CloseHR: an experimental study on the effects of interpersonal touch on the sense of presence in an immersive Hybrid Environment

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Abstract
The possibility to experience a multi-user immersive Hybrid Environment (HE) is becoming accessible to a wider group of researchers, artists and developers due to low-cost consumer VR technology and a growing community of open-source software users and developers. An important measure to indicate if an immersive environment is successful is the sense of presence which can be described as a feeling of really being in the mediated environment, or as a psychological state in which virtual objects are experienced as actual objects. To measure the sense of presence we developed an interactive art installation called *CloseHR*. The system consists out of a 3D representation of the environment the users are physically in, 3D representations of their bodies mapped to be visually correct in first person view, and virtual objects the users can interact with. By touching each other's hands, physically and/or virtually, the users could break down a wall standing in between them.
Next to qualitative data collection we used a questionnaire and a *within subject design* research method to answer the question: Does interpersonal human touch affect our sense of presence in an immersive Hybrid Environment?
The results did not show a significant effect of interpersonal touch on presence, but we did discover a positive effect of interpersonal touch on the sense of embodiment. With the findings presented in this paper we are able to get a better understanding of the interesting and complex construction of the sense of presence and related processes in a multi-user HE.

Introduction
While interpersonal haptic feedback in shared Virtual Environments (VE) is researched extensively for telepresent VE's, which up until now has been unexplored for immersive Hybrid Reality (HR) environments where users share both the same virtual as well as physical space. We hypothesize that the ability to touch the hand of another participant will increase the sense of presence and embodiment when interacting in an immersive HR.
When being physically together in a HR environment, where facial expressions are blocked by head mounted displays, it can be good to look at new ways, or rediscover old means of communication by using body language and our sense of touch to interact with each other.
Touch is the first of our senses to develop, and it provides us with our most fundamental means of contact with the external world.[1] By means of our skin, which is filled with tactile receptors, we are in direct contact with the outside world. Although we may not see touch as the most important sense we use in daily life today, the skin is the oldest and by far largest of our sensing organs.[2]

For this explorative study we developed a system called *CloseHR*, an art installation which allows two users, whose bodies are represented in their VR headsets through real-time Kinect sensor data, to

interact with each-other. A virtual wall stands in between the two users, which can be broken down piece by piece by touching each other's hands. We measured the effect of interpersonal touch on the embodiment and presence of users experiencing the immersive Hybrid Reality environment with the subjective measure of a questionnaire and through observations and interviews.

As an artist/researcher I have been working with digital material for over eight years, in the works I have created so far, often in collaboration with other artists, I have always tried to include the body and/or physical material to create Mixed Reality experiences. The choice to use VR technology to develop hybrid experiences was made during the quest for more seamless and immersive experiences than can be obtained by using mere screens and video projections.

With the execution of a previous experiment called Manilocus[3] we were surprised by the effect of touching a physical object in a HE had on the users of the installation. The users had the ability to touch a plant standing in the room, which triggered a virtual plant to move. We discovered that next to reactions of pleasant surprise, the possibility to really touch virtual material gave users of the experiment a feeling of trust in the virtual environment and as such had the tendency to move more freely. We also found that the interaction between two people using the installation worked well, the ability to share an experience while wearing a VR headset was appreciated by users and viewers outside the installation. These findings inspired us to further explore the relatively new field of research into interpersonal touch in an immersive Hybrid Environment.

Related work

Several studies have reported a positive effect of touch on our sense of presence in an immersive VE. S. Lee and G.J. Kim[4] proposed a haptic teleoperation system with which they looked for the effect of haptic feedback, stereoscopic image and image resolution on performance and presence when teleoperating a mobile robot. They found that haptic feedback among the three factors made the highest contribution to the improvement in performance and presence.

For another research Dinh, Huong Q., et al used a fan to simulate the wind of a virtual fan, and a heat lamp to simulate the warmth of the sun in a VE. They found that the overall sense of presence and memory of objects in the VE increased with the addition of tactile cues and ambient sounds.[5] After we touch a virtual/real object in mixed reality, we experience other virtual objects differently when the ability to touch is absent. This is shown in a study where H. G. Hoffman[6] et al let users pick up and feel a real kitchen plate, which is also visible through VR technology. This had a large influence on their perception of the properties of other virtual objects. The "See and touch" group expected other virtual objects to have properties that were more realistic than the estimations by the "See only" group for the same objects.

Not only does the use of a Kinect sensor provide natural human computer interaction, but whole body movement also has a positive effect on the subjective reported presence of participants in an immersive VE. As Slater et al. showed with their experiment where users wearing a VR headset had to crouch down, stand up and use head movement to perform a task in VR.[7]

It is also shown that a represented image of the body displayed in a virtual reality headset contributes to the sense of being in the virtual location[8] and has a positive effect on the sense of presence of users of immersive VE's.[9]

"The unique state of Being in immersive VEs has created a paradigm shift in what humans are now able to experience, and affects how we understand our embodied selves in an increasingly digital world"
Jacquelyn Ford Morie [10]

If we want to measure presence in a Hybrid Reality we could think we need to look at the place where the virtual begins and the physical stops. This is difficult, if not impossible, to do when realities are intertwined to a level where we cannot distinguish if the sensed experience is mediated or not. We can even argue all experiences are always mediated by our brains. Virtual Reality (VR) expert and psychologist Jack Loomis has equated this to the unaware state most people have of their everyday embodied existence: "The perceptual world created by our senses and the nervous system is so functional a representation of the physical world that most people live out their lives without ever suspecting that contact with the physical world is mediated…"[11]

Augmented Virtuality / Hybrid Reality
In our daily lives we increasingly use digital media for communication, education and entertainment, to name a few possible applications. It is common to share media with others in the same physical space; we watch a movie or television together, we play multiplayer games while sitting next to each other, or even communicate over text messages when it is impossible to speak out loud.
Using digital media today is more than just an augmentation of the virtual to the real, as they both would stay unchanged in this situation. We can call this new world Hybrid Reality because "the real affects and alters the virtual, and maybe more importantly, the virtual becomes real. "[12] Another example of these changes taking place in both directions, is when we are working with a VR simulation we learn new movements and gestures to control the virtual with greater ease. Neural configurations of our brains change during this process: "The computer molds the human even as the human builds the computer." [13] For this reason it is helpful to let go of the idea that the real and the virtual exist unchanged in parallel as the concepts of Mixed and Augmented Reality may suggest, but instead use the concept of Hybrid Reality to describe the new types of environments, experiences and worlds that are being created. When we look at today's mediated environments, we could see boundaries that separate realities of a seemingly different nature, but we could also see these boundaries blurring and realities merging into a single Hybrid Reality.

