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Bachelor Thesis

Exploring the Traces of Use Effect on Mid-Term Asynchronous Shared VR Space Usage

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Zusammenfassung

Diese Bachelorarbeit befasst sich mit der Frage, inwieweit soziales Bewusstsein und Nutzer-Raum-Beziehungen durch Gebrauchsspuren in virtuellen Welten beeinflusst werden. Sekundär wird auch die Wirkung von Gebrauchsspuren auf die soziale Wahrnehmung gemessen. Dazu wurde eine Laborstudie durchgeführt, bei der die Teilnehmer innerhalb von zwei Wochen wiederholt einen asynchron geteilten virtuellen Raum betraten. Unterstützt wurde die Methode durch einen Tagebucheintrag, der von zu Hause aus ausgefüllt wurde.
Die Studienergebnisse zeigen, dass die soziale Präsenz sowie die emotionale Bindung an den virtuellen Raum durch die Spuren signifikant gesteigert werden konnten. Obwohl nicht keine signifikanz festgestellt wurde, gibt es Hinweise darauf, dass das soziale Bewusstsein teilweise durch Spuren verändert wird. Weiterhin konnte festgestellt werden, dass die Einhaltung von Normen des Sozialverhaltens auch in virtuellen Umgebungen erwartet wird.

Abstract

This bachelor thesis covers the issue in what way social awareness and user-space relationships are influenced by traces of use in virtual worlds. Secondary, the effect of traces of use on social awareness is also measured. For this purpose, a laboratory study was carried out in which participants repeatedly entered an asynchronously shared virtual space within two weeks. The method was supported by a diary entry that was filled out from home.
The study results show that the social presence as well as the emotional connection to the virtual space could be significantly increased by the traces. Although not found to be significant, there is evidence that social awareness is partially altered by traces. Furthermore, it could be determined that compliance with norms of social behavior is also expected in virtual environments.

Task

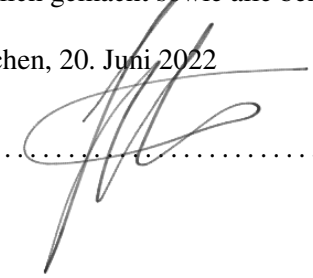
Communicating via Traces in VR/ VR specific Traces
Our real, physical environment shows traces everywhere of how we use it. Those traces can serve as memory cues and indicate prior interaction or user behaviors. Hence, they are signs of prior experiences. VR environments or objects currently do not include such traces of use and it is unclear how to represent traces of use in a virtual environment. This disconnects the virtual space from the experiences that we make in it. In this thesis, we want to explore ways to use traces in VR, either for asynchronous communication or for the effect of aging VR environments.

Aufgabenstellung

Kommunikation durch Spuren in VR/ VR spezifische Spuren
Unsere reale und physische Umwelt zeigt überall Spuren davon, wie wir sie nutzen. Diese Spuren können als Erinnerungsstütze dienen und auf frühere Interkationen oder Nutzerverhalten hinweisen. Daher sind sie Zeichen früherer Erfahrungen. VR-Umgebungen oder Objekte weisen derzeit keine solcher Nutzungsspuren auf und es ist unklar, wie Nutzungsspuren in einer virtuellen Umgebung dargestellt werden sollten. Dies trennt den virtuellen Raum von den Erfahrungen, die wir darin machen. In dieser Arbeit wollen wir Wege erforschen, entweder für asynchrone Kommunikation oder für den Effekt alternder VR-Umgebungen, Spuren in VR zu nutzen.

Ich erkläre hiermit, dass ich die vorliegende Arbeit selbstständig angefertigt, alle Zitate als solche kenntlich gemacht sowie alle benutzten Quellen und Hilfsmittel angegeben habe.

