PaintAR - Effects of Haptic and Audio feedback on Immersion in an AR Tool for Painting

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Link to video demo: https://vimeo.com/666533672

Abstract

With today's technologies and design opportunities, there is a greater focus on developing and creating human-computer interactions that mimic human-to-human or human experiences with the environment by using multiple modalities. Therefore, this project explored the potential to paint in a 3D augmented reality (AR) environment with functionalities that replicate and mimic a natural experience of painting. The purpose of the project was to discover whether incorporating haptic and audio feedback while painting in 3D in AR affects the application's immersion and user experience. To explore this idea, an android application was developed using Vuforia and Unity implemented with different painting tools and color options. The application was tested with a within-group experiment to investigate the effects of the different modalities separated and combined. Results show a positive effect on immersion when including sound and haptics and a slightly positive impact on the in-app UX with the inclusion of sound and haptics. For future research we suggest improving the app's usability to further evaluate the impact of the added modalities to the AR experience. Secondly, we suggest testing a greater variety of sounds and vibrations that potentially can enhance the experience further.

Introduction

Creativity has been expressed through drawings and paintings since the early days of human existence and it is one of the oldest techniques used by humans for communicating, sharing experiences and memorializing happenings of our existence (Henshilwood et al, 2018). Although many of the traditional techniques and tools used for painting remain, technology has been part of changing and developing how we are able to create and express art. With today's technologies and design opportunities, there is a greater focus on developing and creating experiences between humans and computers that mimic human-to-human or human experiences with the environment by using multiple modalities. By combining the means of multimodal interaction together with the creative possibilities of creating art, our goal is to design a user experience that illustrates the feelings of using different tools for painting by utilizing sound and haptic feedback. Thereby this project seeks to understand the effects of multimodality to the interaction and user experience.

Related work

There are many areas of use for augmented reality (AR) and, more specifically, for modeling and drawing in an AR environment. Häggvik (2017) did a thesis project at KTH where an AR 3D drawing application was created through the use of Unity Engine and Vuforia. The idea with the project was for users to be able to create 3D models and drawings in a natural and simple way that does not require a large amount of skills, as can be the case with other 3D modeling programs. With the use of a physical item that acts as a pen, the users can make 3D drawings that become visible in the AR environment through the camera of a phone. The phone can be moved around the drawing so that it can be viewed from different perspectives. This interface is similar to what we want to produce and our project is, although much simplified, inspired by this thesis. There has been similar work done by Wacker et al. (2019), but this project focuses more on the aspect of using real, physical objects as a guide for drawing in the AR environment. It is also emphasized how haptic feedback can improve immersion with the application.

A study by Ismail et al. (2019) researches how multimodality can make interaction with an AR interface more natural than using mouse and keyboard. The authors propose an interface where both hand gestures and speech is used for input, which is intended to help make the interaction more robust and therefore improve the naturalness and immersion of the AR environment. Even if our project only features gestures as input from the user, we do want to study what effects there can be on naturalness from implementing a multimodal output.

Irwansyah et al. (2018) considers AR to be an effective learning medium, especially when using its 3D functionality. The study aimed to describe the stages for AR-based learning and to investigate its potential to be applied for the learning of chemistry, molecular geometry in particular. The first stage was to design a molecule model along with its marker using software such as Google Sketch Up, Corel Draw X5 and Unity 3D. A molecule model was paired with a marker (Image Target) and could later be tracked and observed using the Vuforia Augmented Reality engine in Unity 3D by walking around the marker with an Android phone running the Vuforia engine. The second stage of the study used a questionnaire to collect information about the potential learning aspect from the users. The results showed that the first stage was successfully developed and the second stage showed that there was potential for AR-based learning to be used for the learning of chemistry and molecular geometry.

