# Exploring the value of adding airflow to the VR-developer’s toolkit

By: Robbert Troost

Supervisor: Kai-Mikael Jää-Aro
Södertörn University | School of Natural Sciences, Technology and Environmental Studies
Master’s dissertation 30 credits
Media technology | Spring semester 2019
Interactive Media Design Programme

SÖDERTÖRN UNIVERSITY | STOCKHOLM
sh.se

# Exploring the value of adding airflow to the VR-developer's toolkit

**Robbert Troost**
Södertörn University
Stockholm, Sweden
robbert01.troost@student.sh.se

#### ABSTRACT
To achieve the highest levels of immersion and presence possible in a Virtual Reality experience, all of the sensory input we receive in the real world must be simulatable in Virtual Environments (VE) as well. Foregoing the more popular audio-visual feedback, this project aims to better understand the benefits of adding tactile feedback (namely that of airflow) to the VR-developer's toolkit. Through user tests, involving a hairdryer to produce a strong airflow that is easily redirected and changed in temperature, feedback was collected on the user experiences and applications of airflow in a VE made to simulate a walk through river lands similar to the ones found in Sweden. While there was no singular way that the participants experienced the added sensory input, most reported the airflow as being equally important to feeling immersed as background music, and on average almost as important as other audio cues. Perhaps most importantly, rich insights were gathered that can guide further research.

#### Author Keywords
Immersion; presence; airflow; virtual environments.

#### ACM Classification Keywords
H.5.1 [**Multimedia Information Systems**]: Artificial, augmented and virtual realities –Virtual Reality for Art and Entertainment

#### INTRODUCTION
For Virtual Reality (VR) to truly live up to the second part of its name, the experience must become as immersive as the situation of use calls for. The experience must in the user create a high level of *presence*, defined as 'a mental state in which a user feels physically present within the computer-mediated environment' [5]. This does not necessarily mean that every VR experience should include the full range of sensory input that life has to offer; for instance, a VR experience aimed at showcasing Arctic wildlife does not need to make the user feel the freezing temperature associated with that environment as well. It does however mean that every such sensory dimension should be understood in terms of its impact on immersion, and the ways it uniquely interactions with our system of perception. Only then can the proper considerations of implementation be made, in terms of factors such as financial investment, usability, and user experience.

Whereas currently VR is often limited to stimulating the audio-visual senses only, researchers with all kinds of specializations (ranging from psychologists to software engineers) are hard at work investigating and understanding ways to make full immersion possible [2].

In this paper, our objective is to investigate a less-considered environmental factor that impacts how we perceive our surroundings: the flow of air. While not as informative as visual feedback [8], the granularity of wind still offers up a lot of information that we feel is underappreciated in current research. Since airflow can be manipulated in terms of strength, direction, and temperature, we believe that research into the impact of airflow on VR experiences is a worthwhile pursuit. Valuable insights might also appear when considering airflow in relation to the concept of crossmodal interactions [21] [18]: the phenomenon that our senses interact in such a way that one sense's information might influence or even override another sense's.

As such, this paper covers the considerations made while designing an artefact that would be capable of adding, on top of other sensory input such as audio and video, airflow to VR experiences. First, we explain the considerations crucial to designing for the field of VR. Then, we explain how these considerations shaped the user testing we underwent as the main source of our data. Finally, we present the data, quantitative and qualitative, as gathered from our user testing, and our interpretation of this data as part of the ongoing discussion about VR and its potential.

#### VIRTUAL TECHNOLOGY
Virtual Reality technology is often quoted as the next revolutionary step in how we interact with technology, the world and reality itself. Even today, limited by hardware and (time) investments, VR has already proven its ability to bring unique, new dimensions to subjects ranging from art [4] to medicine [16].

Virtual Reality holds the greatest potential when VR hardware in combination with a software-based Virtual Environment (VE) makes it as easy as possible for a user to believe that the VE is their current reality, hence achieving a high level of presence in the VE. Understanding this combination of three pillars (the hardware, the software, and the user experience) is crucial to realizing the technological dream of enabling, if not actively favoring, full immersion.

### The Hardware

For so many applications, hardware remains a limiting factor which stops us from turning concepts into realities. The same is true in VR, and especially for commercial VR products, where a computer is required to simulate and process entire Virtual Environments. As the amount of calculations that a computer can do during any given time span is limited, research is focused on making the most out of the calculations that do happen. It has been shown that the other two pillars (software & user experience) of VR can help in this regard [10].

The other kind of hardware required to make VR possible is that which provides the user with the sensory feedback aimed at simulating a different reality. Small scale VR experiences are often supported by Head Mounted Displays (HMDs), which work as glasses-helmet hybrids that primarily focus on delivering audio-visual content.


**Figure 1. VR peripherals at varying stages in the prototyping process**

Different kinds of controllers for interacting with the VEs are also provided. However, the current generation of controllers should be seen as temporarily, non-ideal artefacts that prevent full immersion from being acquired. For the level of presence to be maximized, VR users should be able to interact with the VE solely in the way they would with the real world, which excludes current controllers that make use of physical buttons, thumb sticks, etcetera.