München, 20. Juni 2022



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1 Introduction

While virtual reality (VR) has been of concern to researchers for many years [12], interest in virtual reality systems as non-scientific tools has only increased recently [28]. These developments have brought virtual worlds into focus. According to Ralph Schroeder, virtual worlds are "virtual environments that people experience as ongoing over time and that have large populations which they experience together with others as a world for social interaction" [15].
With the metaverse on the rise, the concept of virtual worlds expands by combining physical reality with digital virtuality [16].
A closer look at the different concepts, focusing on their virtual environments (VEs), reveals a common problem, namely the lack of memory of previous activities due to system resets. Laurie Anderson once said "VR would never look real until they learned how to put some dirt in it" [30]. Since virtual reality attempts to be an exact replica of the real world [14], the lack of traces of past activity can negatively impact the immersive experience. This means that, compared to the real world in VR, there are no traces that allow people to draw conclusions about certain actions or emotions of other users from their previous actions.
In a previous work, a within-subject study was conducted to examine the effects of traces in VEs on asynchronous social presence and social awareness by comparing users' experiences with and without traces [13]. But how do traces of use affect users when they repeatedly enter a shared VE and perceive traces of others? Among other things, issues like this led to the research question "How do traces of use affect user-virtual place relationship and social presence in a permanently shared virtual environment?".
Therefore, this thesis aims to strengthen existing concepts with traces of use. The primary goal is to increase social presence and user-place relationships through traces of use and secondarily to evaluate whether traces of use have influence on social awareness in VR. The method used to achieve these goals is a mid-term laboratory study supported by diary entries.
At the beginning of this thesis, an overview of the current state of research is provided. On the one hand, gaps in the research are shown and on the other hand arguments are made as to why certain methods were selected for the study design. Then it is described how the concept for the virtual environment was approached and how its specifics were implemented, including the hardware description. In the next step, everything related to the study is described. First, the methods used in the study are specified so that the structure of the study can then be explained in detail. After presenting and discussing the study results, the most important findings are summarized in a conclusion and an outlook on further research is given.

2 Related Work

This chapter gives a theoretical overview of the most important terms and their current state of research in connection with this work. In the first step, social presence covering social awareness as well as asynchronous virtual environments, is presented, followed by traces of use. This is to lay the foundation for a later understanding of the course structure.

2.1 Social Presence

Social presence is a subcategory of presence [8] and can be measured and can be examined through four different aspects: personal-impersonal, sensitive-insensitive, warm-cold and sociable-unsociable [7]. Social presence describes the mental and physical perception of the communication partner by the other [6]. In other words, it is difficult to feel social presence when there is no communication partner. Therefore, research on social presence is more focused on the area of synchronously shared virtual spaces to create higher immersion.
Some works deal with the relationship between non interpersonal in relation to social presence rather than an interpersonal relationship. An example is the study conducted by Bailenson et al., in which both of the above relationships were analyzed. Users were faced with an avatar controlled by a real human as well as a computer-controlled character. On the one hand, the social presence increased through the juxtaposition of the participant and the avatar and on the other hand through direct eye contact. [18]
In the asynchronous context, there is less research on social presence. One of the few studies was done by Shih and Swan. The influence of social presence on students' perception of asynchronous online learning was examined.[5] However, the study was not about a VR environment, but about online environments. In the study by Linda Hirsch et al., on the other hand, social presence was examined in an asynchronously used virtual environment. Participants should alternately enter a room with traces of use and one without in order to analyze the effect of the traces. The result was that social presence was increased under the influence of traces. [13]
None of the studies mentioned analyzed the role of social presence in asynchronously shared virtual spaces in which people actively interact within a given period of time. This gap should be closed with this bachelor thesis.

When talking about social presence, social awareness should also be considered. Social awareness, like social presence, depends on an environment used by several people, which can be physical, virtual or a mixture [4]. Thus, social presence is required for social awareness. Indications from the environment are used to feel social awareness. Therefore it makes sense to analyze both aspects.

2.2 Traces of Use

Traces in the real world are important not only for historians [2], but also for emotional attachment to an object. Traces on objects, can be appreciated and loved by the owner, even if they limit their functionality. [1] An example of this would be a stuffed animal that has been owned since an early age. The more you cuddle with him, the more the surface wears off. The fabric may tear after a few years, but you can't part with it because it has been with you throughout your lifetime. You love and appreciate it as it is now. Traces are unavoidable in the real world. Which makes it possible to have implicit, non-physical communication with fellow human beings, for example by leaving messages for them through conscious traces. As soon as you take the remote control off the table and put it on the couch after use, a trace of use has already been left behind [26]. Tracks can be classified into three different areas, material traces of use, material traces of skill and material traces of time [3]. Since this work focuses on the traces of use, the other two areas will not be discussed further.