Suzuki et al. (2020) presented an AR interface for sketching interactive graphics and visualizations they call RealitySketch. In their paper they discuss and introduce a concept of embedded dynamic and responsive graphics. The user draws graphical elements on the screen and binds them to physical objects, detaching the movement and interaction with the painted object from the screen making them dynamically movable with the corresponding physical motion made to the physical object. Using physical objects to control and possibly paint using objects in the environment is something we are interested in investigating in our project, i.e using a phone as the object. With inspiration from this paper, we learn that identifying objects with a color might be useful and possible. This paper also provides inspiration for other use cases, which in an extension of this project could be interesting to investigate, such as for educational or sports purposes.

Aims and Research question

The aim of this project was to implement an AR environment where users can creatively paint 3D objects in the air with the use of a smartphone application. Through using Vuforia and developing the means of the intended interaction in Unity, we wanted to enable users to paint using a tangible tool and their android smartphone as a display of the 3D objects and the UI. In addition, the goal with the implementation is to enable the user to paint with at least one type of brush and have the possibility to erase what they have painted. Furthermore, the intention was to also provide multimodal feedback from the system depending on the painting tool the user is using. The purpose of adding these multimodal features to the interaction is to investigate whether they have the potential to add to the immersion of the experience of using the application.

In order to further understand the effects of multimodal human-computer interaction in AR environments we were aspiring to answer the following questions:

- How can audio and haptics be applied to an AR 3D painting application?
- What effects do haptic and auditory feedback have on immersion in an AR environment?
- What effects do the added modalities have on the user experience of the interaction in an AR environment?

Abilities and Limitations

Designing for multimodal interaction consists of creating interfaces with modalities that complement each other and enhance the experience together. It also serves the purpose of increasing robustness, system flexibility, efficiency, and wearability in order to heighten the naturalness in the interaction between humans and computers. With the currently available technology of a regular smartphone, audio and haptic feedback were chosen to accompany the visual and proprioceptive modalities of AR. Even though designing multimodal feedback requires sophistication in terms of being able to develop a natural experience for the users, we were aware of the limitations regarding the ability to design feedback that fully mimic the natural experience of creating art.

Furthermore, the purpose of the project was not to create an elaborate painting tool but rather to explore what effects haptic and auditory feedback have on immersion in an AR environment. The painting tool was therefore restricted to three different states: two types of brushes and an eraser. Color options were red, green and yellow.

Background

Multimodal interaction

Multimodality is inherent in human interaction with the world due to the employment of multiple senses, both sequentially and in parallel (Turk, 2014). External stimuli is experienced for example through hearing, touch as well as proprioception, to mention a few. Properties of the environment can be enhanced by a single sensing modality while multiple modalities have the ability to provide a wealth of information to support interaction with the surrounding environment. Multimodal interfaces are described as interactive systems that seek to leverage natural human capabilities to communicate and enhance a more sophisticated pattern recognition to human-computer interaction. The aim with designing multimodal interfaces is to develop technologies that remove existing constraints on the historically used unimodal interaction between humans and computers towards a full use and more humanly natural experience of the interaction. Among other things, it can aid in enhancing the interaction by providing a more flexible system that is adaptable to each user and context (Dumas et al., 2009).

AR environments

Augmented reality is an experience where designers and developers enhance parts of users' physical environment with computer-generated input. Developers and designers create inputs ranging from the different modalities and other functions in digital content which respond to the changes in the user's environment in real time. Thereby the design is made to create digital elements that appear in real-world views (Interaction Design Foundation, 2021). A great part of this project focuses on immersion, which can be described as the users being enveloped by the augmented reality environment through their interaction with it (Kim, 2013).

Vuforia Engine

Vuforia engine is the most widely used platform for AR development. The engine makes it possible to create AR experiences that can interact with the environment and with objects (Vuforia, 2022). The Vuforia Engine offers tracking of objects and spaces that can be categorized into images, objects, and environments. It enables images to be registered and recognized by the camera, turning them into Image Targets. An Image Target placed in the real-world environment acts as an anchor for where virtual objects will appear in the AR environment.

