Thermics: Evaluating Effects of Tactile Thermal Feedback on Invincibility in Virtual Reality

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ABSTRACT

Virtual reality commonly stimulates the visual and auditory senses in order to prompt the user to have a level of ownership over the virtual body. In some cases, this may enable the user to behave with lowered cautiousness, knowing that there are fewer consequences to their actions. We define this type of acting with lowered cautiousness as invincibility. Additionally, haptic technology offers a wide range of feedback methods that potentially deepen the user's sense of immersion and ownership. We chose to examine an application of thermal feedback, which can be presented as a situation with an amount of risk that has a common response in the real world, but may have varied effects in virtual reality. In particular, we will explore how virtual reality can affect a user's sense of invincibility by prompting them to interact with hot interfaces. Physical reaction times and responses as well as levels of presence are considered to be metrics that contribute to this sense of invincibility and will be evaluated.

Index Terms: Virtual Reality, Thermal Haptics, Presence, Perception, Invincibility

1 INTRODUCTION

Our project focuses on investigating the relationship between people and their sense of invincibility within virtual environments when subjected to varying levels of perceived visual thermals and thermal haptic feedback. There is little existing research that uses the term invincibility in this context, or that explores this concept in the space of virtual reality. There is significant research on how to define presence and immersion, in which invincibility is deeply rooted. We define invincibility as a sense of lowered cautiousness, which is theorized to be correlated with a lowered sense of presence and a lower level of virtual body ownership. This is to say that when the participant is more conscious that they are in a virtual setting, they will be more willing to put their virtual body in harm's way, as the knowledge of lowered real-life consequences is more apparent. Conversely, those who experience high levels of presence and virtual body ownership (i.e. people who feel very immersed in a virtual environment) will still react to surprising and dangerous scenarios by flinching. In this situation, the user may subconsciously be more aware that negative consequences can occur, despite being in a virtual setting.

We will be creating a space in which users will interact with a common household appliance, a stove, to facilitate a scenario that is known to be associated with intense heat. This will allow us to explore whether or not people act differently towards a familiar situation in a virtual environment. For example, will people trust that the virtual environment won't hurt them? If the user is presented with a hot surface, will they exhibit a sense of invincibility and react as if nothing will happen when they come in contact with it? We hypothesize that users who exhibit lower scores of presence and immersion will have a higher level of invincibility, and thus be less wary of thermal feedback from the real world, which can also result in slower reaction times.

Figure 1: Virtual kitchen scene.

2 BACKGROUND AND RELATED WORK

Although the concept of invincibility appears to be a unique lens of looking at the virtual experience, Thermics defines invincibility as a byproduct of the combination of presence and embodiment, and thus draws on an array of different concepts from multiple fields, including human psychology and thermoception, virtual reality, and telepresence. Ultimately, Thermics evaluates the combination of the findings from the following previous research:

2.1 Enhancing presence

In order to enhance the sense of presence of users within virtual reality experiences, studies and surveys have looked into how VR affects the human psyche, and to establish a relationship between virtual stimuli and human psychological responses. Dinh et al. [3] shows that there is a strong indication that the addition of tactile, olfactory and auditory cues to a virtual environment increased the user's sense of presence and memory of the environment, with a surprising addition that increased visual detail did not increase either sense of presence or memory. In order to measure presence, a specific definition must be established. There are hundreds of terms related to this word, but the main two that will be examined are media and inner, which were specified by Coelho et al. [2]. These two types are heavily-weighted considerations when designing a VR system because it is important for the experience to lessen the user's conscious attention on the medium/function of the given medium, and further compel the user to take certain actions or feel specific