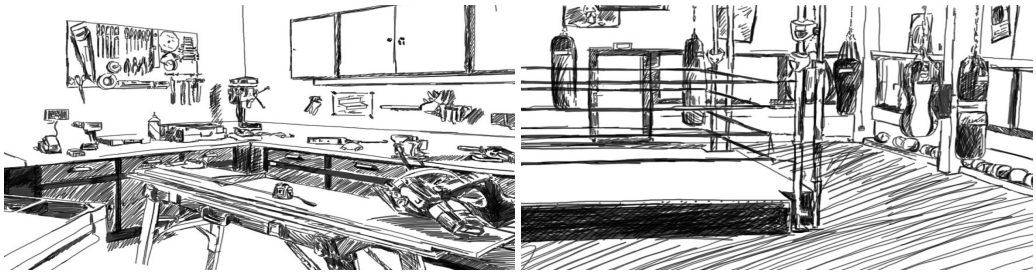
According to Baxter et al., traces of use can also be categorized: object context, object settings, object characteristics, and object states. For the former, the example with the remote control was given at the beginning of this chapter. Object settings are changed configurations of the object, such as the TV being turned on. Object characteristics describes irreversible states of an object, such as scratched surfaces or torn paper. In contrast to the characteristic, the object states describe reversible conditions, such as a crumpled pillow. [26] In this work, traces of use of all four categories are analyzed for their effect on users in an asynchronously shared environment.

3 Virtual Environment

Since the virtual environment is a major part of the study, this chapter aims to clarify the technical data. This includes the concept approach, which covers hardware and design decisions, as well as the special features of the implemented software.

3.1 Concept approach

Before designing the VE, it was important to determine the appropriate hardware. The three products VIVE Pro, Oculus Quest and a Cardboard were available as VR headsets.The latter was excluded after the decision to conduct a laboratory study. In the end, the VIVE Pro was chosen due to its higher refresh rate and a wider field of view. Both a higher frequency, which results in a more natural representation of movement, and a wider field of view are supporting an immersive and realistic experience [31].
To ensure users can walk around physically without any doubts about their safety, the dimensions



(a) Handicraft workshop (b) Boxing studio

Figure 3.1: Sketch examples of developed concepts

of the virtual environment were adapted to the dimensions of the cleared area of the real environment. In the first step, the available area was measured with SteamVR Room Setup. This created a safety grid of approximately 5m x 4m within the VR applications, showing users the boundaries of the space. Since this grid is perceived as disturbing and unnatural, the sense of presence is negatively affected. To avoid the appearance of this grid, the area of the virtual space was minimally reduced in the next step. The specified requirements later served as an exclusion criterion in order to develop a suitable scenario.

After mind-mapping a variety of different spaces shared in real life, concepts that would be difficult to realistically implement in VR were discarded. This includes, for example, a shared kitchen, since certain senses such as the sense of smell cannot be easily addressed in VR applications. Figure 3.1 shows two concepts that were also considered towards the end of the concept finding process. In the hobby workshop 3.1a, the participants should be able to asynchronously either put together a handicraft object collaboratively or work individually on their own project. In both cases, everyone should be able to see each other's work. In contrast, the participants in the boxing studio 3.1b should be able to train by themselves. There would be no explicit legacy from other participants, such as the objects worked on in the workshop. These two concepts implied new problems such as a high implementation complexity in a limited time and the required area to realize the virtual environments which exceeded the predefined size of the virtual space. This results in new exclusion criteria, which, among other things, ultimately led to the concept of the shared office (see Figure 3.2).
For the most authentic experience possible, the room has been equipped with professional 3D models, materials and textures.
The features realized in the room should allow participants to actively leave traces of use in each

Figure 3.2: Shared office top view

session. However, the various traces of use that can arise in this room are discussed in more detail in the chapter on study design.
During the design process, the decision was made to choose a fixed starting point for all participants. This should ensure a consistent start as well as prevent participants from standing in objects such as the tables as soon as they enter the room. As in real life, it should appear as if you entered the room through a door. So the player was placed in the program facing the room. In addition, a corresponding mark was placed on the floor of the laboratory.
The program should not only consist of functions that allow the participants to interact in some way, but also features that should measure the quantitative data. This includes how long an object was viewed and how many times an object was touched, intentionally or not.

3.2 Implementation

The game engine Unity version 2020.3.20f1 was used for the development of the virtual environment. In order to realize some of the traces of use, several of used low poly models had to be modified using Blender version 2.91.2. This includes broken glass items, torn paper, crumpled Post-Its and pillows. Traces caused by changing the material in Unity, such as fingerprints and scratches, have been adjusted in GIMP version 2.10.30.
The VIVE Pro integration was done with the SteamVR plugin provided by the Unity Asset Sto-