Unity

The Unity Game Engine is an all-purpose, cross-platform game engine that supports both 2D and 3D graphics and scripting through C# (Unity, 2022). Unity provides developers with multiple built-in features such as 3D rendering, physics, and collision detection (Jerga, 2021).

Methodology

Research

The method used to research, develop, test and evaluate the implementation of the project was qualitative research through a design method. With inspiration from the first lab of the course DT2104 Multimodal Interaction and Interfaces at KTH about visuals in AR interfaces, we initiated the project with a literature study together with online research for inspiration related to projects made using Vuforia and Unity to create multimodal experiences in AR. Sourcing for resources and previous studies were made using Google Scholar, and search phrases and keywords such as "AR Applications", "3D painting tool" and "multimodal interaction" were used.

After the initial sourcing for project ideas, we discovered and found inspiration for creating a 3D painting application in AR. The idea was discussed with our supervisor Mario Romero who directed us towards focusing on the multimodal aspects of the interaction as well as gave us proposals for how to proceed with the project. Thereafter, the development and implementation phase of the application started.

Application

Throughout the entire process of the application development, continuous testing was applied to evaluate each change made to the system. The first functionality that was implemented was to enable the Image Target recognition feature from Vuforia and the possibility to track the movements of the tangible artifact to create the first 3D painting in AR using Unity. Two additional colors were added and tested before the implementation of the spray can was developed. Next, the functionalities to erase parts of the painted image and to clear the canvas were added. We took inspiration and created the basis of our code from tutorials by Mistry (2019) and 3DJeeps (2021-06-04).

After completing the functionality implementations to our satisfaction, meaning that all the functionalities were working as intended, we started to research royalty-free sounds and test different ways to implement vibrations that, according to us, would suit the interaction. Our idea was to make the experience of using the PaintAR application with the added modalities similar to the naturally expected experience of using the painting tools. The sounds used for the spray can and eraser were found on Epidemic Sound (Epidemic Sound, 2022), while the sound for the brush was found on Freesound.org (Freesound, 2022).

Lastly, after all sourcing was completed and the functionalities worked as expected with the sound and haptic feedback, we made some final touches to improve the application's interaction and experience further. After that, we designed our testing procedure, including testing two versions of the application and developing an immersion questionnaire in PsyToolkit (Stoet, 2010, 2017). Furthermore, we established criteria for our intended user group before we proceeded to recruit participants to perform the user testing experiment of the application.

Experiment

A within-group experiment was conducted where two different conditions were evaluated: one where the application gave haptic and audio feedback and one where this feedback had been removed. The focus of the evaluation was to investigate whether experiencing auditory and haptic feedback when painting affects the user's immersion with the application. A total of 10 people participated in the experiment, three identified as female and seven as male. The ages ranged from 18 years to 54 years with a mean age of 33 years . The subjects chosen for this study were recruited by convenience sampling due to the COVID-19 situation and the need for physical meetings to perform the tests. The intention was to gather a sample representation of potential and intended users for testing the application. The participants had restricted or no prior experience with AR environments or applications and were not informed that there would be a change in modalities between the two conditions.

Before the experiment, each participant was asked to read and sign a consent form to participate in the study. Each participant was also made aware that their participation was fully voluntary and that they had the ability to withdraw from the study at any time. Furthermore, the participants were also informed about how their data would be collected, stored and handled. The test was performed in a calm room indoors environment. Each test was performed with one participant and one facilitator, the responsibility of the facilitator was to provide the participant with the necessary instructions to complete the task. The participants were first allowed to paint freely in order to familiarize themself with the application and try out all features, after which they were instructed to paint either a 3D cube or pyramid. All participants tested both versions of the application in random order and answered an immersion questionnaire after each of the two conditions.