Larger scale VR installations are often referred to as CAVEs (cave automatic virtual environment) [3]. Instead of restricting the user's perception to only the VE, CAVEs are instead real life spaces that are made to look like different immersive environments through the use of audio and projectors, and motion capture systems. This approach to VR brings with it a lot of perks, and provides an experience that is not strictly comparable to that of a HMD. Eventually, however, this approach's reliance on physical factors will make it more restrictive than the theoretical full immersion that HMDs, or functionally equivalent technology, can achieve.

More importantly for this research project, the industry has been hard at work envisioning and creating additional hardware peripherals that enhance the default experience by adding additional types of sensory input. Figure 1 shows such a collection, ranging from gloves that act as haptic interfaces to an omni-directional treadmill that allows the user to walk freely in any VE. Our focus for this research project will be on the concept, sensations, associated hardware, and uses of airflow as a different dimension that could possibly be added to the VR-developer's toolkit.

### The Software

The second pillar of VR, software, is the one that makes use of any functionality offered by the hardware in order to create the VE that the user will inhabit. For the above mentioned treadmill to truly work for instance, the software has to be capable of correctly translating their real movements into virtual ones, or the illusion of immersion is lost. Decisions made in the software development will impact what hardware is required, and what possibilities the user will and won't have during their VR experiences. For instance, it has been shown that software is capable of manipulating the user's perception in such a way that it can lessen practical limitations such as hardware of space available in the real world [10] [7].

A clearer use of software is the creation of the actual Virtual Environment. Whether the technology is used to simulate an operating table, or a walk along the beach, whatever sensory input is communicated to the user has to be programmed. Video game worlds can be seen as an example of fictional environments that could possibly become fully-virtual environments in the future. It is important that whatever VE is in use, it takes enough measures to make it easy for the user to believe that they are actually in that physical space (ie. immersed).

### The User

Finally, the user is a crucial pillar because eventually everything revolves around their wishes for the experience, as well as the efficiency of the Virtual experience to fulfill the user's needs. Barring direct brain stimulation, a user cannot be forced to feel immersed, but only convinced by the efforts of the software and hardware into suspending their disbelief. We cannot succeed at full immersion on the hardware/software level if the user does not agree it is so. Similarly, the VR experience cannot convince the user of its value if the user does not see the purpose of acquiring VR technology, This is why, at every step of the design, considerations must always be made in regards to the financial investment required for as well as the usability associated with the desired user experience.

So the user is very much an active part of the process, but there are also passive, subconscious factors that are in play. Human perception is not perfect, and this most interestingly comes in play through so-called crossmodal interactions: the fact that our senses are not independent of each other but can be influenced by each other. In fact, it is known that some of our senses (vision, hearing) are usually more dominant than others (feeling, tasting) and can override conclusions made by less dominant senses. These intersensory biases are the result of two kinds of factors [5]: structural factors (timing of different sensory input, active versus passive interaction with the feedback, etc.) and cognitive factors (the user's awareness of sensory feedback, their willingness to accept their surroundings, etc.). However, a certain measure of manipulation can be performed to warp the perception of an event according to our wishes [18].

In current development of the VR industry, some senses are prioritized higher than others. As shown in Figure 1, a lot of peripherals focus on the facial area as well as the hands [13] as ways that the user actively or passively interacts with the VE. Some sensory feedback is also more easily simulated than others: heat can quickly, easily and reliably be generated but generating a certain smell at a certain moment for a certain duration brings along far more complexity. Evidently, to support full immersion the complete range of sensory information should be capable of being simulated in virtual worlds. This leaves a lot of work to be done in understanding more subtle sources of sensory input.

As such, it is clear that the hardware enables whatever is required, the software is crucial in combining all factors into a believable experience, and in the end the user is persuaded into accepting the resulting VE as their current reality.

## RELATED WORK

Other researchers have also seen the potential design space that is yet to be perfected in VR peripherals. As much as this paper aims to provide a jumping off point for future research, previous prototypes have also influenced our approach.

In a CAVE setting, visitors are freer to interact with the physical world, either by moving around or touching physical objects. This means that the distance between the user and sensory stimuli sources is greater, and different decisions have to be made in terms of hardware and software. Hülsmann et al. offer an extensive model for incorporating wind and warmth into the CAVE scenario [9], and gained significant insights from their pilot study:

- if the graphics quality of a VE is too high, other factors might not be able to provide meaningful additional immersion
- immersion is the outcome of an equation of different factors which also includes time spent within the VE

Cardin et al. experimented with a system that could generate wind in 8 different directions onto the head of a HMD-wearing user [1]. This experiment provided interesting data that showed that the participants were capable of quickly judging where the wind was coming from even when it changed, given that the wind source was very close to the participant's face or neck.