(a) Broken glass (b) Crumpled pillow (c) Scratched protection mat

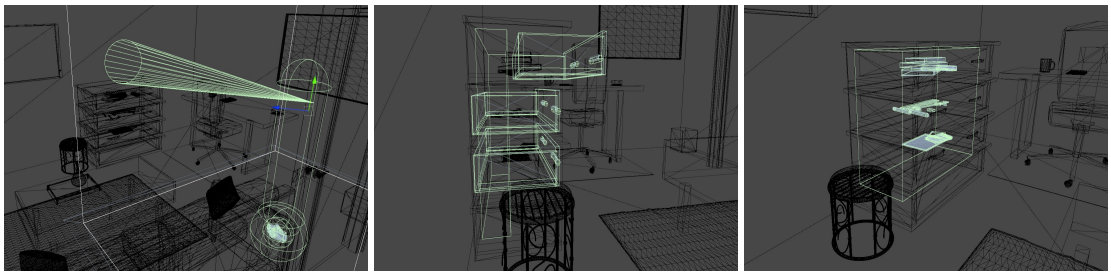
Figure 3.3: Examples of traces of use

re. However, the player settings and features of this package were not used, preferring a realistic representation of the hands for an immersive experience. Instead, the Auto Hand Package was installed, which provided visually realistic hands. In addition, the package provides pre-written

scripts from the responsible developer, which made it possible to grab objects like in real life. These are some auto hand functions used in the program:

- Pull-Apart Events
- Grab Events
- One-Handed Item Swapping
- Multi-Handed Grabbing
- Hand Collision Touch Event
- Catching
- Throwing
- Automatic Grab Pose
- Drawer Example

Using the examples of glass objects and cushions, the following description will explain how some of the features have been implemented. Once a glass object or pillow collides with the floor or the walls, the object is destroyed and replaced with an adjusted version as you can see in Figure 3.3a and in 3.3b. The state of the pillow can be reset once it is placed back on the sofa. The principle of destroying and replacing objects was also used for other traces such as crumpled notes, torn paper or switches. Fingerprints and scratches (see Figure 3.3c), on the other hand, were achieved by changing the material of the object after a certain number of touches. Another interaction in the room was writing on the whiteboard and cleaning it afterwards, the functionality of which was taken over by a VR developer [32].



(a) Head tracker (b) Observer: Drawer state (c) Observer: Object state

Figure 3.4: Head-Tracking System

Figure 3.4 shows a head-tracking system implemented in Unity to check what objects participants were looking at and how long they were looking at them. A cone used for the head tracker (see Figure 3.4a), simulated the player's field of view and a timer has been attached to all non-static objects (e.g. sofa and tables). The timer was started as soon as the cone intersected the respective object and stopped when contact with the object ended. To achieve this, the cone's mesh renderer was disabled and both the mesh collider property *Is Triggered* and the ridgidbody property *Is Kinematic* were set to *true*. In this way, the *OnTriggerEnter* and *OnTriggerExit* functions could be implemented to start and stop the objects' timers. Objects are only considered viewed after a viewing time of 100 milliseconds, because that's how long it takes the eye to fix something [17]. A problem was identified while testing the head tracker. Namely, objects that were in the drawers and therefore could not be seen, were also recorded. Thus, two more box colliders were added to

the drawer, which, like the cone, were set to *is triggered*. The collider used to observe whether the drawers were open or closed was placed on the inside of the drawer's back wall . As soon as drawers were opened or closed, it was checked whether they were still in the area of the collider or not (see Figure 3.4b). A corresponding message was displayed by the console. The second collider used the same method to observe whether there were objects in the drawers or not (see Figure 3.4c). The dimensions of the second collider covered the entire interior of the drawer and used the same functionalities as the first one, to observe whether items were in the drawers or not. The associated scripts have been added to objects that were able to be placed in the drawers and to individual drawers.
Furthermore, it was tracked how often something was touched. For this, the Auto Hand scripts for grabbing and touching objects have been extended with a counter. As a result, a message with the current number was displayed whenever a non-static object was touched. All tracked data was saved in an extra file along with the respective object names. A video recorder integrated into Unity itself was used to record the individual sessions of the participants.
The tutorial for the participants consisted of a small area from the exercise room that was also provided by Auto Hand. The objects represented in the training environment contained the basic functions of the shared office. The trigger buttons of the VIVE controllers were set as the grip function for both virtual environments. Other buttons of the controllers were not integrated. There was no implementation that saved the final states of each participant's session. Instead, these were saved manually in order to be able to analyze the individual states in detail after the study. The entire hierarchy in Unity had to be copied at runtime without the player and not changeable objects. After the application was stopped, the copied states were pasted into the hierarchy and the old states were disabled.

4 Methodology

The software used for the study was described in the previous chapter. In order to complete the basics of the study, first the methods used to explore the predefined variables will be explained in detail below. Afterwards the flow of processes used during the study and after the study is described, this includes the aspects of study design, data collection and data analysis.