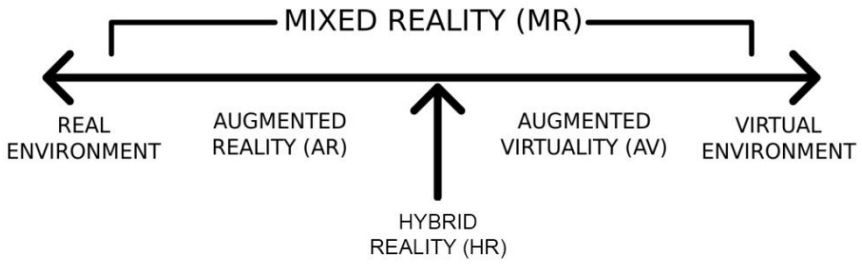


Fig. 1 Adjusted version of the virtual-real continuum model

Presence

Many different definitions of presence have been developed to describe the phenomenon by VR researchers and scholars of other disciplines, such as psychology, philosophy, medicine, engineering, communication and others. M. Lombard and M. T. Jones organized different definitions and varieties of presence into an interactive framework, presented on a website. http://matthewlombard.com/presence-definitions/

They begin to categorize the definitions on a broad level on the top left, and become more specific in the categories below. Here we can for example see how some describe non-technological ways of experiencing presence as:

"Presence is reacting to the external world or what seems like the external world, as it happens"

And descriptions of presence where media technology is used, but where users react in ways as if the medium is not there:

"Presence is a psychological state or subjective perception in which, even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience." [14]

International Society for Presence Research (2002)

Carlos Coelho et al. distinguish two different views on how to describe presence as *media presence* and *inner presence*. They explain it is a difference between a rationalist and a psychological/ecological point of view. There are many different variations of definitions of media presence with objective measures that allow standardization for measuring presence. They almost all come down to the feeling of 'being there' in a virtual environment.[15] Researchers in the field of media presence look at what kind of technology is used to create immersion and how much the medium and its technology disappear from our consciousness. They also look at how much the user is able to do, sense and feel when immersed in a VR system, because it can affect the sense of media presence.

This is different from how inner presence is described as a neuropsychological phenomenon felt along different types of human experiences independent of any technology. Waterworth, John A., et al. explain how this psychological type of presence is induced by the affordance of the (virtual) environment.

"Presence is what it feels like to be embodied and consciously attending to an external, perceptible world. The key formal requirement for presence to occur is that information is presented in a form that an observer can make sense of intuitively, in a bodily way, rather than having to think about it (…) To be truly present in a world is to feel and act accordingly." [16]

Here they see presence as opposed to a sense of absence where one is preoccupied with an internal world, which occurs when we, for instance, are daydreaming or are immersed by reading a book. It is important to keep a balance between being present and absent, for it is in a state of absence that we internally process the information we have collected and the emotions we have experienced when we were present in the outside world.

Presence has been seen by many researchers as a binary state for the sense of being either in- or outside the virtual environment. For our research on a Hybrid Environment where the border between the real and virtual is blurred, the perception of presence as a binary state is not useful. We would rather consider presence to be a continuous experience which varies in intensity over time. Kim and Biocca[17] suggest a fluctuating variation of the concept of presence where they distinguish the process

of becoming present in a media experience into two factors of "arrival" for the feeling of being there in the virtual space, and "departure" for not being there in the physical environment.

The definition of presence we will use

We will examine the level of presence of users in a Hybrid Environment where the digital represented surrounding and represented bodies of the users will look the same as their physical reality, only there are virtual objects added to the environment.

The most commonly used definition to measure the level of presence in a Virtual Environment is Witmer and Singer's: "Presence is defined as the subjective experience of being in one place or environment, even when one is physically situated in another."[18]

For our research we will use a more suitable description aiming at the presence of virtual objects instead of complete environments for the reason that the virtual environment of our experiment looks and feels similar to the physical environment at which the user is located. Therefore it is difficult, if not impossible, to know if the user feels present in either the virtual or their physical environment. To measure how real the virtual objects feel inside the Hybrid Environment of our experiment we will use Kwan Min Lee's definition of presence:

"[A] psychological state in which virtual (para-authentic or artificial) objects are experienced as actual objects in either sensory or nonsensory ways." [19]

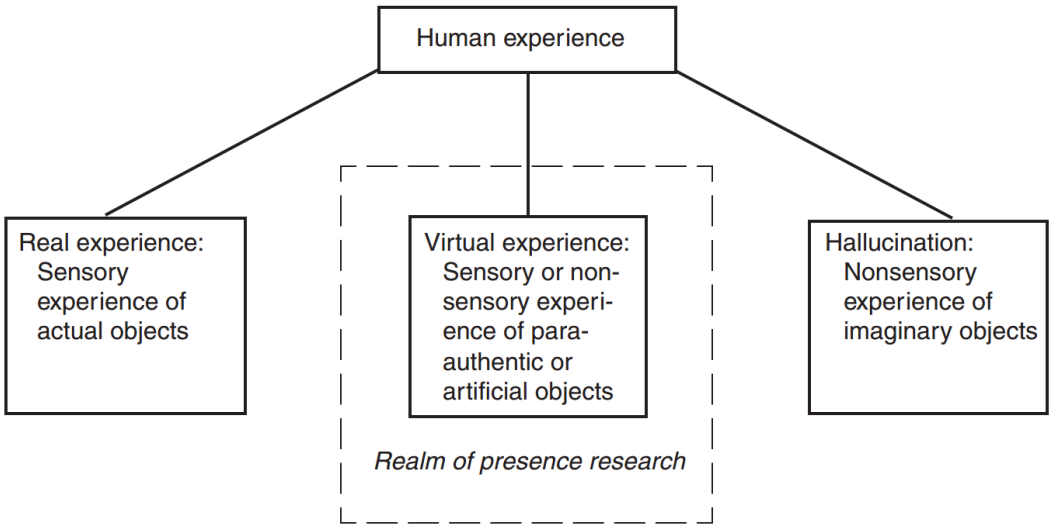


Fig. 2 Typology of Human Experience for the Study of Presence

To get to this definition Lee divided the human experience in three categories as seen in figure 2.