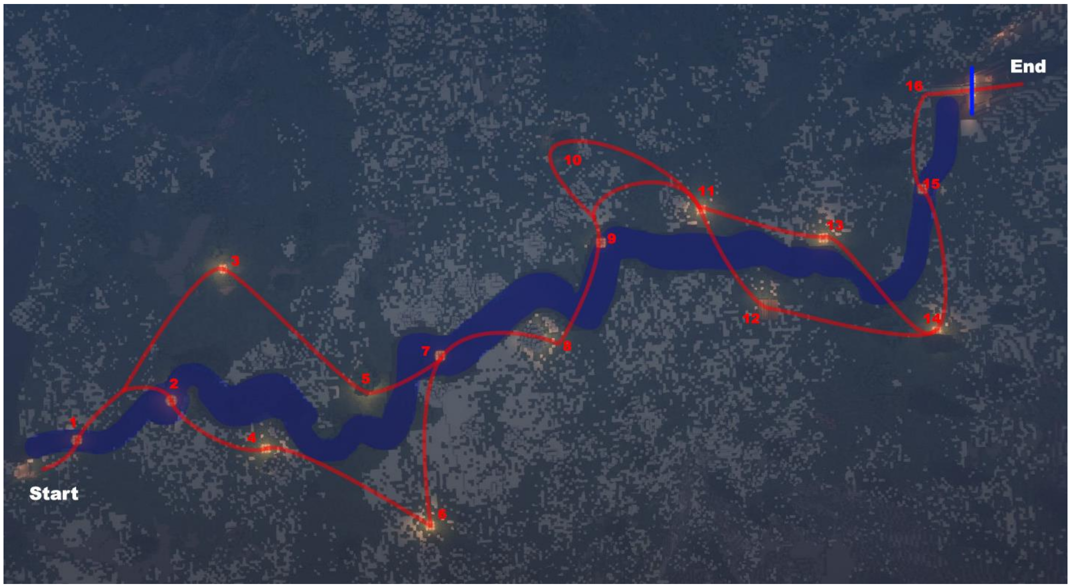


**Figure 2. Bird's-eye view of the Virtual Environment used in our user testing, featuring potential routes users would walk through the environment**

Peiris et al.'s ThermoVR is another prototype that tested the effects of thermal feedback on the immersion of VR users [14]. Thermal modules were placed inside a HMD, touching the user's face just above and below the eyes, in order to provide hot and cold stimulations with *"relatively high speeds"*. Results confirmed that their participants were significantly better at identifying the direction of cold stimulations than of hot stimulations, matching previous non-VR data [19].

The approaches of Peiris et al. and Cardin et al. can be found combined in the AmbioTherm prototype, created in 2016 [15]. With a fan facing the bottom of the face and a thermal module on the back of the head, Ranasinghe et al. provide an example of the power of combining heat and airflow for the purpose of increasing immersion. While their work primarily focused on the hardware, their initial user experiment showed significant increases in *"Perception"* and *"Stimuli"*, and an improved user experience.

The majority of prototypes shared above, aimed at adding the sensations of temperature and airflow to the VR experience, depend on attaching extra hardware to the HMD. Some research has been done on the user experience and wearability of these HMDs. Potential risk factors have been identified that come into play when designing the head mounted display and attached peripherals [6]:

- Weight and Balance of HMD
- Material impact on skin (rashes/itching)
- Fashion (overall look of product)
- Ease of use (putting the HMD on and taking it off)

As such, we are interested in investigating ways to implement temperature and wind-based stimuli that do not directly attach to the HMD. We are interested in design approaches that, in this sense, are more similar to the omnidirectional treadmill (Figure 1, [11]), than to the thermal/wind-based prototypes listed earlier.

## EXPERIMENT

### Participants

A total of 14 participants completed the experiment; 11 were male and 3 were female. All participants were or had at some point been students of a technical subject, including Physics and Game Design. As such, the majority (N=10) had experienced VR before.

### Materials and Game Design

For the experiment a special Virtual Environment (see Figure 2) was designed and built using Minecraft's versatile world-building capabilities. In order to make the Minecraft world VR-compatible, a community-created modification was installed [20]. The VE was made to resemble the Swedish river lands, a sight that would be familiar enough to the participants to enhance their presence while still being extraordinary enough to make immersion for the users worthwhile. The river was core to the experience, in order to investigate the possibly synergy between getting the participant to interact with the water while exposing the participant to wind in a way aimed at mimicking the flow of water.

In order to maximize user interaction with the different sensations available in the VE, the environment was populated with a total of 16 treasure chests that the participants were asked to find and interact with. In order to make these chests easier to find, the time of day was set to permanent sunset and indicator lights were installed that would provide light until the chests were opened (see Figure 3). The chests were placed in such a way that the location of the next closest chest could always be found within a few seconds of looking around in the environment, and that going from one chest to another would often force the player into crossing the river (see Figure 2).


**Figure 3. An example of a chest before and after being opened**

The HTC Vive headset, with associated controllers, was used as the primary device for delivering the VR experience. The controllers were not used to enable gesture interactions, but relied on their physical buttons to enable the gameplay. Due to space constraints in the real world, movement by the participants within the VE was also button-based, and not by physically moving in the real world. In order to minimize motion sickness, an option was enabled that limited the participant's vision by blocking their peripheral vision while moving.