4.1 Study Design

Before suitable methods could be considered, variables had to be defined first to produce proper foundations. After initial research, the hypothesis "Evolving traces of use enhance social awareness, user-virtual place relationship and social presence in permanent shared virtual environments." was established. As a result, the presence and absence of traces of use could be derived as independent variables, and dependent variables social presence, social awareness and user-virtual place relationships could be determined. Further investigations showed that social awareness in VR is not as well represented in research. Therefore, social awareness was considered a side dependency. In the course of this chapter, the methods of the experiment defined in advance are discussed first, followed by the process of the experiment to gain an accurate understanding of the procedures used in the study.

4.1.1 Methods

The methods used within this study included various traces that should evolve in the shared office through the tasks assigned to the participants. Questionnaires covering various subject areas were also used. In addition, the experiment was divided into an experimental group and a control group. The individual points are discussed in more detail below.

Traces Both conspicuous traces, such as broken glass, and less conspicuous traces, such as fingerprints, were realized in the shared office. Traces that could evolve were based on Baxter et al. [26] categorical levels of indicators of use. As an object setting, it was possible, for example, to open and close drawers and turn the television or the roof light on and off. The indicator object characteristic was represented by scratches on the protection mat, shattered glass items, broken cubes and paper ripped from a notebook. Traces like posters detached from the walls covered the object state. However, the objects used showed predominantly traces of use by object context, which means that a large part of the objects could be rearranged. The table 8.1 with the objects used and their categorical levels of indicators of use can be found in the appendix. One of these objects used in the virtual space was a whiteboard that could be written on. The participants attempted to leave greeting messages despite the task stating that "written notes are not allowed.". Therefore, the states of the whiteboard could not be transferred to the next session of another participant.

Questionnaires The questionnaires used should provide information about various aspects of the users and their experiences with this virtual environment.
In order to create a balance between the time that should be spent in the shared office and the time invested in answering the questions, different questionnaires were created for the individual days. Table 4.1 provides an overview of the different components of a questionnaire per day.
Personal information questions should be answered at the beginning of the study in order to gain information about the background of the subjects, such as age and gender, as well as previous experiences with 3D worlds and VR headsets.
To quantify the dependent variables, the items social presence, social awareness and place attachment were queried. The questions on social presence were taken from a standardized ques-

	Day 1	Day 2	Day 3	Day 4	Day 5
Personal Informations	X				
General Presence	X				X
Social Presence	X	X	X	X	X
Social Awareness	X	X	X	X	X
Place Attachment	X		X		X
Open Questions	X	X	X	X	X

Table 4.1: Questionnaire Timeline

tionnaire, the original aim of which was to synchronously measure the social presence between a user and an avatar [18]. For this reason, the original questions had to be adapted to the asynchronous human-to-human relationship used in this study. For example, the wording of the original question “I perceive that I am in the presence of another person in the room with me.” has been rephrased into “I perceive that another person was in the room before me.”.
In contrast to the social presence, no standardized questionnaires could be found for social awareness, which reflected the virtual reality context in relation to this study. Therefore, the questions asked were based on a component of the Social Emotional Competence Questionnaire (SECQ) that covers social awareness [20]. They were to be answered on a five-point Likert scale from “strongly disagree” to “strongly agree”.

1. Knowing that I am not the only user of the room changes the way I look at the room.
2. In the room I can draw conclusions about how other users felt in the room.
3. I feel comfortable in the room.
4. I feel uncomfortable in the room.
5. Why do you feel the way you do?

The first question reflects the meaning of social awareness, the ability to draw context for one’s own actions through the actions of others [21]. The second question was originally taken from the SECQ and adapted to the study context. The remaining combination of two quantitative and one qualitative question were asked to gain an impression of participants’ subjective awareness.
For the user-virtual space relationship, the standardized Abbreviated Place Attachment Scale (APAS) was used. This is a 6-item questionnaire used to measure place attachment. On the one hand, the APAS includes questions about place identity, related to emotional or symbolic attachment to a place and on the other hand, place dependency, based on the ability of a place to satisfy one’s recreational needs or facilitate the attainment of goals [22].
In order to measure the dependent variables not only quantitatively but also qualitatively, following open questions were answered daily:

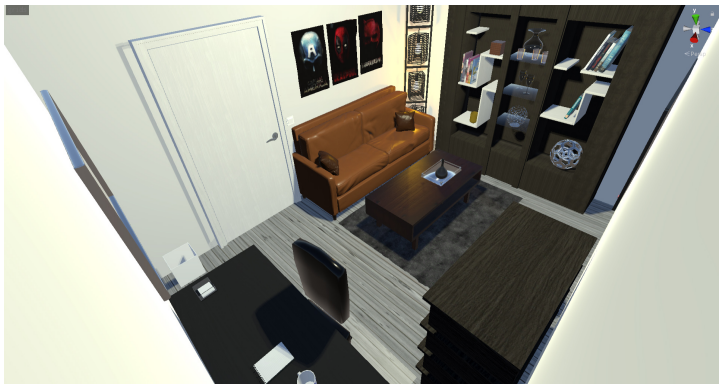
1. What have you done in the room?
2. What would you have liked to do?
3. What affect has the room had on you?
4. What have you noticed particularly positively or negatively?