Here, para-authentic objects are objects that have qualities or properties of the real or represented objects, but are perceivable only with human-made technology. Artificial objects are created or simulated with human-made technology, and without the technology we are unable to know of their existence. Lee explains how books are just like VR headset-technology used for mediation and are thereby capable of inducing the sense of presence. An important difference between the two is that in the case of reading a book none of our senses are directly stimulated, but it is our imagination that lets us feel immersed in a story. This is why he included the nonsensory ways in his definition of presence.

Sense of Embodiment

There are many different fields using the term embodiment for slightly different goals, for this research we will use the term Sense of Embodiment (SoE) coined by Kilteni et al[20] who use it to describe the ensemble of sensations that arises in conjunction with being inside, having, and controlling a body. They describe the definition of Sense of Embodiment as follows:

SoE toward a body B is the sense that emerges when B's properties are processed as if they were the properties of one's own biological body.

Here B stands for the virtual, represented image of the body. In the construction of the definition Kilteni et al. divide the SoE in three subcomponents: the sense of self-location, the sense of agency and the sense of body ownership. We will use these to analyze the data of our questionnaire.

Riva et al. [21] describe how presence emerges from processes related to the process of embodiment, even before the invention of all communication and media technology, we used our body to process and express information.

We are familiar with seeing our own hands and the rest of our body in daily life, which is why it feels natural to see ourselves within a VE. The more natural the VR feels to us the stronger our sense of presence can become. Meredith Bricken[22] explains how a representation of her hands in VR work as "convincing evidence that you're There." Here we see the entanglement of embodiment and presence at work; without the sense of ownership over the hands we feel less like being in the virtual, without believing the virtual the hands will not feel as if they are ours. Or, as put differently by JR Mensch[23]; "things are present to us insofar as they affect us bodily. Similarly, our own self-presence is founded on our bodily self-affection." This is why it is important to measure the SoE when we want to have a better understanding of the processes that affect our sense of presence in an immersive HE.

> "What embodiment secures is not the distinction between male and female or between humans who can think and machines which cannot. Rather, embodiment makes clear that thought is a much broader cognitive function depending for its specificities on the embodied form enacting it." [24]
> Katherine N. Hayles

When present in daily physical reality we embody our natural physical bodies, we then experience our bodies as part of ourselves, or as an interface between our mind and the outside world. Our sense of embodiment and sense of presence are tightly connected and cannot be seen separate. In order to feel present we need to feel embodied within the world or the presented VE.[25] This has to do with bodily action in a mediated environment, which is required in order to induce the feeling of presence[26].

Consumer VR manufacturers have discovered the importance of body movement, which is noticeable when we look at the VR interfaces on the market today, such as the HTC Vive, the consumer Oculus Rift, Microsoft Kinect and Leap Motion, which all make use of our proprioceptive and kinesthetic senses to allow us to feel embodied and thus present in VE's. Next to these senses our tactile senses can also be used to induce the sense of presence, as shown in the famous rubber hand illusion experiment where they proved the importance of tactile stimulation in the embodiment process. The sense of the ownership of a fake hand can be induced by stroking or touching a visible rubber hand and simultaneously stroking or touching a concealed real hand. Tsakiris, Manos, et al's[27] analysis shows that greater levels of embodiment were observed after the session with the synchronous compared to the asynchronous touch. Kalckert, Andreas et al.[28] show that not only the combination vision and touch, but also vision with active and passive movement of the hand can induce illusory ownership of a model hand. In our experiment we used these findings by choosing to show a digital real-time representation of the user that visually moves synchronous to their own body. We chose to

use live sensed Kinect data to represent the user's body instead of a different looking avatar to reduce intersensory conflict between the sensed physical and virtual body, which is favorable for increasing the SoE.[29]

Sense of Touch

When we think of VR, we often first think of virtual visible and audible worlds and easily forget we have important other senses that could be used to create immersive simulated environments. We can confirm this by looking at the products on the market today, which are mostly goggles aimed at serving our eyes and ears. Our preference to hearing and sight is deeply rooted in our culture and especially in science, the eyes and ears make it possible to objectify what is being looked at without really having to interact with it. This is different with the sense of touch, which has the ability to change the reality of what is sensed, sensing also becomes an action which involves physical movement. By touching, the percipient in Hybrid Reality could have a more lively or true experience than that can be obtained by using mere hearing and sight: "success in generating compelling virtual experience is gained not by simulating visual images but by stimulating tactile, proprioceptive, and kinesthetic sensations."[30]

We have discovered that increasing the visual quality of a VR system does not increase the feeling of presence for a great deal[4], this is why researchers are now looking in other directions on the quest to increase the sense of being in the virtual. To introduce our sense of touch in the development of VE seems like an obvious choice. "In fact, certain researchers have even gone so far as to argue that simulating believable tactile and haptic sensations might represent "the Holy Grail" of VR."[31]

Our skin is the largest receptive sensing organ we have, and is a way of understanding the world around us. When we were toddlers we had to not only see and hear, but also touch and taste objects that were new to us. Touching is a way of checking reality, whenever we see something new or hard to believe we feel the urge to touch and make sure it is not our imagination or an illusion that is fooling our mind.

There is a rise of haptic and tactile devices such as data gloves and full-body suits using vibrotactile stimulators which are sensible when a virtual object is touched. It is a nice way to sense feedback of the VR this way, but it is difficult to accurately simulate the feeling of the surface or object on the skin. Another and maybe more realistic way to feel virtual objects is to sense their volume and weight by means of an exoskeleton which can provide force feedback. The downside is the fact that they are difficult to manufacture and maintain, not to mention bulky and uncomfortable to wear.