For our specific conditions, a silent model hairdryer (*Björn Axén Tools Excellent Pro*) with different force and temperature settings was chosen as the best artefact to fit the requirements. Its focused force was necessary for providing the participants with exact wind exposure, while its ease of switching between different temperatures and speeds allowed for quick adaptation to decisions made in the VE.

### Questionnaire

Every participant went through the experiment in isolation, away from other (future) participants. As part of the procedure, a questionnaire [22] was filled in beforehand to quantify their general level of being immersed in media content. The questionnaire also included questions to judge how familiar the participant was to both Minecraft and VR in general. All questions in the preliminary questionnaire were answered by marking a box in a scale of 1 to 7. The 1 option was consistently labeled as Never (or equivalent), the 4 option was consistently labeled as Occasionally (or equivalent), and the 7 option was consistently labeled as Often (or equivalent).

### Procedure

To start the main part of the experiment, the user testing, the HDM was correctly equipped, adjusting settings to exclude as much external input as possible. An external (YouTube) recording [12] of the game's background music was used in favor of enabling it in-game as the latter option proved inconsistent in terms of when the music would play, making it unreliable at blocking out the sound of the hairdryer. Secondly, the participant was asked to get familiar with the controls on their own pace. After announcing they were ready to start, the participant would be asked to find as many chests as possible while following the river. At the same time, the hairdryer was turned on and kept on throughout the user test to make the associated noise as much part of the experience as possible (instead of being a disrupting factor when switching between on and off which would likely decrease the participant's immersion). For this reason, the hairdryer's airflow was manually directed towards or away from the participant to fit the VE's intended sensations.

The participant was free to explore the VE as they wished, and the airflow of the hairdryer was directed at the participants at key moments identified by the researcher through a secondary display, which showed what the participant was seeing in their HMD.

The hairdryer was directed at the participant's upper legs any time they would be wading through the water, in an effort to make it feel like the water's surface, and aimed away whenever out of the water. Due to the river's formation, at certain times the direction of the wind would mimic the direction of the water flow relative to the participant, while at other pre-determined times these would actually conflict.

In a similar way, the temperature of the hairdryer was also alternated. At the start of the test, 40% of participants were initially exposed to a warm temperature airflow while 60% of participants were initially exposed to a cold temperature. Then, throughout the test, the temperature was changed regardless of the VE environmental factors. This was done to gain as much information on whether the participants would feel these changes, whether the initial understanding of the VE's temperature would prove to be dominant, or whether the participants could not accurately determine the temperature at all.

Near the end of every user test, in order to finish, the participant was required to walk through a waterfall. At that moment, the horizontal orientation of the airflow was changed to a vertical orientation to mimic the new direction that the water was flowing from (above). As such, during this brief moment the participant's head was exposed to the airflow from above instead of on their upper legs.

### Interview

After the user testing phase, each participant was interviewed about their VR experience guided by the questions as found in the questionnaire Slater, Usoh, and Steed have used and improved on since 1994 [17]. This questionnaire is often used to quantify the concept of presence that is felt during a VR experience, and was modified and used as the basis for qualitative interviews. Audio of the interviews was recorded, and data was categorized and analyzed after all participants had gone through the experiment.

Although no time constraints were put on any of the phases, the whole procedure averaged to 25 minutes per participant.

## FINDINGS

In analyzing the data from the questionnaire and interview, different comparisons were made. Based on the initial questionnaire, participants were labeled based on their familiarity with VR and Minecraft on a scale of 1-7. Anyone who reported 4 or higher was labeled familiar, and lower than 4 was labeled as unfamiliar.

Distinctions:

- Male (N=11) versus Female (N=3)
- Familiar with VR (N=4) versus unfamiliar with VR (N=10)
- Familiar with Minecraft (N=4) versus unfamiliar with Minecraft (N=10)

### Questionnaire

As all questionnaire questions were answered on a scale of 1-7, we can easily compare the data between topics and participants.

All participants shared feeling physically fit (point score average of 5) and mentally alert (point score average of 5.2) at the moment of user testing which made it safe to exclude both as independent variables. As expected, the participants reported an above average amount of time spent on video games (point score of 5), which is something that helped them get used to a VR experience and thus is not representative for the average user.

### Interview - Quantitative

The interview questions, based on an existing but modified questionnaire [17], provided a combination of quantitative and qualitative data. The participants were asked to grade (again on a scale of 1 to 7) their experienced levels of presence during the Virtual Experience. Similarly, they were also asked to grade the importance of four distinct factors that made up the sensory feedback gathered during the Virtual Experience.

These four factors were:

- **Video**, everything that the user could see
- **Audio**, all audio cues that were native to the Virtual Environment (including footsteps, splashing of water, sounds that animals made, etc) but excluding the music soundtrack
- **Music**, the external recording of Minecraft background music soundtrack
- **Tactile**, everything related to the hairdryer's airflow in terms of force, temperature and direction

As shown in Table 1, while it does appear that differing levels of importance were allocated to the different contributing factors, the sample size proved to be too small to make any statistical conclusions. Ordinal logistic regression analysis could not conclude a significant relationship between any of the factors and the level of presence, nor can a proper statistical comparison between the factors be substantiated.