In addition, participants were asked how long they estimated their presence time in the virtual space and whether they felt that others had invaded their intimate space [23].
In order to be able to rule out a correlation between the answers and the feeling of being present in

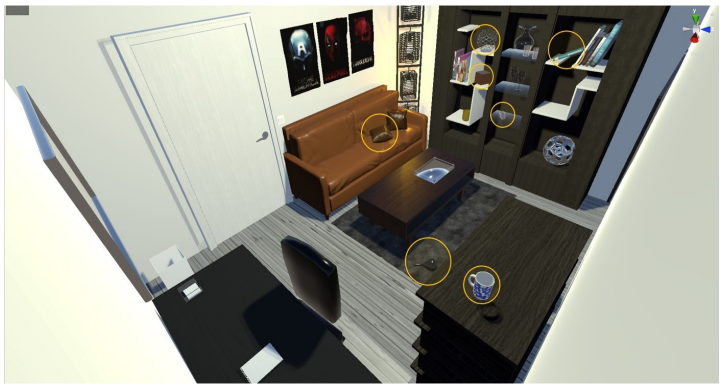
the case of negative answers in the questions mentioned so far, questions about general presence were asked on the first and last day. As before, the questions of a standardized questionnaire were adapted to the context of this study [24].

Diary Entry The diary entries were a 2-item questionnaire that should be completed one day after a session in a familiar environment, i.e. outside of the lab set up. On the one hand, this gave the participants time to process what they had experienced and, on the other hand, they were able to make a comparison between the virtual environment and a well-known surrounding while the questions were being answered.

A/B - Testing The comparison between presence and absence of traces should be ensured by randomly separating the participants into two groups, which should experience different starting conditions of the shared office. Since the area of the VE was limited, the control group (A) and an experimental group (B) were each divided into two subgroups.



(a) Clean initial state



(b) Used initial state

Figure 4.1: Shared Office

On the first day, each participant assigned to group A entered an unused and tidy setting (see Figure 4.1a). In contrast, this condition was not experienced by any participant in the B group. In group B, the first participant in each subgroup entered a predefined “used” state. After these participants submitted their changes, the current state was saved as the starting state for the next group member. The same procedure was carried out in group A from the second day. The process then continued iteratively until the end of the study. The initial “used” state was adopted from the changes made by the first participant in the pilot study carried out beforehand. As you can see in

figure 4.1b a vase was thrown on the carpet, a water glass was separated from the group, neatly arranged books were tipped over, etc.

Tasks The participants received a daily task, which was divided into an observation phase and an interaction phase. The observation phase was designed to encourage participants to think about the room and its current state. On the first day, each participant had to explore the shared office for two minutes without touching anything. The duration of the remaining days was not specified, as the participants were asked change awareness questions formulated at a higher level [19], which took different amounts of times to complete. The set of questions answered orally included:

1. Where have changes been made?
2. Who has made the changes?
3. What changes were made?
4. How were things changed?
5. When did the changes take place?
6. Why were the changes made?

However, these questions were not asked primarily for evaluation purposes, but to get the participants to actively occupy with the changes made by the previous participants.
After that, a constant three-minute period began, during which the participants were given time to change things in such a way that others can notice their presence even though they have left the room by then.

4.1.2 Approach

So far, the fundamental components of the study, i.e. the software, hardware and methods used, have been discussed. These are put into context below by describing the approach of the study.
The basic idea for the concept of this study came from a previous study, in which participants were first sent to an unused state of a shared virtual living room and then to a used state of the same virtual space and vice versa, to analyze the effect of traces of use on social presence and social awareness [13]. This resulted in the idea of an asynchronous shared virtual environment and for this the duration of the experiment should be extended. In other words, the participants should repeatedly enter the asynchronously shared virtual space within a certain time and interact with its components in order to be able to develop their own traces of use so that the next user can perceive them.
The first step in realizing this concept was to think about the place where the experiment should be put into practice. The decision that the participants should be able to move freely in the virtual space without using controllers for locomotion would lead to restrictions in the search for study participants in the case of an in-the-wild study. Due to this condition, on the one hand all participants would need the same minimum of free living space and on the other hand the study would require participants who are familiar with the use of head mounted systems in order to be able to carry out the experiment alone from home without any problems. Finally, to ensure more control over the experiment led to the decision to conduct a laboratory study. However, in addition to covering aspects of non-laboratory setups, diary entries were also included.
In the second step, the plan for a two-week study period was drawn up. In order to let the participants experience the virtual space as often as possible in such a short time, the attendance was scheduled for every other day, excluding the weekend. Thus, the shared office should be entered a total of five times. A time period of at least 24 hours has been set for any exceptions that may