Interpersonal Touch

The internet has brought us many new ways of communicating with each other. We are able to chat with strangers located on the other side of the planet without showing our faces, we can share pictures and video images of our real-time experiences and are able to make contact with large groups of people with a single e-mail. Unfortunately all these advantages of electronic communication are at the expense of the physical and tactile qualities of our interpersonal interactions.[32]

It would be a shame to neglect our tactile senses within the research and development of electronic communication and interaction systems, because it is proved to be a powerful and direct way to convey information and emotions, or how Field puts it:

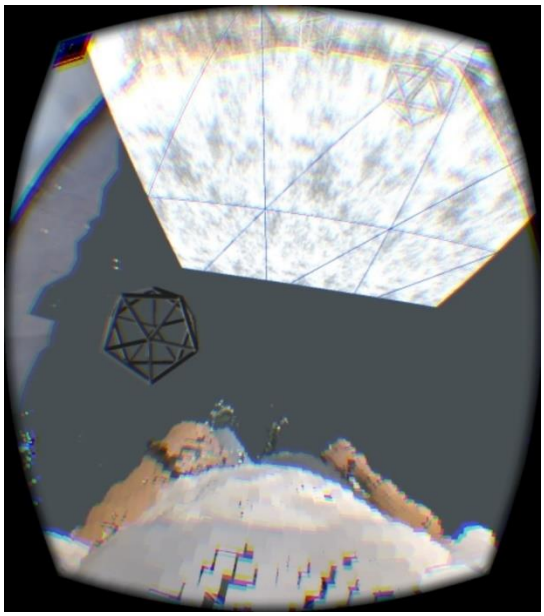
"Touch is ten times stronger than verbal or emotional contact, and it affects damned near everything we do. No other sense can arouse you like touch . . . We forget that touch is not only basic to our species, but the key to it." [33]

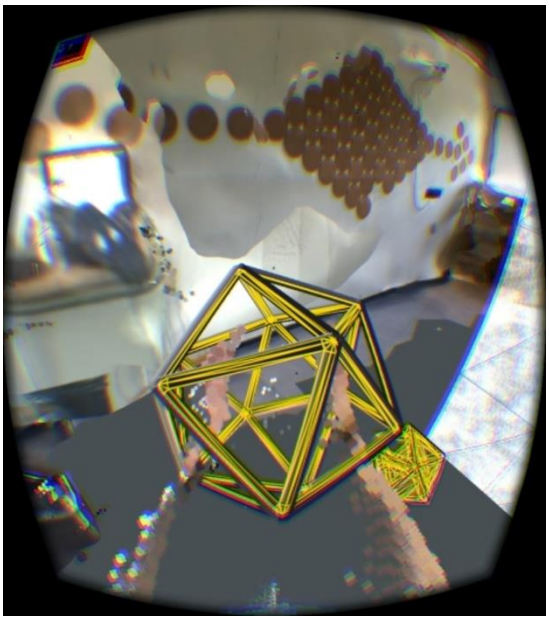
Research Method

To answer the research question **Does interpersonal human touch affect our sense of presence in an immersive Hybrid Environment?** we developed an experiment called *CloseHR*. In this experiment two users interact with each other and a computer driven system by touching hands, physically and/or virtually.

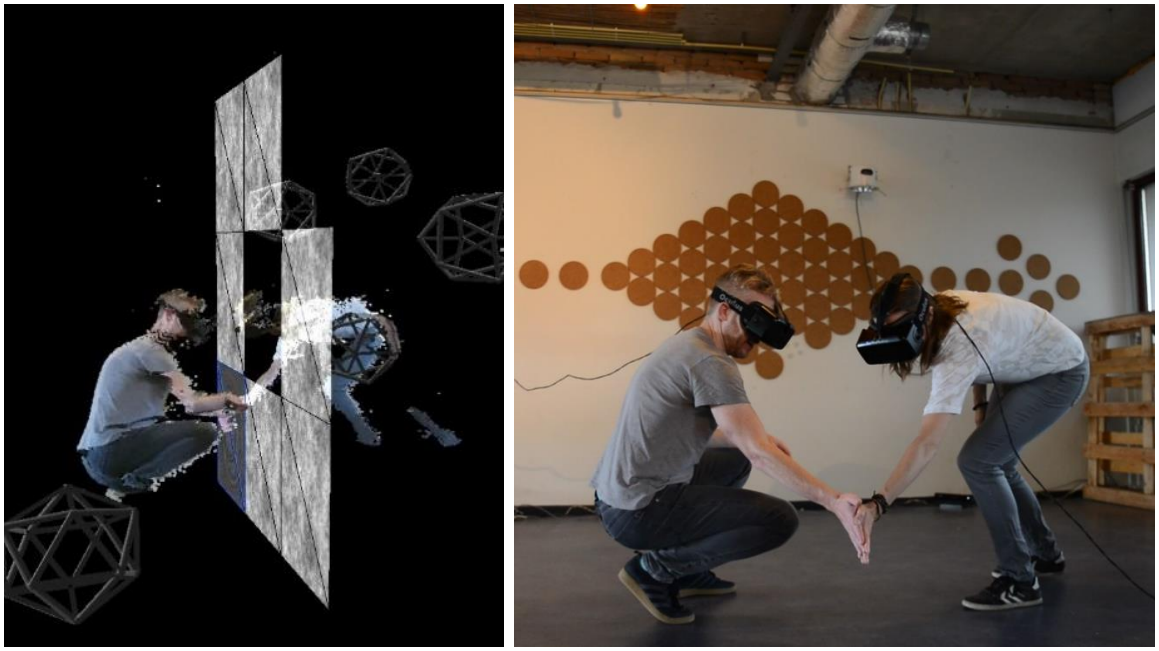
To create two conditions to compare with each other, *CloseHR* is made up of two different setups: setup 1 for the *Touch* condition and setup 2 for the *No Touch* condition.
Setup 1 enables two users to interact with each other by touching each other's hands, setup 2 enables the users to interact by touching each other's virtual-, but not their physical hands. Apart from this difference we have kept both setups as similar as possible to isolate the effect of interpersonal touch on the sense of presence of the participants.