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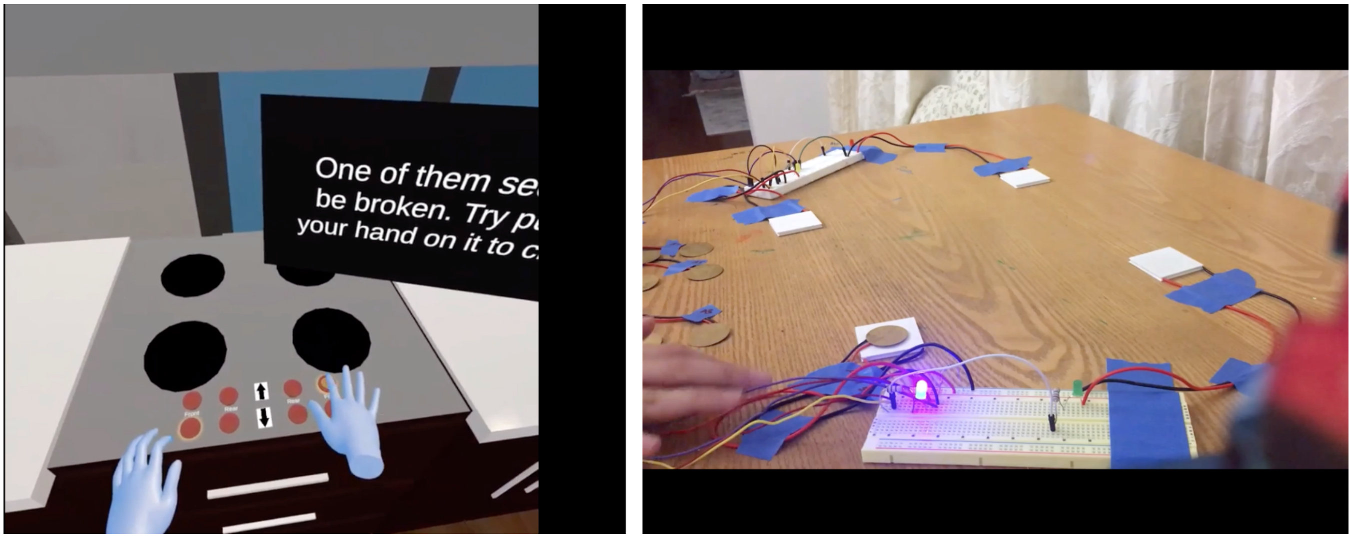

Figure 2: Thermics panel and VR side-by-side.

emotions independent of the type of technology. When evaluating these metrics, Schuemie et al. [8] discusses six main questionnaires and some other measures in Research on Presence in Virtual Reality: A Survey. Witmer and Singer's Presence Questionnaire [9] is widely used, notably in related works Ambiotherm [6], Haptic Around [4], and Season Traveller [7]. Because these papers are heavily related to this study and the concept of presence can be difficult to otherwise measure, the decision was made to use the same method with minor modifications.

2.2 Multi-tactile environment and interaction

Head-mounted displays (HMDs) have been a staple for recent virtual reality experiences, but can be limiting for multi-feedback and interaction features. The Ambiotherm [6] team attempts to get around this by developing their own modules that attach to pre-existing HMDs. They included thermal and wind modules that applied heat to the neck and wind to the cheeks. However, this approach isolated the interaction to purely looking around with feedback restricted to above the neck. Season Traveller [7] builds upon Ambiotherm's interface by adding an olfactory module, but has the same constraints.

Another approach that Haptic Around [4] implements is a system with an overhead device that works in tandem with a HMD and a custom hand-held controller. With this setup, the team was able to provide partial-body haptic feedback from multiple components including thermal, wind, force, and wetness. Although it is not a full-body experience, Haptic Around was able to engage users with more features over a larger portion of their bodies. However, this experience also had limitations regarding space, portability, cost, and power consumption.

Trigeminal-based Temperature Illusions [1] builds on this concept of the olfactory module. Brooks et al. uses micropumps and an atomizer to release odors that trigger both the olfactory bulb as well as the trigeminal nerve, responds to both temperature and chemicals. Using different scents to simulate heat and coolness sensations replaces the more known approaches of using heat lamps and Peltier modules. This research was successful in simulating thermal experiences without the need for a power-consuming device.

There is little literature that discusses a centralized panel that maps to the virtual world as an additional medium of interaction that provides multi-tactile feedback in a compact, effective way. Additionally, the concepts of presence and simulated and real thermal feedback are explored, but there is little to no research on the specific realm of lowered cautiousness within virtual reality.

3 Design Considerations

With an open-ended concept like invincibility and virtual reality, there are a great number of different methods available for use. Here we discuss our reasons for choosing the approach, design, controls, and implementation methods for Thermics.

3.1 Type of tactile feedback

We had honed in on tactile feedback as another layer to the virtual experience. However, this still left many types of tactile sensations to explore; vibration, pressure, texture, and so on. We explored existing literature on simulating textures and similar sensations using hardware, but found that many of the components necessary were hard to acquire due to cost or size. As discussed in Sect. 2, many studies in this research area used thermal haptics, given the relatively broader options for implementation. For our purposes, we found the Peltier thermoelectric modules to be both low-power and cost-effective, as well as adequate for thermal feedback applications.