	Week 1					Week 2				
	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Option 1	*G1A, G2B*		*G1A, G2B*		*G1A, G2B*		*G1A, G2B*		*G1A, G2B*	
Option 2		*G3A, G4B*		*G3A, G4B*		*G3A, G4B*		*G3A, G4B*		*G3A, G4B*

Figure 4.2: Study schedule

occur, which must have elapsed between the previous and the next session. As shown in Figure 4.2, two participation options were designed, each containing a subgroup of the control group and one of the experimental group.
Participants were recruited in advance. For this, a time template was made available to the participants via google documents so that they could choose their time slots within the applicable conditions. Since the document was write-protected to prevent external manipulation, the selected time slots were communicated to the study supervisor, who entered them in the document. In this way, other prospective students could keep track of which slots were still free. After 17 partici-

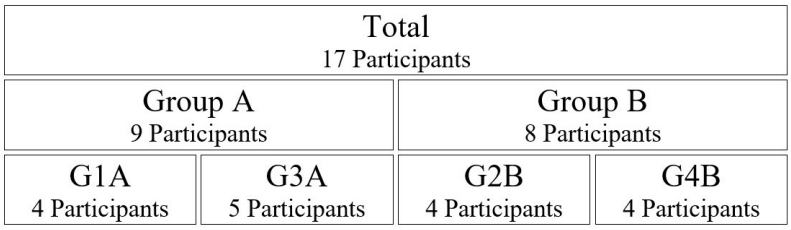


Figure 4.3: Group formation

pants were recruited, the groups were formed one day before the study (see Figure 4.3). For this purpose, the total number of participants in each option was divided into two groups of roughly equal groups. and then assigned to either the control group or the experimental group. they were then assigned to either the control group (Group A) or the experimental group (Group B). This resulted in two groups, each with two subgroups. After the experiment had started, one participant canceled on the first day and on the second day he didn't show up so he got excluded from the study. The participant was assigned to group G2B and due to the strict study plan, the groups could not be balanced afterwards. Therefore, group G2B continued with only 3 participants.
On the first day, an introduction, was followed by a short questionnaire on personal information. After that, each participant had to complete an exercise to become familiar with the VR system (see Figure 4.4). The provided virtual tutorial environment contained objects with various properties that were also represented in the shared office. Using a small game in which stacked cubes could be knocked over, interaction types such as throwing should be practiced. One-handed and two-handed grasping of objects and nudging should also be tested.
After that, the main study began, in which the VR tasks were completed first and then a questionnaire was filled out. Before the participants entered the shared office, the study administrator read out the task to the participants. The steps of the main study were repeated for the remaining days. From the second session onwards, the participants received a link to the prepared questionnaires for the diary entries and their personal identification number (ID) via email on the following day of each session. In the case of the exception described above, this information was sent on the same evening of the last session.