In *CloseHR* two users experience a Hybrid Reality comprised of a 3D scanned representation of the room they are already physically in, augmented with two types of virtual objects.
The first type is a 3D geometrical icosahedron shaped object, 5 of these objects are floating around the room. When the user *touches* one of the virtual objects with both hands, the object will start to rotate and glow, its color changes from blue to yellow when the user keeps his/her hands inside the object for 1,5 seconds and it is then possible to drag the object to another location. The second type of virtual object is a wall, represented as a rectangularly shaped plane standing in the middle of the room. The wall consists of a 4x3 grid of tiles the users are able to activate. In setup 1 when both users touch each other's hands while their hands are located inside a certain tile, this tile will animate and will disappear after 10 seconds. With setup 2 their virtual bodies will be mapped in a manner so that they will touch each other inside the visible and auditory virtual world but not in the physical real world.

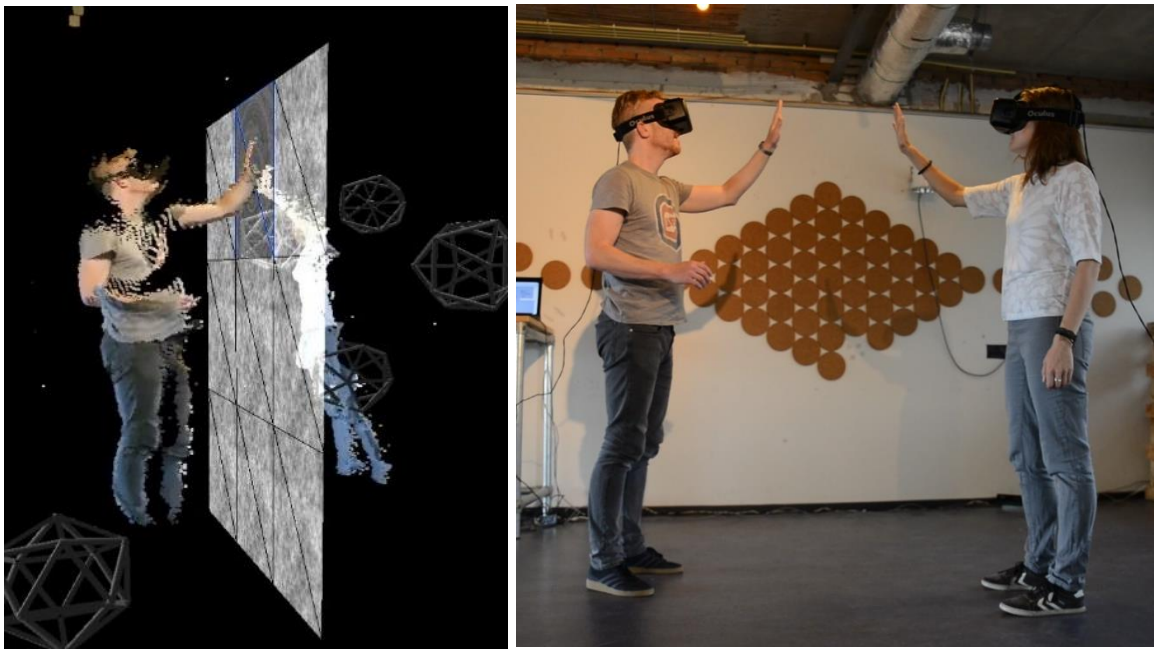




Screen captures of Oculus Rift output



Setup 1, *Touch* condition



Setup 2, *No-Touch* condition

Participants
14 participants took part in the experiment from which 4 were female and 10 were male. Their ages ranged from 27 to 42 and they came from different educational backgrounds.

Hardware
Both participating users of the experiment wear an Oculus Rift DK2 head-mounted VR display (HMD) that are connected to two individual gaming laptops connected by means of a network. The users are scanned and tracked by two Microsoft Kinect 3D sensors installed in two opposite corners of the experimentation room. The point cloud information of the Kinect is used to show the bodies of the users in real-time and the skeleton information obtained through the Kinect SDK is used to track their hands and head position.

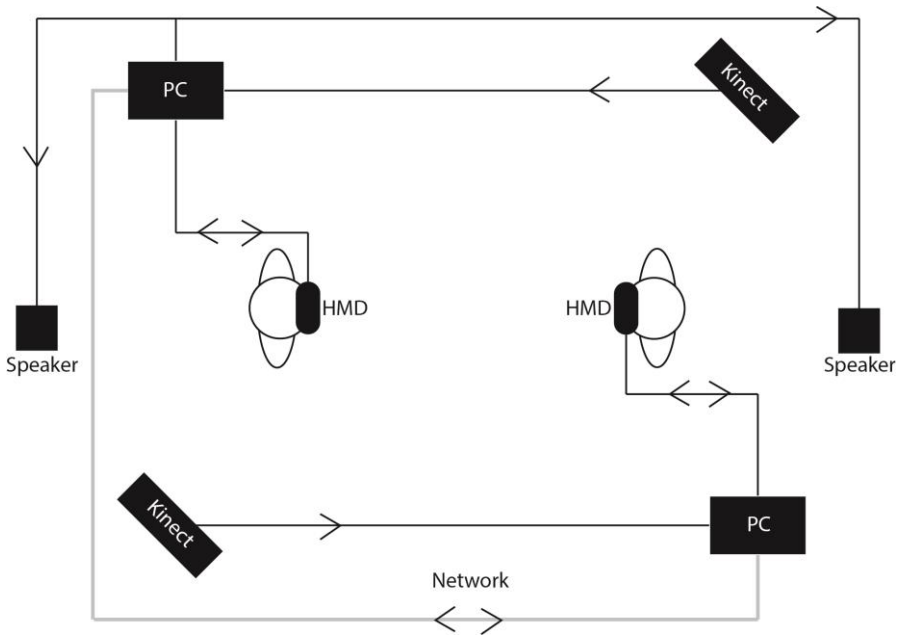


Fig. 3 Schematic top view of CloseHR

Software
CloseHR runs on a programme developed using vvvv, a hybrid visual/textual live-programming environment for easy prototyping and development.[34] The environment the installation is located in, is scanned with a free application by Autodesk called 123D Catch[35] and after modification in 3D modeling software, is imported into the vvvv programme using the Assimp open asset import library.[36] Both users are initiated by the programme by looking at the relative position of the skeleton data of each user in the room. By using the same skeleton information, the virtual camera in vvvv is positioned on the location of the tracked head of the user, which enables the users to walk naturally around the virtual/physical hybrid interaction space. The tilt and rotation of the virtual camera are controlled by the HMD sensor data.

