of surprise and anticipation (38.5%). Regarding HMD, only 23.1% of the subjects were experiencing VR for the first time. For HMD Oculus Quest 2, the most reported emotion was surprise (53.8% of the participants), then Joy and anticipation (46.2%) and fear (38.5%). [1] worked on an affective driven content for therapy in their article ***'Toward Emotionally Adaptive Virtual Reality for Mental Health Applications'*** where reflected the fact that the player involvement is higher for this technology due to a full audio-visual immersion. Surprisingly, Augmented Reality even generated few levels of trust (7.7%).

C. User Interface and Interaction with Objects

In terms of emotions reported due to UI (User-Interface), HMD had specific emotional reports: 69.2% of participants reported joy and 38.5% anticipation (see Fig. 6). Augmented Reality also brought joy on 38.5% of the subjects but also 30.8% of anger or frustration. Mobile VR had two main emotions highlighted this time: joy and surprise.

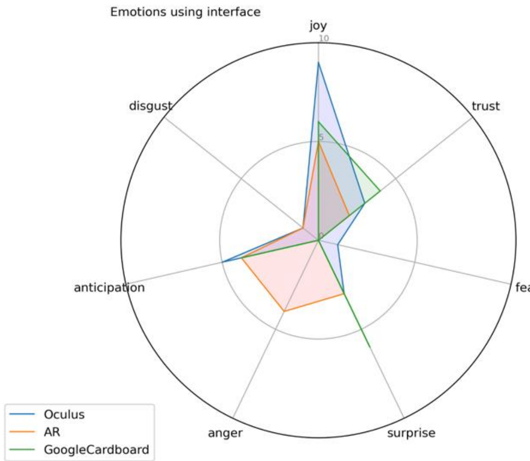

Fig. 6. Emotions: UI

The object's emotional reports of interaction (see Fig. 7) provide the information that HMD is superior to the other device on this subject. Because of the controller's presence, 76.9% of the players felt joy and took pleasure to interact with objects and 61.5% of them felt surprised. Augmented reality this time again generated anger with 46.2% of the participant's votes. In between mobile VR with one button as the only interactive function brought joy (46.2%) and same amount of joy and anticipation (30.8%).

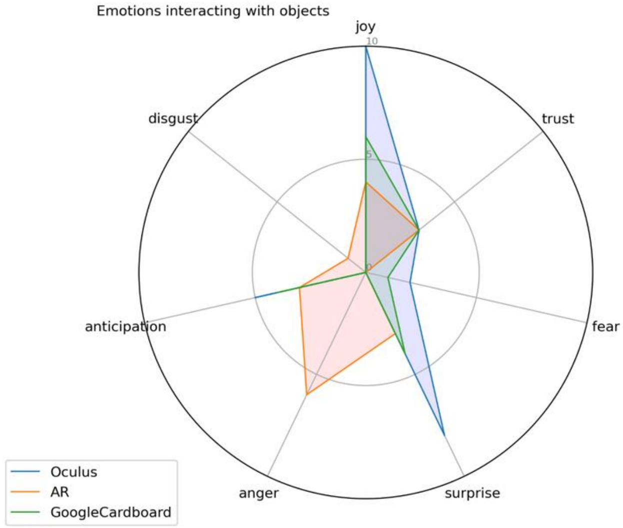

Fig. 7. Emotions: interacting

V. Mental Effort

As aforementioned, mental effort was measured via NASA-TLX scale. The result is presented in Fig. 8 below. Throughout our observation and user's feedback, the HMD device – Oculus Quest 2 required the most effort in all four aspects. For the first question, we asked susceptibility in relation to visual-audio instructions in the virtual environment and the average score is around 5 (10 is the maximin value). Majority of users graded 3 to 4 for mobile VR whilst 6 to 9 for HMD. This suggested that participants found a high level of difficulty in following HMD instructions and a low level in mobile VR. It also suggested that mobile VR seemed to be the easiest in terms of content engagement and interaction with objects. Mobile AR received a relatively middle range score between 5 to 6. This result showed that participants felt a relatively stable mental effort during AR test play and a moderate susceptible feeling of interactive cues in IKEA Place. The second question is a built-up process that asked user's mental investment regarding reaching and seeing virtual objects. A similar pattern is that mobile VR and HMD sat in polarized positions – most participants rated 2 to 4 for mobile AR whilst 6 to 7 for HMD. Mentality for mobile AR was positioned in between two VRs, with an average score of 5. This finding indicated that users could process and proceed virtual information in a shorter response time on mobile devices in general.

Question three and four are interrelated that one focused on full-body physical movement and the other was about upper-body movement. As for whole-body mobility evaluation, mobile VR, mobile AR and HMD received an average value of 3.4, 4.4 and 5.2 respectively. This result indicated that HMD required a higher amount of effort and mobile VR asked for the least in terms of user's locomotion in a specific virtual environment. The interview analysis demonstrated that mobile VR (the Within app) has a relatively straightforward tutorial instruction. Participants also mentioned the “drizzling” feeling (aka motion sickness) when wearing HMD device, which might cause a lack of trust to move their body in the physical playground. For the last question, generally, all devices asked a low degree effort for looking around the environment whilst standing still, with a mean value of 3.8. This showed that users could perform upper-body movement (e.g. head-turing) with ease. In the interviews, several participants admitted such movements were more “naturally occurring”. One participant specifically pointed out that looking around in the virtual context was motivated by curiosity and surprise and thereby less efforts were spent – “I just want to know what is happening around me”.