Table 1. *Immersion questionnaire divided by categories Interest, Usability, and Engrossment*

Interest	
I1	I enjoyed the activities in the AR environment
I2	I liked the activity because it was novel
I3	I wanted to spend the time to complete the activity successfully
I4	I wanted to spend time to participate in the activity
Usability	
U1	It was easy for me to use the AR application
U2	I found the AR application confusing
U3	The AR application was unnecessarily complex
U4	I did not have difficulties in controlling the AR application
Engrossment	
E1	I was distracted by other information in the AR environment when I performed a task in the AR tool
E2	I had a strong sense of involvement in my own work
E3	I was more focused on the activity rather on any external distraction
E4	I felt that what I was experiencing was something real, instead of a fictional activity
E5	I so was involved, that I felt that my actions could affect the activity

The immersion questionnaire consisted of 13 seven-scale likert statements divided into three categories; *Interest (I), Usability (U),* and *Engrossment (E),* see Table 1. All statements were taken from or inspired by either Georgiou (2017) or Kim (2013). The categories and the statements were presented in random order and the participants were asked to respond with their level of agreement to each statement using one of seven options: strongly disagree, slightly disagree, disagree, neutral, agree, slightly agree, and strongly agree.

Due to the restricted sample size, the collected data was analyzed using a combination of qualitative and descriptive statistics. The qualitative analysis evaluated the results of the tests based on key observations or specific comments made by the participant during the tests. The descriptive analysis of the data from the immersion questionnaire was processed using Microsoft Excel to facilitate the creation of graphs to be used for further analysis of the results.

Results

PaintAR

The application, dubbed *PaintAR,* has three different states: a brush, a spray can, and an eraser. Furthermore, three different color options are available for both the brush and spray can. The application also has a clearing option, visualized by a trash can. (see Figure 1a) The user is able to control the active state through the touch screen on the mobile device and activates a state, i.e., paint, by pressing down on the mobile screen. When either of the different states of the painting tool is used, correlating haptic and audio feedback is given through the mobile device to the user. The feedback is unique for each of the three different states, where the audio correlates to the action performed, i.e., a paintbrush sound for the brush and the sound of a spray can being used for the spray can state. The vibrations are synchronized to the audio. The feedback is only activated while the user is painting.

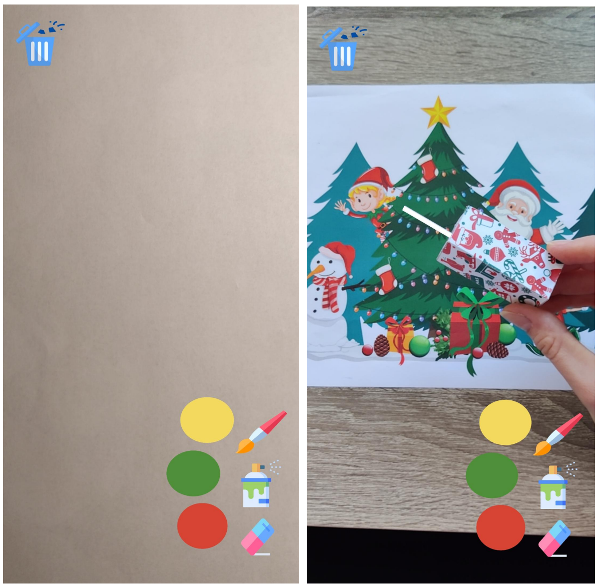

Figure 1a. *Interface of PaintAR: color options, brush, spray can, and eraser to the right; trash can to upper left*
Figure 1b. *Interface of PaintAR when the two Image Targets are detected: the canvas and the pen*

PaintAR consists of two different Image Targets, see section *Background - Vuforia,* one, a 2D image, which acts like a canvas to which the painted virtual object is anchored to, and the other, a 3D printed cube, functions like a pen. A virtual tip is anchored to the physical cube (the pen) when it is detected by the application to clarify its detection to the user, see Figure 1b. Both Image Targets need to be in view of the camera in order for the painting to function. The location of the pen is tracked, i.e., the user's movement of the pen, in order to paint in 3D space.