When the users look down, they will see their virtual body located in the same location of their real body in physical reality. The virtual bodies of the users are constructed out of the 3D point cloud taken from the depth image data of the Kinect, with a shader that draws a cube on each point and colors them with the color information taken from the Kinect's RGB camera.
The head location data is also used to place a filter that subtracts the point cloud data of the user's head, which is favorable to the user's ability to see. In setup 1 the world is mapped to the real world by means of a checkerboard calibration technique.[37] Setup 2 is mapped the same way with a small difference, a space of 0,5x4x2 meters is taken out of the middle of virtual representation of the room, and the two ends are put together. This enables the users to *touch* each other in the visible virtual world, on the edges of the deleted space, whilst not touching in physical reality.

Procedure

To enable the experiment to be reproducible and to have the conditions as stable as possible we chose to let one participant interact with an instructed researcher who acts in a scripted manner. This way we could prevent unexpected behavior that could unwillingly distract the participant.
We used a within subjects design method, where the users tested both setup 1 and 2, counterbalancing the order. By counterbalancing the order of setups we prevented biases due to either training effects or fatigue effects.
Both setups were identical, except for the fact that users in setup 2 did not physically touch hands, although it visually seemed like they did. Both setups began with practice time for the users to get accustomed to their virtual body and the environment. They were asked to activate all the floating geometrical objects by holding both hands inside the objects. They did this until they felt comfortable within the environment. Because everyone reacts differently to being in Virtual and Hybrid reality, it is important to give people the time they need to get accustomed to it. To accomplish the geometrical object activation task, the users had to walk around the space, lift their hands high and bend their knees to reach all the objects. By actively using their body and the space, they feel a sense of embodiment relative to their virtual body, which has a positive effect on the sense of presence. [38]
After this practice time they were asked to touch the hand of the other user on the wall. In setup 1 they physically touched each other's hands, in setup 2 the image looked as if they touched, but in physical reality they were 50 cm apart. We chose to keep the two users in the same room, only 50 cm more apart from where they think the other person is, in order to isolate the sense of touch as best as possible. We chose this design over a tele-presence system, because this would also create a change in the olfaction and hearing senses, which would most likely influence the person's sense of presence.
Once the users had broken down the wall, they were asked to activate all the floating virtual objects again. By interacting with the objects they were forced to move around in the space, and use their body for interaction. This way they had the chance to experience (the absence of) an overall sense of presence of the objects in the world. When all the objects were activated the participants were pulled out of the experience to answer the questionnaire. When the questionnaire was completed, the users went back into the Hybrid Reality to complete the remaining setup. Once all objects were activated, the wall was broken down again and they had activated all objects again, the user answered the second questionnaire.

Questionnaire

We constructed a 30 item self-report questionnaire using a 5-point Likert response scale out of a modified version of the Embodiment Questionnaire (EQ) developed by Piryankova et al.[39] and a modified version of the Presence Questionnaire (PQ) developed by Witmer et al. [40]. We also added 2 short-answer questions to collect qualitative data on the self-reported experience of the participants and added a multiple-choice question to the EQ. Because we make use of a *within subjects design* method, and thereby do not compare the scores from individual participants, it was not necessary to execute an immersive tendencies questionnaire.

For analysis the EQ is divided in three subcomponents: Ownership, Self-location, and Agency. The PQ is divided into three Subscales: Involvement/Control, Natural, and Interface Quality. Participants were asked to answer the questionnaire after completing each condition.

1	I had the feeling that I was in the same location as my virtual body	SL
2	I had the feeling that I had control over my virtual body	O
3	I felt I could move my virtual body if I wanted to	A
4	I felt as if the virtual body was my body	O
5	When looking at my virtual body I had the feeling I was looking at myself	O
6	I had the feeling that the other and their virtual body were the same	O
7	It felt as is I could really touch the virtual hand of the other (virtual) person	A
8	I had the sensation as if I could touch the virtual objects	A
9	How much were you able to control events? (the wall, your body and the floating objects)	I
10	How responsive was the environment to actions that you initiated (or performed)?	I
11	How natural did your interactions with the environment seem?	N
12	How completely were all of your senses engaged, how immersed where you?	
13	How much did the visual aspects of the environment make you involved in the environment?	I
14	How much did the auditory aspects of the environment make you involved in the environment?	
15	How natural could you move through the environment?	I/N
16	How aware were you of events occurring in the world outside of the installation	D
17	How aware were you of your head-mounted display, the Oculus Rift?	D
18	How inconsistent or disconnected was the information coming from your various senses?	
19	Were you able to anticipate what would happen next in response to the actions that you performed?	I/N
20	How convincing was your sense of moving around inside the virtual environment?	I
21	Were you able to get a good understanding of the objects around you?	
22	How well could you examine objects from multiple viewpoints?	
23	How well could you move or manipulate the floating geometrical objects in the virtual environment?	
24	To what degree did you feel confused or disoriented at the end of the experimental session?	
25	How involved were you in the virtual environment experience?	I
26	How quickly did you adjust to the virtual environment experience?	I
27	How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	I
28	How much did the visual quality interfere or distract you from performing assigned tasks or required activities?	D / IQ
29	How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	D / IQ
30	Were you involved in the experimental task to the extent that you lost track of time?	I

SL=Self Location, O=Ownership, A=Agency, I=Involved/Control, N=Natural, IQ=Interface Quality