3.2 Locality

We discussed several potential methods to implement thermal feedback in our project. We considered the fact that the user would not be seeing the hardware in any case, but we had limited options for development space. While the idea of a portable system, such as a controller attachment, seemed plausible, the Peltier modules are of a set size and shape and cannot be comfortably held in a natural grasp. Furthermore, they required direct skin contact to be effective, which would reduce the level of surprise during the experience. Ultimately, this led us to find a medium between the two. Thermics utilizes a simple but stationary physical panel. This panel does not need to be mounted in place and can be simply put on a table, but is detached from the participant and allows the participant to move freely.

3.3 Control mechanism

Other research has examined using custom controllers, controller attachments, and no controls at all. A custom controller was unnecessary for our use, particularly as our research revolves around recreating a familiar scenario in virtual reality. Learning a new control mechanic would only be distracting. Although we considered using the Oculus controllers for more mechanics (e.g. locomotion, camera control), we ultimately opted for using Oculus Hand Tracking. This would allow the user the full freedom to move their arms and hands naturally as they would outside of VR. Furthermore, this frees up the hand to touch the physical panel containing the Peltier modules.

3.4 Implementation

We used Unity 2019.2.4f1 to create the virtual scene, and utilized existing 3D models from Google Poly [5] with minor modifications. The app runs on the Oculus Quest and uses native Hand Tracking capabilities. The hardware was implemented using an Arduino Mega and the Arduino IDE.

4 Hardware Design

Our original intent was to communicate via the serial port between an Arduino Mega, Oculus Quest and Unity using the Oculus Link. Unfortunately, the devices available were not compatible. We considered multiple workarounds, including Bluetooth connection. However, the pairing between the Oculus Quest and the HC-05 Bluetooth module was poor with noticeable latency issues.

This led us to remove the serial communication between these components, which prevented us from using a physical potentiometer setup to sync and emulate the virtual stove knobs. Therefore, we switched to using Piezo (capacitive) touch sensors. Using an Arduino Mega, we wrote the Peltier thermoelectric modules to receive one of 4 heat settings based on the Piezo sensors, which were aligned to buttons in the virtual scene. The Peltier modules used were rated for 12V, but all experimentation ran on a 5V system from the Arduino Mega. A PWM signal was sent to each Peltier module to control the heat, in which the low setting was a 50% duty cycle, medium was 75%, high was 100%, and 0% was the off setting. LEDs were wired to simulate the low/medium/high color visualization in the virtual scene, and so that the moderator can see the PWM signals working properly. The setup that we had would have required a power modulator in order to draw enough current for extremely high levels of heat transfer on the Peltier modules. However, due to limited resources, the highest heat setting is only relatively warm to the touch.

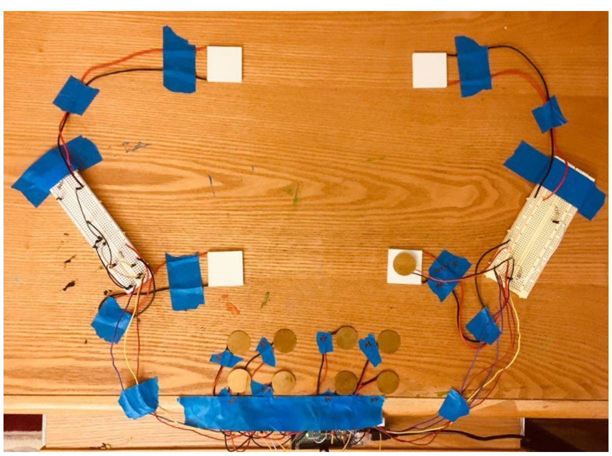

Figure 3: Hardware panel.

5 Calibration

In order to line up the virtual scene with the physical panel, we needed a straightforward way to calibrate the two such that the participants would be able to painlessly complete the necessary steps, and robust enough to allow for accurate 6-DOF positioning.

Figure 4: Cube calibration method.