We can however discuss the reasons that we see as having contributed to the participants' scoring of these questionnaire questions, and predict the trends that would show up in a repeat experiment with a larger number of participants.

Those familiar with VR had existing expectations of the Virtual Experience which, due to our approach, we can expect to not be significantly surpassed. This can be explained due to the choice of Minecraft as the environment provider, which is well known for having a particular, lower fidelity graphics style. In contrast, those not familiar with VR experiences reported the VE as being closer to their experience in a real place. This can be explained by the idea that these users arguably had lower expectations of VR technology going into it, having less of an idea of what to expect.

Those familiar with VR saw video as playing a lesser role in their immersion than did those unfamiliar with VR. Because vision is our most dominant sense [8], most forms of our entertainment make use of it and as such we are used to it being supported and it being put a lot of effort into. We believe that those unfamiliar with VR scored it higher because the initial difference between vision in VR and consumption of other media (TV/video games) is larger than that of hearing. This effect should lessen as users get used to the novelty of having 360° vision in a non-real setting.

The audio factor, covering things such as the splashing sound of water and the sound of footsteps while walking, was as expected the second most important factor. We know that Vision and Hearing are our most important senses, and Vision is the most dominant in how we perceive our surroundings. We see a substantial drop-off to the third most important factor, but cannot given the amount of data conclude a significant difference.

| | All | 95% LCL | 95% UCL | Familiar with VR | 95% LCL | 95% UCL | Unfamiliar with VR | 95% LCL | 95% UCL |
|---|---|---|---|---|---|---|---|---|---|
| **Level of Presence** | **4.9** | 4.2 | 5.7 | **4.5** | 1.2 | 7.8 | **5.1** | 4.5 | 5.7 |
| **Video Factor** | **5.9** | 5.5 | 6.4 | **5.5** | 3.4 | 7.6 | **6.1** | 5.7 | 6.5 |
| **Audio Factor** | **5.4** | 4.8 | 6.1 | **5.3** | 2.5 | 8.0 | **5.5** | 4.8 | 6.2 |
| **Music Factor** | **4.3** | 3.6 | 5.1 | **3.8** | 2.2 | 5.3 | **4.5** | 3.4 | 5.6 |
| **Tactile Factor** | **4.4** | 3.9 | 5.0 | **4.3** | 2.7 | 5.8 | **4.5** | 3.8 | 5.2 |

**Table 1.**

The music was seen as the factor that added the least to the participants' feel of immersion; it still averaged a score of 4.3 out of 7. Of course, music is a form of audio that does not exist naturally in the world. It must be added artificially, through movie soundtracks and/or a person wearing headphones. The choice was made to play a generic Minecraft soundtrack that was not adapted to the experiment, which also affects its potential.

Regarding the main factor we added to the VR experience for this paper, the tactile feedback of wind created by the hairdryer, we see a reported average score of 4.4 out of 7. This score is lower than that of the Audio and Visual, but comparable to that of Music. While, as discussed, music is not intrinsically a feature of our everyday life (it is created artificially instead of organically), our participants did report that the Music added to the feeling of immersion/presence in the VE. As such, it can arguably be concluded that the tactile feedback was equally accepted as a contributing factor to the feeling of immersion and presence, even if the way that it was created was also artificial. This is interesting because background music is an element present in just about every type of media, whereas we can be certain that our users have not experienced the element of wind on an equally frequent level.

In our results we see that the tactile sensory input seems to show equal importance between those familiar and unfamiliar with VR, explained by the fact that regular VR experiences don't incorporate this type of exposure to airflow. The fact that some of our users had experienced more VR installations without airflow did not mean that they therefore rejected said airflow as a valuable part of the VR experience, but still considered it as a valid addition.

### Interview - Qualitative

#### *Presence*

In the interviews we learned that some people experienced a surprising (also to them) level of presence in the VE, often saying that they forgot about the real world during the experience. Only when they had to take off the HMD did they remember where they had been before, to a degree surprising to them.

Multiple people mentioned that while they knew constantly that they were effectively standing still in the real world (and not physically wandering around in the VE), they could easily ignore that voice in their head and pretend they were actually in the VE.

Some people reported never really feeling fully immersed, or perhaps only for brief seconds, because of practical factors taking them out of it. Factors that were mentioned included:

- External Sound (3), which made players remember that the VE was not the only reality they were perceiving
- Moving into objects in the real world (3), which limited the players' confidence in interacting with the VE
- Getting confused with the controls (5), as this is an element that is not ever experienced as such in the real world
- In-game physics (2), since this made participants feel like the VE was more limited than it should be if simulating an actual reality

#### *Experience*

To showcase how the users experienced the VE, and how they remembered the experience afterwards, we look to their comments on two specific questions of the post-test interview:

- Do you think of the VE more as images that you saw or more as somewhere that you visited?