Test results

The following sets of graphs, Figure 2 through Figure 4, and their accompanying commentary, illustrate the participants' answers to the likert statements in the immersion questionnaire for each of the categories: *Interest, I; Usability, U; Engrossment, E.*

Interest

I1 - The two graphs are similar. However, all participants felt equal or more enjoyment with added modalities, apart from participant 10. The responses range from 'Slightly disagree' to 'Strongly agree'.

I2 - The answers mostly overlap. The responses between the test from participant 6 differed by two points, where the test with sound and haptics scored higher. The responses range from 'Neutral' to 'Strongly agree'.

I3 - Every participant, apart from participant 10, had a neutral or positive opinion towards the test with sound and haptics when it comes to spending time completing the activity successfully. The responses range from 'Neutral' to 'Strongly agree'.

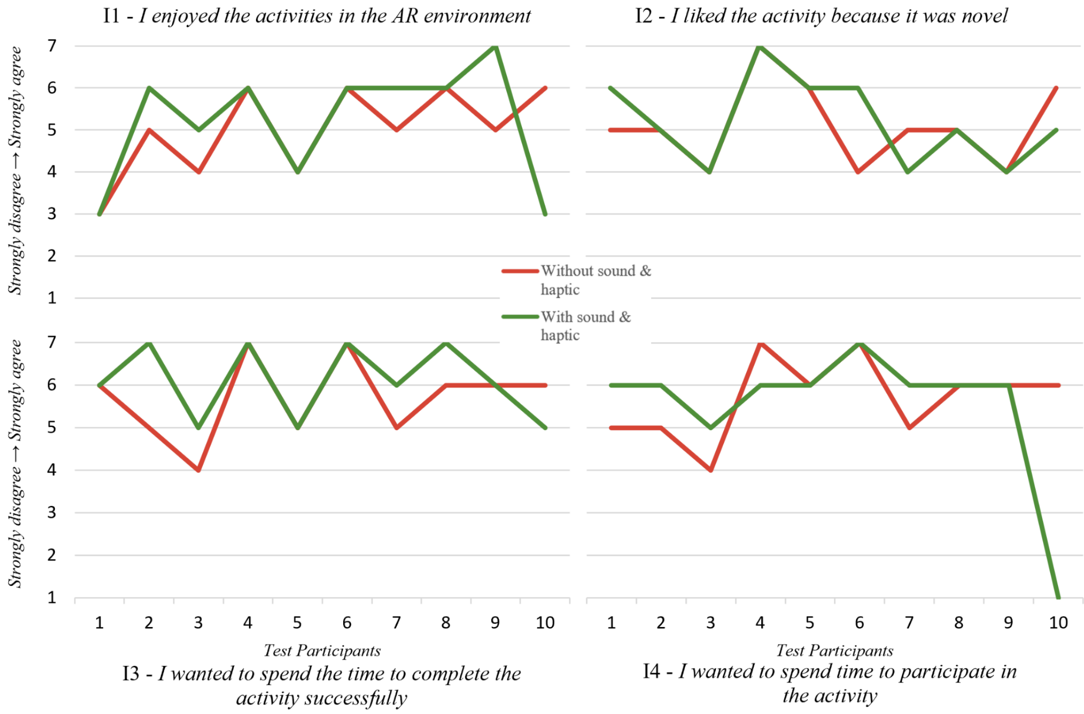

Figure 2. *Individual responses to each of the Interest-statements, without and with sound and haptic*

I4 - Little variation between answers can be noted regarding all participants apart from participant 10. Their response differed by 5 points between the two tests, where the test with additional modalities scored much lower. There is a big contrast between the answers, ranging from ‘Strongly agree’ to ‘Strongly disagree’.