5.1 Cube calibration

The first attempt at this used custom scripts that inherited the Oculus OVR classes to enable object grabbing within the Oculus Hand Tracking scripts. The base concept was to have the participant grab a cube that existed in both the virtual and real worlds and place it in a designated spot on the front of the physical panel. In theory, this allowed the object's rotation and position to match based on this calibration point. However, the virtual object grabbing was inaccurate in both orientation and offset, causing the rotation and position to be significantly incorrect. As we did not have the equipment capabilities to track the physical object in real-time, we changed our approach.

5.2 Pinch calibration

Instead, we tried another method that would not require the participant to remove the headset. The front edge of the panel is something that is easy to feel without needing to view it, so this approach builds on that concept. We tracked the locations of both hands in the virtual world. A line is calculated between these two hand positions, and the angle between the original world-scale x-axis and this newly calculated line is found. This angle is then used to calculate a new location and position. For our purposes, if the two hands are located along the front edge of the physical panel, the calculated angle allows the virtual setting to reposition the virtual stovetop based on those two points. When the participant pinches the index and thumb of both hands simultaneously, the angle calculation is triggered, and all of the objects reposition based on this calculated angle. The kitchen scene is already sized to be analogous to the physical panel such that no rescaling was necessary. When the physical and virtual worlds are calibrated, the participant presses a virtual button that locks in this new setting. This setting cannot be reset for the rest of the experience in order to ensure the physical and virtual worlds stay aligned.

6 Experimental Setup

It was necessary to guide the participant through the steps required to progress and complete the experience, so an onboarding process

Figure 5: Pinch calibration method.

was created. We used world-space text panels located throughout the scene to achieve this. The first prompt explains that the participant can use their hands freely through the experience, due to using hand tracking. They are then walked through the steps required for calibration (as discussed in Sect. 5. Next, the stove control buttons are explained. Each set of up and down buttons correspond to each stovetop, and each one can be set to low, medium, or high. The color of the stovetop (from dark red to bright red) matches each level of "heat," as seen in Fig. 6. As discussed in Sect. 4, these are mapped to the capacitive touch sensors, and the Peltier modules are heated to a similar level. The front bottom stovetop is "broken," i.e. the virtual buttons will not appear to heat the stove. However, the capacitive touch sensor is still operational, and the physical Peltier module is still heated to the level appropriate to the number of times the buttons were pressed. When this broken button is pressed for the first time, another prompt appears, encouraging the participant to touch the seemingly broken stovetop.

Other miscellaneous aspects are added to the kitchen scene in order to add a sense of "realism," such as a background hum emitting from the non-interactive fridge model, lights shining in from the windows, and a basic room model that contains the kitchen scene.

7 Evaluation

As invincibility is a multifaceted concept, we want to gather both quantitative and qualitative data to more comprehensively measure it. These metrics will measure the levels of presence and reactions in our experiment.

Presence and immersion are measured using a questionnaire based on Witmer and Singer's Presence Questionnaire, measuring sensory, control, realism, and distraction factors. These results are quantified using a seven-point Likert scale, where 1 corresponded to "Strongly Disagree," and 7 corresponded to "Strongly Agree."

To measure reaction speed, capacitive touch sensors in our setup as well as collisions in the virtual scene. This allows us to calculate multiple metrics with respect to the source of thermal feedback:

- Number of times the broken button was pressed before touching the stove (i.e. level of heat set)

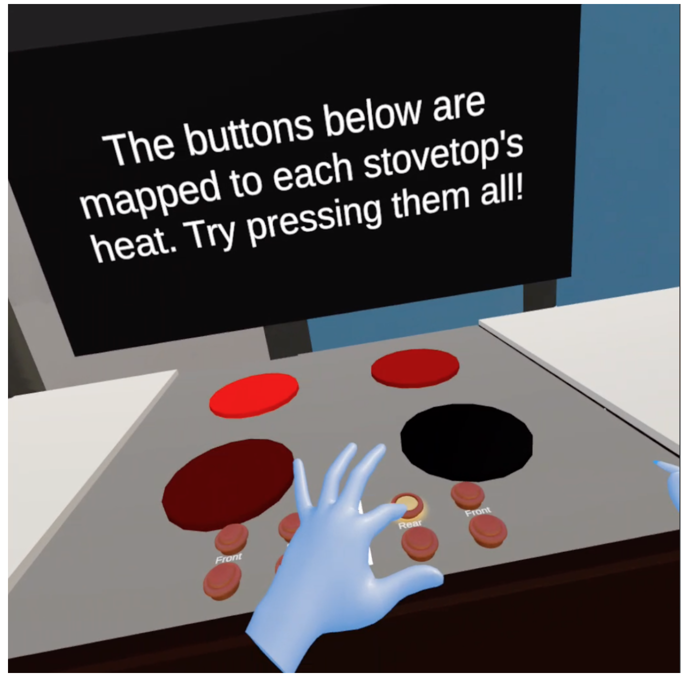

Figure 6: Heated stove.