A large majority of participants (N=11) answered with a definite 'somewhere I visited' to this question, even though they also mentioned the lower graphical quality of the VE. This shows the power of VR in creating an immersive enough experience just by the nature of it removing external sensory input.

One person offered an interesting comparison to a real life scenario, stating the experience was like visiting a gas station during a long trip: "*You walk around a bit, mostly without a goal, and just enjoy a new country"*. This comparison highlights an interesting way of considering VEs. Similar to that gas station, you don't really know how you got to that specific place (since people are more focused on getting to a destination than on the areas they have to move through to get there), you know you are only temporarily there, and the goal of that visit is mostly out of your hands (e.g. because your vehicle had to tank or because the driver wanted to take a break).

One person stated: "*I know it was a game but still I feel like I am there and I take the decisions. I am not playing a dude that is at that place"*. This is a statement that proves a high level of presence. The user shows he had no problem moving his consciousness to the VE, thinking he was the person in that environment instead of merely controlling a character in that environment.

- How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today?

A total of 6 participants mentioned their memories of the VE having positively different colors than their usual memories. This is interesting, as statements about the graphical quality of the VE as experienced during the user tests were negative to neutral.

A secondary aspect of the memories that was mentioned a lot was the way the size of the VE felt. For some, memories of the VE were similar to memories of similar real places in this aspect. "*I felt like it was very large, like the area that I was supposed to be in wasn't to reach my goal but I felt like if I wanted to I could explore more."* As the environment showed a landscape and horizon, and there was never a point where the users could see the end of the game's bounds, it was made to seem that the VE was a very large place. Some participants truly experienced it as such, while others quoted the faster relative movement speed and nature of the goal of moving from chest to chest as aspects that made the VE feel smaller than it would be in real life:

*"Also, the world seems large but at the same time you move fast and the proportions aren't quite right so that makes it less realistic."*

One user mentioned feeling both of these elements, without actually considering them to be conflicting: "*It was a huge place, a big building or cave that felt far away though I got there very fast. It felt huge".*

Even though the purpose of our user testing was to explore the impacts of adding airflow to the collection of sensations experienced in the VE, the statements above show that we designed a VE that was in the basis convincing enough as an ordinary VR experience (like one they would consume as entertainment). This is important, because for the findings of our research to be applicable to non-academic scenarios the research must also feel as such to the participants.

*Impact of airflow*

The goal of the airflow initially was to mimic the feel of water against your body. We cannot conclude in this paper that wind is an effective replacement for water, but did receive some promising feedback.

Several participants mentioned understanding and eventually anticipating the feel of wind against their legs whenever moving in water. One person mentioned "*The wind on my legs felt natural like a new mechanic [...] but didn't feel like a necessity to feeling more immersed*". Others shared this view of considering it a game mechanic, made to enhance the experience but not so much a natural way of including more sensory feedback into the experience. Perhaps it stood out in this experiment whereas it wouldn't in a Real Virtuality [2] experience that supported all five senses completely.

The airflow, and especially its temperature, did have a larger impact on the way the participants experienced the VE. One person said: "*You obviously feel it's not water but it felt warm which made me think the water was warm, and now I associate this place as being on a summer's day because your mind fills it in. So in that sense it adds to the immersion even when the wind isn't blowing. It adds to the whole world*".

One person offered a possible way to make the airflow feel more like water: *"With the waterfall, yes it helped with the direction and place but the weight wasn't the same so maybe if you had put something heavy on me at the same time it would have been more immersive"*. Indeed it seemed like while the temperature of the wind did convey temperature of the water correctly, what was missing in the equation was the weight that comes with water being a heavier substance. This gives an answer to one of our questions beforehand, about how strong the crossmodal interactions would be when working with airflow: simply seeing and hearing water in the VE did not make up for the lack of mass that the users would associate with water.

The biggest downside of the method we used for creating a strong airflow proved to be the associated sounds. Even though we picked a specific model advertised as being quieter, the most frequent downside associated with adding the element of wind was that the sound prevented participants from getting immersed in the VE or even hearing the music and/or audio cues. One person also called the blowing of air "mechanical" and "out of place".

*Alternating temperature and direction*

As part of every user test, the temperature of the airflow was alternated to test the participants' ability to judge changes even when their exposure was decreased by wearing pants. About half of the participants (6) mentioned perceiving these intermittent changes in temperature, and sharing that it made them feel less immersed, while a similar amount (4) mentioned not having noticed any changes in temperature at all. The former use case can be explained by the idea that the participants felt the VE did not realistically simulate a real environment and thus the changes in temperature were experienced as errors instead of natural variations within the VE's temperature.

Similarly, at certain times the direction of the wind did not match the direction from which the water would have hit the user. This was due to the river meandering while the direction of the wind was kept uniform. Several users noted at some point realizing this discrepancy, but the effect was not as impactful in their levels of immersion as the changes in temperature.