Usability

U1 - The score from participants 1, 5, 6, and 10 substantially differ from the other participants. Apart from participants 4 and 5, the answers from individual participants show little to no change between the two tests. There is a stark contrast between the responses, ranging from ‘Strongly agree’ to ‘Strongly disagree’.

U2 - Participant 5 felt that the application was somewhat confusing in both tests, which coincides with their answer in U1 regarding ease of use without added modalities. Participants 1, 4, and 8 felt that the application became more confusing with the addition of modalities, while participants 6 and 10 felt that adding modalities made the application less confusing. However, the graphs are similar as each participant's answers differ by at most two points between the tests. The answers across all participants range from ‘Strongly disagree’ to ‘Slightly agree’.

U3 - The graphs indicate an agreement between participants as there is only a slight dispersion. The complexity of the application was not changed in any way between tests. However, some participants' slight increase in score when sound and haptics were enabled could be attributed to the added modalities.

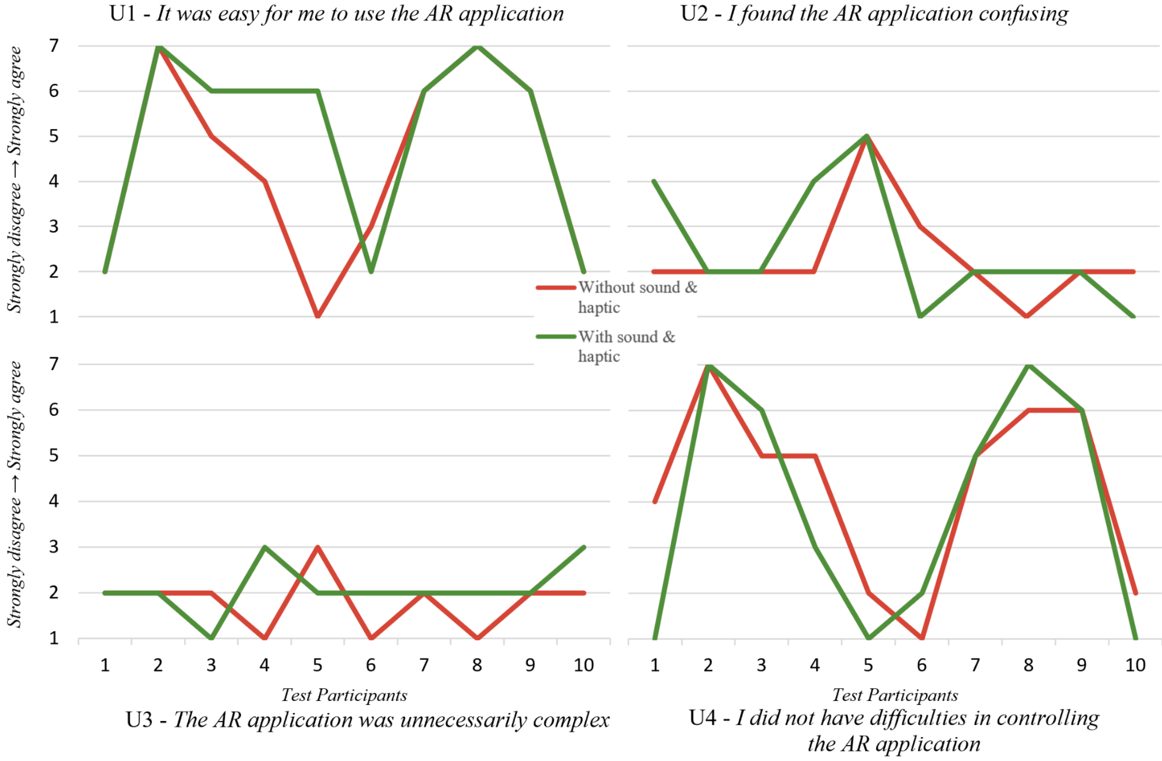

Figure 3. *Individual responses to each of the Usability-statements, without and with sound and haptic*

U4 - The two graphs are almost overlapping, indicating that the addition or subtraction of modalities did not alter the difficulty controlling the application. Participants 1, 5, 6, and 10 felt difficulty controlling the application, coinciding with their answers in U1. The U4 and U1 graphs are M-shaped, indicating that participants' individual opinions are repeated. The responses range from ‘Strongly agree’ to ‘Strongly disagree’.