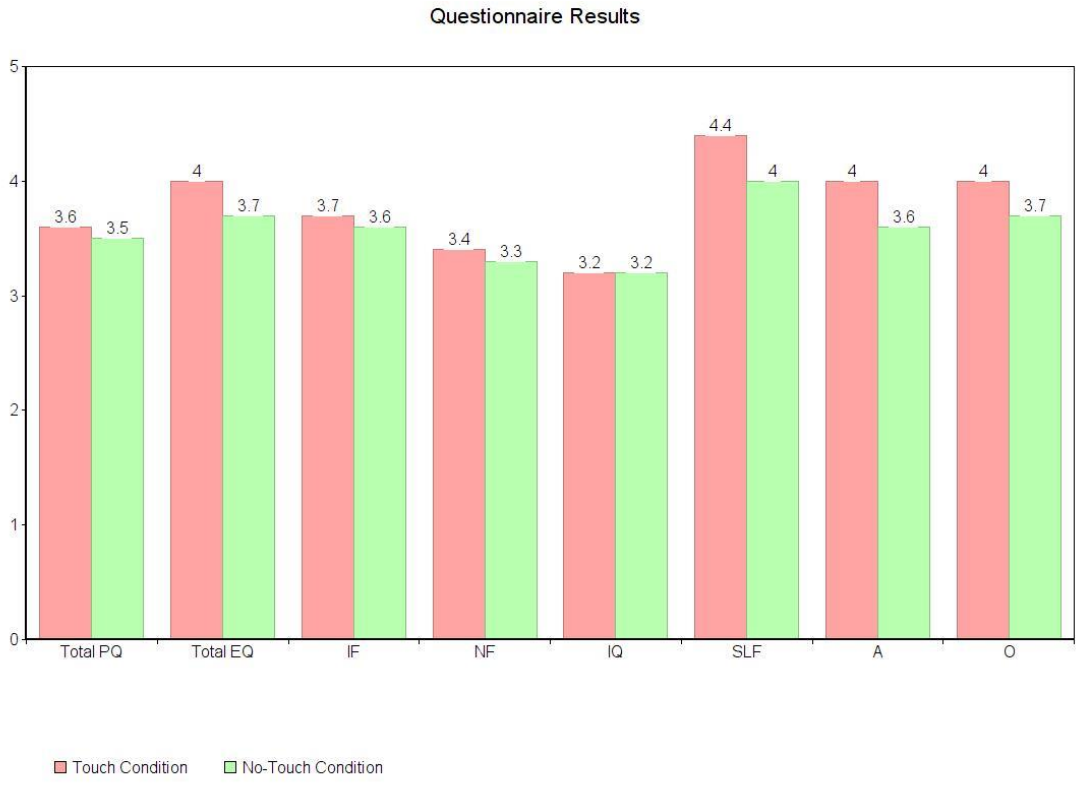
Questionnaire Results

We analyzed the data gathered through the questionnaires with the analytics software IBM SPSS using a paired *t-test*. We calculated a presence total score by using the results of the PQ and excluding questions 8,9,20 and 21 which were part of the distraction subscale. A paired samples t-test showed no significant differences of the sense of presence between the two conditions, t=0.96, p=0.35. The mean score for the *Touch* condition was 64.29 with a standard deviation of 6.35. For the *No-Touch* condition the mean score was 62.71 with a standard deviation of 8.37.

Three subscales were identified from the cluster analysis of the PQ data. Again, paired samples t-tests showed no significant differences found between the two conditions. The PQ subscales were labeled Involved/Control (9 items; *M 33.71, Sd 3.56 for the Touch condition and M 32.57, Sd 4.67 for the No-Touch condition*) , t=1.15, p=0.27, Natural (3 items; *M 10.14, Sd 1.35 for the Touch condition and M 10, Sd 2.48 for the No-touch condition*) , t=0.24, p=0.81, and Interface Quality (2 items; *M 6.36, Sd 1.0 for the Touch condition and M 6.42, Sd 1.57 for the No-Touch condition*).

The total mean score for the EQ *Touch* condition was 32.42 with a standard deviation of 5.78, for the No-Touch condition the mean was 29.85 with a standard deviation of 6.36. For the EQ we also performed a cluster analysis with three subscales, Self-Location (1 item; *M 4.36, Sd 0.74 for the Touch condition and M 4.0, Sd 0.96 for the No-Touch condition*), Agency (3 items; *M 11.92, Sd 2.34 for the Touch condition and M 10.78, Sd 2.75 for the No-Touch condition*) and Ownership (4 items; *M 16.14, Sd 15.0 for the Touch condition and M 15.0, Sd 3.38 for the No-Touch condition*)

The results of the paired samples *t-test* show a significant higher overall Sense of Embodiment (*t=2.9, p=0.01*) in the *Touch* condition, also the levels of Agency (*t=2.8, p=0.01*) and Ownership (*t=2.3, p=0.04*) were significantly higher in the *Touch* condition compared to the *No-Touch* condition.



The questionnaire also contained a multiple choice question where participants had the possibility to check more than one answer. When we compare the answers of the two conditions we see that the first and last questions are somewhat stable, and there is a rise of participants who checked answer b) *I felt myself somehow connected to the virtual body* while experiencing the *Touch* condition.

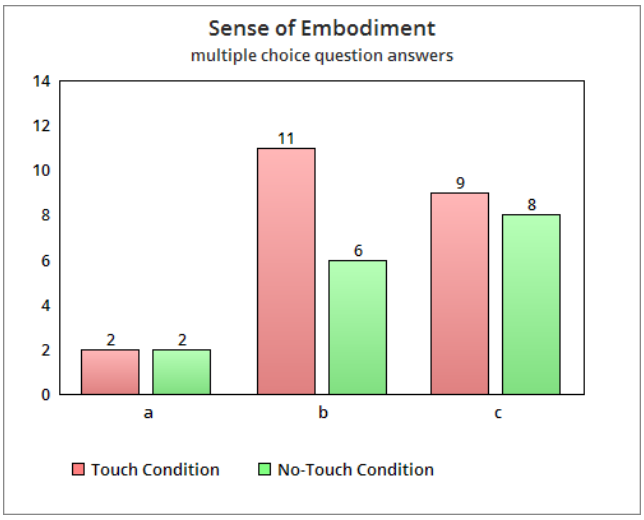


Fig. 4

A) It felt as if I had more than one body
B) I felt myself somehow connected to the virtual body
C) I had the feeling that I and the virtual body were the same

Qualitative Research Results

The results taken from interviews, observations and the answers of the free questions on the questionnaire overall tend to support the impression of a more surprising, pleasurable or involving experience for the *Touch* condition compared to the *No-Touch* condition.