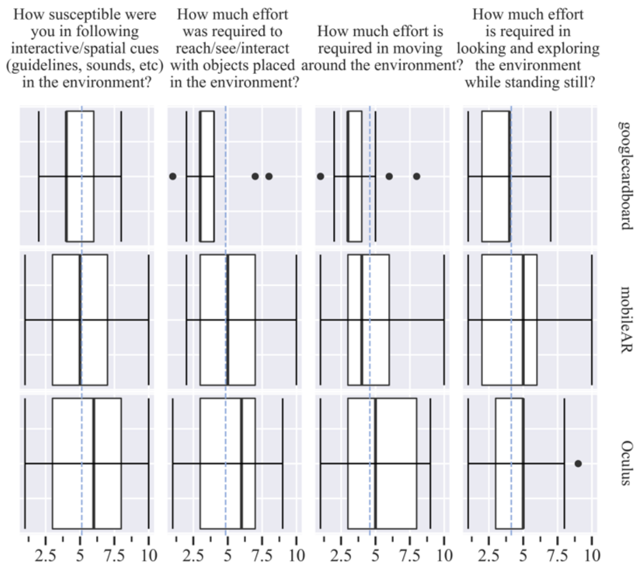

Fig. 8. Mental Effort

VI. COMPARATIVE DISCUSSIONS AND CONCLUSIONS

“Difficulties in Understanding Input Across All Devices?” Overall it seems that our participants were using the 3 devices with good ease. Google Cardboard finally proposes a very cheap and comfortable experience. Regarding the AR, the findings are the same, the device elicited some frustration during the use. This might be caused by the obscure user interface elements such as pictorial instructions. This problem is less intrusive with Oculus Quest (HMD) due to the presence of controllers.

“Simple Input / UI Components for Better Usability?” Participants found greater engagement in applications with a simplistic UI/input setup. Mobile and immersive display applications were more easily comprehended and utilized by participants than devices like HMDs, due to their simplified level of input. This approach allowed for greater engagement with the VR applications. By investing more time into explanations how each button affects the overall experience, users become better immersed in the process.

“Concrete Solution towards VR Locomotion?” Moving in the environment was well perceived in Virtual Reality and we overserved that there is a wide range of reactions in the HMD case. Oculus Quest has the largest interquartile ranges in the boxplots. However we have the same conclusion about the inability of the digital content to monitor our users. This information also shines among our questions about what features are currently missing and how it can be a must have. For VR, 53.8% of the participants think that emotional feedback is a key feature to be implemented now. A cross device examination (HMD vs. Mobile VR) would be beneficial for the end user too.

“Interactivity to Support User Engagement?” Most of the participants reported that AR and Mobile VR are yet to be good to be used. Regarding VR, 46.2% of participants mentioned that there are not enough people that they know using such equipment at the moment. Augmented reality and its ability is the most comfortable device for this particular aspect but the emotional responses seemed less important due to a lack of User Engagement.

“Higher Mental Effort for AR to Interact than in VR?” The mobile AR seems to have the highest level of mental effort amongst the three test plays. Many participants reported software performance in terms of unclear guidance, unstable camera scanning and so like. Also, the use of hand and fingers to control the screen might increase the effort to manage digital input. We suggest that AR designer should focus on software stability and clarity of user interface elements to improve usability.

“High level of Engagement present across all Devices?” Using the emotional data, we have the same conclusion on the level of engagement. High levels of Joy and surprise often occurred in all three devices. AR appeared to be the only device that can generate not only anger and frustration but surprise. Only 23% of users never tried VR before whilst 53.8% for AR. This demonstrates that AR and VR immediately bring a high level of engagement to a user.

Comparative Research. This reproducible paper work was really interesting and brought us some confirmation and some new information. Through our interviews, we concluded that most participants felt satisfied with test play in three different MR devices. People with rich MR experiences (greater than ten times MR play) still stayed positive towards our selected equipment and virtual contents. That said, participants also gave some suggestions for better user-experience support. Regarding the device itself, one of the common complaints is the uncomfortability in both mobile VR and HMD Oculus. Users found that their design (hardware or software) did not consider short-sighted people with the need for eyeglasses. Another complaint is about software performance in mobile AR. Users found the instruction unclear in terms of the details of description and guidance. Also, technical errors such as software crashes were frequently seen during the test play. We observed that these factors more or less affected our experiment and thereby our findings. For example, a blurry view in Oculus tasks might reduce the user’s engagement with the digital content and therefore result in less mental effort and infrequent bodily movements. That said, a surprise finding is that the Google Cardboard was perceived as the most comfortable device even compared to the high-end last generation of HMD. This point of view is very interesting as it might involve hardware design such as the very light weight and the ease to equip the Mobile VR headset. Mobile VR evoked a lot of emotions in particular joy and trust. The same clue to pick for developers is confirmed that they need to focus on the user’s comfort with ultra light weight hardware design and emotional responsive contents in software applications.

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