- Amount of time between prompt to touch the stove becoming visible and touching it
- Amount of time between first touching the stove and releasing
- Amount of times the stove was touched in total

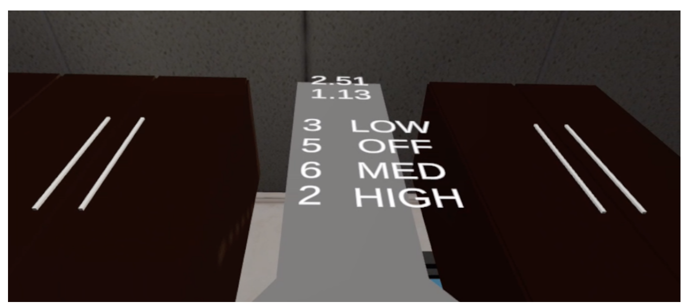

Figure 7: Evaluation metrics.

Fig. 7 shows the output of these metrics, as seen in the virtual environment. From top to bottom, the values are: time between prompt and first touch of front-right stove; amount of time in the first touch of the front-right stove; and the number of touches and stove setting on first touch for the top left, bottom left, top right, and bottom right stoves, respectively.

Freeform comments during and after the experience would also be recorded in order to gather qualitative data on reactions, such as surprise, confusion, or other types of responses.

Ideally, we would have also run ANOVA testing to measure statistical significance.

8 Discussion

This experiment was our first attempt at exploring the concept of invincibility in virtual reality. There are a number of initial findings from this project, as well as a series of limitations.

8.1 Initial Findings

Upon testing our setup, calibration, and evaluation, there were a few initial findings for each section. In terms of the calibration, at times it was a bit finicky because there were not distinct markers for where the pinched fingers should be aligned other than to the edge of the table. The quick work-around for this was to click on the downward buttons and making sure the the virtual environment registered when the Piezo sensor was tapped. However, more tactile cues should be given for this portion. During the evaluation, the Peltier modules did not heat up to the temperature that was expected. So, although it was surprising that there was thermal feedback, it was not to the degree that we initially intended. Furthermore, there is a slight delay between the button click and the heating of the stove top. This is similar to how real heat would transfer on an induction stove, but if the user immediately goes to touch a Peltier module before it reaches its peak, the evaluation results may be skewed. Another note is that the user has blue hands, which may lead to less sense of body ownership or give the impression of a cooler temperature. Applying different skin tones should be considered in the future.

8.2 Limitations

One of the key limitations encountered during this project was COVID-19, which took in-person work sessions into socially isolated work sessions. This became an obvious hurdle with respect to hardware development and especially user testing. Although it was possible to package the app's APK and send it to potential users, there was no way to send the physical panel, and furthermore, the Cornell Institutional Review Board for Human Participant Research (IRB) had a significant backlog of applications, and did not have time to review ours. We were still able to divide the workload and development remotely, but experimentation was extremely limited.

Additionally, the resources available became drastically limited as campus closed due to the pandemic. Our initial proposal included using the Oculus Link for a wired setup in order to use serial communication with the Arduino. This would have enabled the use of potentiometers instead of the buttons with capacitive sensors, and real-time scene updates based on the signal inputs. Unfortunately, the devices available did not have the graphic and processing capabilities necessary for the Oculus Link, and thus we were required to work around not having the serial connection. The hardware and electronics were also limited to what was already on-hand, as shipping times became unreasonable for the scope of the course.

With regards to the product actually built, there were obvious inconsistencies between the panel and the virtual scene. The size and shape of the stove tops were mismatched with the Peltier modules on the panel, which may have caused a disconnect in a participant's mind, as well as faulty numbers with respect to the evaluation metrics. The calibration could be imperfect, which could cause the real world and virtual scene to not line up exactly. Additionally, the Oculus Hand Tracking seemed to have bugs, causing virtual hands to occasionally behave erratically during the experience.