Engrossment

E1 - The answers from each participant are similar between both tests, excluding the answers from participant 4, who felt more distracted by other information in the AR environment when sound and haptics were enabled. The responses show a dispersion ranging from ‘Agree’ to ‘Strongly disagree’.

E2 - Regarding the sense of involvement, the test with sound and haptics scored equal to or higher among all participants aside from participant 6. The responses range from ‘Slightly disagree’ to ‘Strongly agree’.

E3 - The responses show that most participants felt more focused on the activity when sound and haptics were enabled. However, the degree of focus which the participants felt differs from ‘Disagree’ to ‘Strongly agree’.

E4 - The test with sound and haptics scored equal to or higher than those without sound or haptics across all participants. However, the participants are not in agreement, as the responses range from ‘Disagree’ to ‘Strongly agree’.

Figure 4. *Individual responses to each of the Engrossment-statements, without and with sound and haptic*

E5 - Participants 5 and 10 felt less involvement when the test had additional modalities, dropping 4 and 5 points, respectively. The E2 and E5 statements both contain the word 'involved'. The answers from participant 5 coincide with each other from both statements regarding the test with sound and haptics. However, in the same test, participant 10 strongly agreed on 'sense of involvement' on E2 but strongly disagreed on E5. Furthermore, participant 10 answered 'Strongly agree' on all statements regarding the test with sound and haptics throughout the engrossment section except on E5. The eight other participants either stated that the involvement was equally or slightly better when using the application with the added modalities. The responses range from 'Strongly disagree' to 'Strongly agree'.

Discussion

Results analysis

I1-I4 have similar-looking graphs. One outlier is participant 10, who did not enjoy the activities when sound and haptics were added, according to I1. Furthermore, a similar pattern can be observed in I4, where the answer dropped from 'Agree' to 'Strongly disagree' after adding sound and haptics. The negative opinion on the added modalities is unique to participant 10 as most of the answers are either neutral or positive towards the addition of modalities. As mentioned in the method, the participants were shown the application in random order. Participant 10 was first shown the version without sound and haptics, and later the one with sound and haptics. The results from I1 and I4 regarding participant 10 could be attributed to other indirect factors, such as shortage of time or loss of interest in the test itself. However, the sound and haptics added might have clashed with what participant 10 enjoys and therefore directly lessened the experience.

The graphs for U1-U4 show noteworthy data. U1 and U4 show vast disparity between the answers of different participants. However, they are both M-shaped, pointing to the fact that the participants' individual answers were similar for both statements. Participants 1, 5, 6, and 10 had much difficulty in controlling the application in both tests. Furthermore, they all agreed that the application was not easy to use. The words 'control' and 'use' might be seen as interchangeable which perhaps could explain the similarity between the answers an individual participant gave to U1 and U4. The vast disparity of answers across the participants might be attributed to how the statement was interpreted. Is the application itself controllable and easy to use, i.e., functions such as changing paint or switching between paint tools, which was the exact question we intended to ask, or is the painting aspect itself controllable and easy to use? Therefore, the statements for U1 and U4 could be up to interpretation and subsequently be answered with entirely different perspectives.

The individual answers from E1-E5 indicate that adding sound and haptics has a neutral or slightly positive effect on engrossment in most cases. Nonetheless, there is a wide range of opinions in both tests. Furthermore, some individual answers are somewhat contradictory; for example, participants 10 answered 'Strongly agree' on E2-E4 but 'Strongly disagree' on E5. We hypothesize that the statements from the engrossment and usability categories are more open-ended than those from the interest category. This fact would make the statements more prone to interpretation and could lead to the wide range of opinions seen in the results.