Reactions worth mentioning were for example those of participants who had a raised feeling of togetherness while performing the touch condition. One participant mentioned to have the feeling the other was not there in the *No-Touch* condition: “The wall felt like a mirror where the other person was not a real person but could be a mirror image of myself or a pre-programmed avatar.”

Another reaction of a participant who was interacting with the virtual objects after the touch condition was completed, was that he said it felt strange to hear people entering the room, he expected to see them, but he obviously couldn't because he was wearing VR goggles. “It is as if the other people are ghosts, some kind of virtual entities or something else that’s not from our reality, but you hear and feel that they are here.” This can be seen as an indication that the participant felt present in the Hybrid Environment, and felt he shared it with the other person inside the installation and on another level with people in the physical room.

Some participants mentioned to find the touch condition as being more fun compared to the no-touch condition, and other participants had the feeling the environment was more responsive after performing the *Touch* condition.

There were also participants who felt the touch of a real hand did not contribute to the immersion because it pulls them back into the real world: “Somehow the experience became more practical and less ' dream like' with the touch involved. Also because the floating objects reacted with light and

sound, the sudden tactile feedback got me back on the ground again in a way." As we mentioned earlier, presence is not a binary, but a constant adapting psychological state of mind.[17] We argue that when being in an HE it can be desirable to introduce elements that keep or bring the user back into physical reality, this keeps the sense of presence in flux, which we find more interesting than an on/of state of being (immersed, embodied and present.)

We would like to make an exception to this rule when it comes to distraction caused by the used hardware or a low quality of interface. In a correct working HR the user should not be aware of the technology that is used to create the experience.[41] Some participants reported to find the cable connecting the HMD to the computer too short, which decreased their feeling of freedom to move and made their experience less immersive. Many of the participants reported being distracted by the interface, they felt the experience could be more immersive if the tracking and display technology would work better, as a participant mentions at the end of his questionnaire "I believe that most of these questions are heavily affected by the quality of the experience (mapping, frame rate, etc.)." When the technology asks the user's attention, it is difficult to direct our attention to the task or experience that is presented, at the expense of the sense of presence in the Hybrid Reality.

This is why it is important to measure elements that work in favor of a high level of immersion, just like those in favor of the Sense of Embodiment, as they are closely related and work together to create a sense of presence in Hybrid Reality.

Conclusion and Discussion

For this study we designed *CloseHR*, an interactive art installation to discover effects of interpersonal touch on the sense of presence in a Hybrid Environment. In order to study the effect of touch versus no touch in isolation, two setups were designed that were identical, except for the mapping of the no-touch condition where it looked like the two participants touched each other's hands, but in physical reality were 50 cm apart. We expected interpersonal touch to have a positive effect on the sense of presence. To test this hypothesis we collected data by means of questionnaires on presence and embodiment, the results didn't show any significant difference for the sense of presence between the two conditions, for which there could be several reasons. Probably we would have a more clear result if our sample size was larger. The variation of the participants was high when it comes to their work field, experience with VR technology and possibly immersive tendencies. The amount of experience and practice with VR might have an effect on presence, to have "been in the virtual" before helps us believe we are their again. [42]

It could also be that the adjusted presence questionnaire we used, which was originally developed for immersive Virtual Environments, is not suitable for the proper assessment of Hybrid Environments. Because the participants had to perform different tasks in Hybrid Reality, they went through a process of different sensations of presence being high in one moment and low in another, with the possibility of an inaccurate recall of their experience as result. A way to solve this problem would be to ask participants what they are experiencing in real-time, without having to leave the HE. IJsselsteijn, Wijnand A., et al. proposed a *continuous verbal reporting* method to measure temporal variations of the sense of presence,[43] which seems to be a promising direction for future studies.

To create *CloseHR* we used low-cost consumer technology which have the advantage of being easily accessible, and can thereby be experimented with by a large community that shares its knowledge. The downside of using these products is that their level of performance- and interaction-quality drops drastically when trying things they are not originally designed for. The system we created for this experiment suffered from a low frame-rate and a low resolution of head tracking, which caused some of the participants to feel uncomfortable. This interface quality affects the sense of immersion which influences the sense of presence and thereby probably disturbed the research.[15] For future research

we would like to design the experiment using technology of higher quality, to eliminate these distractions as much as possible. There also wasn't any significant effect on the sense of self location, this could be caused by the mismatch of sensory inputs due to imperfect calibration and head tracking. If we would hypothesize that the absence of effects of interpersonal touch on the sense of presence was caused by a lack of immersion due to low quality technology, we could also carefully hypothesize that processes of embodiment are less affected by immersion than the processes of presence are.

From the reactions of the participants during and after performing the touch condition, a raised sense of togetherness was observed. A phenomenon called social- or co-presence which is measured in different studies often using tele-presence technology.[44] [45] This could be an interesting angle for future research, to discover the effects of interpersonal touch on the sense of co-presence in an immersive Hybrid Environment.

Because we used a system that allowed the participants to feel embodied with a virtual representation of themselves, and it is shown embodiment is highly related to processes of presence,[21] [22] [23] we asked the participants to also fill out an embodiment questionnaire. We found a significant raise in the sense of embodiment for the *Touch* condition compared to the *No-Touch* condition. Interpersonal touch had a positive effect on the ownership and agency participants felt over their hybrid body, which probably had a positive effect on the sense of presence.
Possibly this effect was just like the rubber hand illusion induced by the sense of touch in general. [28] Another interesting test would be to compare the effects of interacting with another person through a haptic feedback device to that of physically touching another user in HR. In both conditions of our current research users were touching the ground with their feet, had the ability to touch the walls of the space and their own body and hands. For this study we have chosen not to use these tactile inputs as interaction inputs, it would be interesting to include this as another condition in future research.

This study shows a potentially positive effect of using interpersonal touch as interaction input within a HE on the sense of embodiment and presence. We proposed an alternative measure to the post-non-continuous questionnaire we used for this research, and described the importance of a well-functioning experiment system. We hope these findings shed light on the potentials of including our sense of touch for the development of HR systems with a multi-user approach.

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