## DISCUSSION

### Method

We expect a user's experience when using VR to change from their first to their hundredth try. Like any other type of interaction, a certain learning curve is present that will also impact the immersion and presence that the user is experiencing. Due to the nature of this experiment, users often only had ~15 minutes to get used to the VR scenario. While we did hear from people that they got more immersed further along the experiment, we want to emphasize that their experiences might positively or negatively change if they were to spend more hours in a similar setup.

It is unfortunate that, due to constraints, the biggest concessions had to be made in terms of visual quality. This is an area that we know has a large impact on the VR experience [9] [8], and it's an area that will continue to improve in the future. It is important that the fidelity of the airflow-producing artefact matches the fidelity of the audio and visual quality, which means that any higher-quality equivalent to our means of producing airflow will still have to be iterated on significantly.

### Applications

As we conclude that the addition of airflow to the VR experience brings unique new dimensions, dimensions that cannot be fulfilled by audiovisual feedback alone, the question becomes what other applications, besides the ones used in our experiment, airflow can be used for.

A constant airflow across the head might very well be sufficient to translate the sensation of being on a fast moving horse. Full body exposure to strong winds combined with the visuals of a HDM might make them believe they are trapped in a sandstorm. Or chaotic winds surrounding the player might make them believe it when they see themselves on a small boat in a big storm.

These and other such applications can be tested, and we expect game developers to have even more creativity in finding uses once we truly support Real Virtuality environments [2].

However as mentioned befor1, these next steps should keep in mind the considerations of usability and financial investment. While we found substantial evidence that adding airflow to VR experiences holds value, this paper was not setup to question the balance between that value and the costs associated with supporting it.

### Future work

We hope that the results of this paper interest others to try replicating the experiment with higher fidelity. Both the VE and method of producing airflow in this project can greatly be improved upon, and we imagine that with a more realistic Virtual Environment and better synchronized experience the results will show even greater potential of this addition to the developer's toolkit.

Having seen the potential that comes with adding full body exposure to airflow to the VR experience, the next step would be designing the artefact that the consumer would actually buy and install alongside their other peripherals. We envision a product not much different from the HTC Vive base stations (which are placed to outline the available play area and make motion tracking possible) that can accurately produce wind streams of differing temperature, or a cylinder-like construction that, in combination with omnidirectional treadmills, can provide full body exposure without limiting the user's interaction in any way.

## ACKNOWLEDGEMENTS

I'd like to thank Anton Poikolainen Rosén for their continual availability and help with getting the user testing environment right, and Kai-Mikael Jää-Aro for their guidance throughout the process. Special thanks to Södertörn University and Petri Lankoski for providing the hardware necessary to complete the user tests.

## REFERENCES

1. Sylvain Cardin, Daniel Thalmann, and Frederic Vexo. 2007. Head mounted wind. In *Computer Animation and Social Agents (CASA2007)*, 101-108.
2. Alan, Chalmers, David Howard, and Christopher Moir. 2009. Real virtuality: a step change from virtual reality. In *Proceedings of the 25th Spring Conference on Computer Graphics*, 9-16.
3. Carolina Cruz-Neira, Daniel J. Sandin, Thomas A. DeFanti, Robert V. Kenyon, and John C. Hart. 1992. The CAVE: Audio Visual Experience Automatic Virtual Environment. In *Communications of the ACM* 35 (6), 64-72.
4. Denise Doyle. 2015. Art, Virtual Worlds and the Emergent Imagination. In *Leonardo 48*, no. 3, 244-250.
5. John V. Draper, David B. Kaber, and John M. Usher. 1998. Telepresence. In *Human Factors: The Journal of Human Factors and Ergonomics Society* 40, no. 3, 354-75.
6. Vivian Genaro Motti, and Kelly Caine. 2014. Understanding the Wearability of Head-Mounted Devices from a Human-Centered Perspective. In

*Proceedings of the 2014 ACM International Symposium on Wearable Computers*, 83-86.