8.3 Future Work

In the future, there are several improvements and areas of investigation that can be pursued including developing more thorough evaluation metrics, modifying the physical setup, incorporating more haptics, and applying our hardware to different applications. Because we were not able to test on any participants who were not aware of the experiment, the biggest step would be to launch pilot testing. In terms of evaluation metrics, we want to look at the time of each touch instead of just the first and implement a method in which the user would not have to look up at the values at the end of their session. We have started using the Piezo sensors for reaction time, but it is relatively noisy data that would need further refinement. Furthermore, we want to explore the system performance aspect of evaluation including frame rate and serial communication through Oculus Link, given the proper devices.

For the physical setup, it would be beneficial to redesign the circuitry to include a power modulator to transfer more heat. Regarding the panel itself, right now, the prototype components are taped to wood, but the components could be mounted onto plexiglass with smaller protoboards embedded into it for a sleeker finish. Another addition to the panel could be other forms of haptic feedback such as vibration.

Our hardware can be used for scenarios that are not necessarily using a table top configuration. For example, maybe the virtual environment places a user in a house that is on fire and the walls need to provide thermal feedback so they know whether or not another room is safe. Investigating this sense of invincibility separately from the hardware is also a good starting point for future exploration in a variety of different topics.

9 Conclusion

Our goal was to investigate users' sense of invincibility in virtual reality with thermal haptic feedback. The sense of invincibility, a combination of presence and embodiment, was evaluated using both physical and virtual components including Piezo sensors, Peltier modules, and a virtual kitchen to recreate thermal haptic feedback and mimic thermal visuals for a stove top. The evaluation metrics include reaction time and levels of sense of presence using hardware measurements, questionnaires, and interviews. Although there were quite a few roadblocks, there is a lot of room for further analysis.

Acknowledgments

The authors wish to thank Harald Haraldsson, the Mixed Reality Collaboratory, and Cornell Tech for the support in this project.

References

[1] J. Brooks, S. Nagels, and P. Lopes. Trigeminal-based Temperature Illusions. *Conference on Human Factors in Computing Systems - Proceedings*, 2020-April, 2020. doi: 10.1145/3313831.3376806

[2] C. Coelho, J. Tichon, T. J. Hine, G. Wallis, and G. Riva. Media presence and inner presence: The sense of presence in virtual reality technologies. *Emerging Communication: Studies in New Technologies and Practices in Communication*, 9(c):25–45, 2012.

[3] H. Q. Dinh, N. Walker, L. F. Hodges, C. Song, and A. Kobayashi. Evaluating the importance of multi-sensory input on memory and the sense of presence in virtual environments. *Proceedings - Virtual Reality Annual International Symposium*, pp. 222–228, 1999. doi: 10.1109/vr.1999.756955

[4] P. H. Han, Y. S. Chen, K. C. Lee, H. C. Wang, C. E. Hsieh, J. C. Hsiao, C. H. Chou, and Y. P. Hung. Haptic around: Multiple tactile sensations for immersive environment and interaction in virtual reality. *Proceedings of the ACM Symposium on Virtual Reality Software and Technology, VRST*, 2018. doi: 10.1145/3281505.3281507

[5] Poly by Google. Kitchen, 2017.

[6] N. Ranasinghe, P. Jain, S. Karwita, D. Tolley, and E. Y. L. Do. Ambiotherm: Enhancing sense of presence in virtual reality by simulating real-world environmental conditions. *Conference on Human Factors in Computing Systems - Proceedings*, 2017-May:1731–1742, 2017. doi: 10.1145/3025453.3025723

[7] N. Ranasinghe, P. Jain, N. T. N. Tram, D. Tolley, Y. Liangkun, C. E. W. Tung, C. C. Yen, E. Y. L. Do, K. C. R. Koh, and K. Shamaiah. A demonstration of season traveller: Multisensory narration for enhancing the virtual reality experience. *Conference on Human Factors in Computing Systems - Proceedings*, 2018-April:1–13, 2018. doi: 10.1145/3170427.3186513

[8] M. Schuemie, P. Van Der Straaten, M. Krijn, and C. Van Der Mast. Research on Presence in Virtual Reality: A Survey. *CyberPsychology & Behavior*, 4(2):183–201, 2001. doi: 10.1089/109493101300117884

[9] B. G. Witmer and M. J. Singer. Measuring presence in virtual environments: A presence questionnaire. *Presence: Teleoperators and Virtual Environments*, 7(3):225–240, 1998. doi: 10.1162/105474698565686