Likewise, another uncontrolled variable that could have affected the results and the participants degree of immersion in the application is the individual associations each of the selected sounds and vibrations triggered. Although we tried to mimic the natural sound and haptics of using e.g. a paint brush we cannot conclude whether that association was shared by all of the participants. If a sound and vibration was not perceived as natural in relation to the state of the application, e.g. spray can, it could potentially have had the opposite effect and negatively affected the participants immersion when using the application. This could potentially be an explanation for the disagreement from participant 10 towards statement E5.

An aspect that might have increased the sense of immersion when using the application with the added modalities, is if the sounds and haptics came from the handheld object that is used for tracing the users movements while painting instead of coming from the android showing the visualization of the 3D painted object. It would potentially aid in improving the naturalness of the interaction as described by Ismail et al. (2019) since the feedback would be received in the hand that is painting, as expected if painting in real life.

As mentioned, most participants had no or restricted prior experience with AR applications. Therefore, the learning curve of each participant could be a factor that affected the change in results between the conditions. As participants got more experience, the second condition performed could have been perceived as more straightforward and, consequently, more immersive independently of the added modalities. This potential factor was minimized by allowing the participants to draw freely and familiarize themself with the application before performing a defined task but cannot be completely disregarded.

Personal assessment

Overall, time was managed quite efficiently. When discovering some issues with having target images, such as that users are not free to paint anywhere they want, we researched whether we could use another software than Vuforia, that provides other ways of navigation. But we quickly found that new issues would arise from switching software and before we had spent too much time, decided to continue with Vuforia. This, along with group members working in parallel with different tasks, led us to a working application well in time to start performing testing and allowed us to analyze our results thoroughly.

The supervisor gave two leading suggestions for the project. Firstly, we should conduct two separate tests, one with and one without added modalities. An immersion questionnaire could later be used between tests to evaluate the effect of adding modalities to our AR application.

The results from the suggested questionnaire were used to answer the research questions. The second suggestion was how to present the results as there was some uncertainty of the clearest and most informative way of showing the results. The supervisor suggested a more individualized representation of the participants' opinions, which was later incorporated in the report and was the basis for the results and the discussion.

Future work

Our application depended on two different Image Targets, one acting like a canvas and the other as a pen, which based on the tests and to our impression was one of the main sources of error in the application. In order for the application and painting to work, both targets needed to be in view of the camera which restricted the user's movement. Furthermore, performance of the application depended on the smartphone camera's depth of field and as such was severely affected by aspects such as shadows and light in the room. Future work could explore alternative ways of implementing a painting application which would not depend on Image Targets.

In relation to the restriction of a user's movement, it would be interesting to implement the connection of multiple devices to the same shared AR environment. This would enable a secondary device to be connected to the application and provide an overall stationary view of the AR environment. Furthermore, a shared AR environment could create opportunities of collaboration which, in line with Irwansyah et al. (2018), could be used for learning.

The handheld object could be made more interactive in order to improve the naturalness of the application and thereby the immersion as well. Not only could it give sound and haptic feedback directly, but there could also be other added functionalities applied to it such as controls for painting, changing colors and changing the painting tool instead of controlling those features from the display of the android.

To further enhance the potential flexibility that multimodality can provide (Dumas et al., 2009), future work should provide users with the option to change the different sounds and haptics. It could also allow users to create their own sound and vibration sequences for the different states of the application in order to explore how people's associations differ and whether it could further aid in creating a more immersive experience.

Within the timeframe of this project a restricted number of participants were recruited, therefore future testing with not only a larger number of people but also for a longer period of time would provide more conclusive evidence of whether the added modalities aid in providing a more immersive experience when painting in AR. A longer testing period would also ensure that a difference in the results when comparing the two conditions would not depend on the individual learning curve and experience with the application and AR.

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