7. Eric Hodgson, Eric Bachmann, and David Waller. 2011. Redirected Walking to Explore Virtual Environments. In *ACM Transactions on Applied Perception* 8 (4), 1-22.
8. Ian P. Howard, and William B. Templeton. 1966. *Human spatial orientation*. Oxford, England: John Wiley & Sons.
9. Felix Hülsmann, Julia Fröhlich, Nikita Mattar, and Ipke Wachsmuth. 2014. Wind and Warmth in Virtual Reality: Implementation and Evaluation. In *Proceedings of the 2014 Virtual Reality International Conference (VRIC '14)*.
10. Vedad Hulusic, Kurt Debattista, Vibhor Aggarwal, and Alan Chalmers. 2011. Maintaining Frame Rate Perception in Interactive Environments by Exploiting Audio-Visual Cross-Modal Interaction. In *Vis Comput* 27, 57-66.
11. Infinadeck, Retrieved March 2019 from https://www.infinadeck.com/
12. Minecraft Background Music. Retrieved February 2019 from https://www.youtube.com/watch?v=g9c2WTCj0Pk
13. Mingyu Kim, Changyu Jeon, and Jinmo Kim. 2017. A Study on Immersion and Presence of a Portable Hand Haptic System for Immersive Virtual Reality. In *Sensors* 17(5), 17.
14. Roshan Lalintha Peiris, Wei Peng, Zikun Chen, Liwei Chan, and Kouta Minamizawa. 2017. ThermoVR: Exploring Integrated Thermal Haptic Feedback with Head Mounted Displays. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 5452-5456.
15. Nimesha Ranasinghe, Pravar Jain, David Tolley, Shienny Karwita, Shi Yilei, and Ellen Yi-Luen Do. 2017. AmbioTherm: Simulating Ambient Temperatures and Wind Conditions in VR Environments. In *Proceedings of the 2017 CHI Conference on Human Factors in Computer Systems (CHI '17)*, 1731-1742.
16. Jennifer N.A. Silva, Michael Southworth, Constantine Raptis, and Jonathan Silva. 2018. Emerging Applications of Virtual Reality in Cardiovascular Medicine. In *JACC: Basic to Translational Science* 3 (3), 420-430.
17. Mel Slater, Martin Usoh, and Anthony Steed. 1994. Depth of presence in virtual environments. *Presence: Teleoperators & Virtual Environments* 3, no. 2, 130-144.
18. Barry E. Stein, and M. Alex Meredith. 1993. *The merging of the senses*. The MIT Press.
19. Joseph C. Stevens, and Kenneth K. Choo, 1998. Temperature sensitivity of the body surface over the life span. In *Somatosensory & motor research*, *15*(1), 13-28.
20. Vivecraft. Retrieved January 2019 from http://www.vivecraft.org/
21. Robert B. Welch, and David H. Warren. 1980. Immediate perceptual response to intersensory discrepancy. In *Psychological bulletin* 88, no. 3, 638.
22. Bob G. Witmer, and Michael J. Singer. 1998. Measuring Presence in Virtual Environments: A Presence Questionnaire. *In Presence: Teleoperators & Virtual Environments* 7, 225-240.

## APPENDIX

### SLATER-USOH-STEED QUESTIONNAIRE (SUS) (EDITED)

1. Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place.

2. To what extent were there times during the experience when the virtual environment was the reality for you?

3. When you think back to the experience, do you think of the virtual environment more as images that you saw or more as somewhere that you visited?

4. During the time of the experience, which was the strongest on the whole, your sense of being in the virtual environment or your sense of being elsewhere?

5. Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By ‘structure of the memory’ consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.

6. During the time of your experience, did you often think to yourself that you were actually in the virtual environment?

7. During the time of the experience, were there identifiable moments/factors that pulled you away from or towards feeling immersed?

8. Were there moments during the experience that felt more real to you?

9. Were there moments during the experience that surprised you? For instance because you didn’t think something was possible, or because you found yourself reacting or acting in ways that were surprising to you?

10. On a scale of 1 to 7, how much do you think the following factors added to the feel of immersion?

   a. Video
   b. Audio cues (wind/splashing of water/footsteps/etc)
   c. Music
   d. Tactile feedback (Force/temperature/direction)

**IMMERSIVE TENDENCIES QUESTIONNAIRE**

Gender: Male | Female | Other:

Age: <20 | 20-24 | 25-34 | 35-49 | 50+

---

Indicate your preferred answer by marking an "X" in the appropriate box of the seven point scale. Please consider the entire scale when making your responses, as the intermediate levels may apply. For example, if your response is once or twice, the second box from the left should be marked. If your response is many times but not extremely often, then the sixth (or second box from the right) should be marked.

Have you ever tried VR technology?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

Have you ever played Minecraft?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

---

1. Do you easily become deeply involved in movies or tv dramas?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

2. Do you ever become so involved in a television program or book that people have problems getting your attention?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

3. How mentally alert do you feel at the present time?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NOT ALERT MODERATELY FULLY ALERT

4. Do you ever become so involved in a movie that you are not aware of things happening around you?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

5. How frequently do you find yourself closely identifying with the characters in a story line?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

6. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

7. How physically fit do you feel today?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NOT FIT MODERATELY FIT EXTREMELY FIT

8. How good are you at blocking out external distractions when you are involved in something?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NOT VERY GOOD SOMEWHAT GOOD VERY GOOD

9. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

10. Do you ever become so involved in a daydream that you are not aware of things happening around you?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

11. Do you ever have dreams that are so real that you feel disoriented when you awake?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

12. When playing sports, do you become so involved in the game that you lose track of time?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

13. How well do you concentrate on enjoyable activities?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NOT AT ALL MODERATELY WELL VERY WELL

14. How often do you play arcade or video games? (OFTEN should be taken to mean every day or every two days, on average.)

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

15. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

16. Have you ever gotten scared by something happening on a TV show or in a movie?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

17. Have you ever remained apprehensive or fearful long after watching a scary movie?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN

18. Do you ever become so involved in doing something that you lose all track of time?

|____1____|____2____|____3____|____4____|____5____|____6____|____7____|
NEVER OCCASIONALLY OFTEN