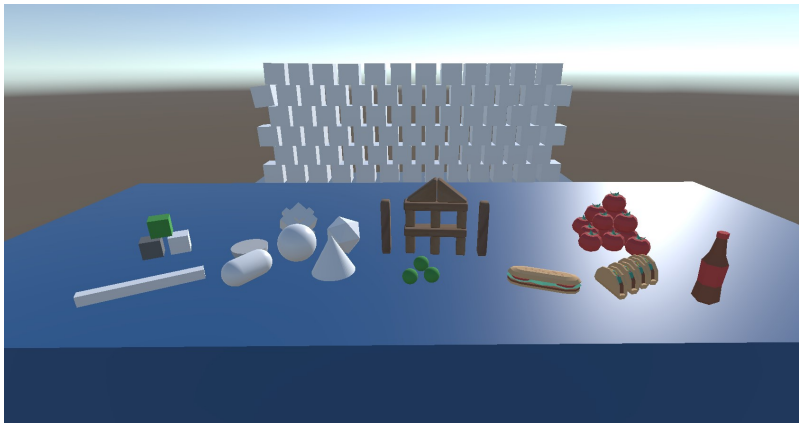


Figure 4.4: Tutorial to explore different types of interactions

4.2 Data Collection

Considering data protection and its purpose to protect the privacy rights of individuals, it becomes clear that the data collected must be anonymized in order to be protected for both ethical and legal reasons [34].Among other things, this aspect clarifies that the type of data collection plays an important role in research. Therefore, this chapter describes the methods of collecting data and how they were processed.
A laboratory study with 16 participants was conducted for this bachelor thesis. Each subject was assigned an identification number ranging from P01 to P17.
The groups to which the participants were assigned were named as G1A, G2B, G3A and G4B. The G stands for the abbreviation of the word group and the number represents the starting order of the groups, followed by a letter A or B. A is to be equated with the meaning of the control group and B with the experimental group. The final group constellations were as follows:

- G1A: P08, P14, P15, P17
- G2B: P01, P02, P04
- G3A: P05, P06, P09, P12, P16
- G4B: P03, P07, P10, P11

All questionnaires and diary entries used in this study were made accessible via a version of SoSci Survey licensed by the Media Informatics Faculty of the LMU [33]. The link to the diary entries and the required identification number were emailed to the participants in the morning. On the same day it was checked in the evening whether the diary entries had been completed by everyone. If this was not the case, a friendly reminder was sent to the subjects concerned.
Change awareness questions were asked orally while using the application and recorded with a sound recording device. The recordings were transcribed afterwards.
In addition to qualitative data collection, quantitative data was recorded via Unity. This covers logs of interaction counts and view times as well as screen recordings of each session. The logs were automatically saved in a text file. Collected logs, screen recordings and audio recordings were separated for each participant at the end of each day and saved in a new file with the associated ID.

4.3 Data Analysis

So far, only the aspects before and during data collection have been explained. Thus, the programs and methods for evaluating the data are described below.

The questionnaire included both quantitative and qualitative measurements in order to identify and interpret differences between individual days, participants and groups at the same time. Data analysis was mainly done using Excel. However, all significance tests were calculated using JASP. Questions about general presence, social presence and place attachment were assessed against standardized norms of these questionnaires.
The general presence was evaluated by counting the number of high answers related to the six questions, with the values 6 and 7 being set as high answers. A participant was considered "present" if at least one question was answered with a high answer. In the case of at least 4 high answers, the sense of presence was classified as high presence. In addition, box-plots of the responses for the individual days of the total number of participants and each of the A and B groups were created.
Possible answers for the social presence questions represented numerical values from -3 to 3. For each question, the values were added, and if the result was positive, it was stated that the participant felt social presence. Whereas a negative number implied no social presence was sensed. In order to be able to compare the results, mean values were calculated for the individual days of the main and subgroups, as well as for the total number of participants.
The latter method was also used to evaluate the place attachment. However, the focus of the evaluation was placed more on the place identity than on the place dependency. In order to be able to evaluate the responses to social perception, the five-point Likert scale from "Strongly Disagree" to "Strongly Agree" first had to be converted into numbers from 1 to 5. 1 is equivalent to "Strongly Disagree" and 5 to "Strongly Agree". As before with the general presence, a box-plot with an inclusive median was created.
Furthermore, all questions about social presence, place attachment and social awareness were checked for significance, since these aspects represent the basis for the evaluation of the dependent variables. After examining whether the difference in the data was normally distributed or not via assumption check in JASP, a table was used to decide whether parametric tests or non-parametric tests should be used [35]. The tests in question were Independent T-Test or Mann-Whitney-U Test for A and B group comparison, Paired T-Test or Wilcoxon-Signed-Rank-Test for comparing two days and ANOVA or Kruskal-Wallis-Test for comparing all subgroups. In the evaluation, 0.05 was used as the α-level for all significance tests applied.
For the Intimate Space questions, the relative proportion of "Yes" and "No" answers of all participants per day and of each group was calculated. Questions about one's own perception of time in the shared office were compared to the time actually spent there and checked for correlations. Finally, open questions were categorized at a high level of abstraction. As already mentioned in the subsection Methods 4.1.1, the Change Awareness questions were mainly used to get the participants to think more about the virtual environment provided. For this reason, the questions were not analyzed.
In order to be able to analyze the log data, 3 further steps had to be carried out beforehand. In the first step, all objects that were placed in the drawers were marked in the log file. After that, the states of the drawers were checked so that all data records that were in a completely closed drawer could be deleted. In the last step, the remaining data was compared with the videos and checked for correctness under the following conditions:

1. In case of all drawers were closed:
    - None of the items inside are visible
    - All drawers can be seen
2. In case of at least one drawer was open:
    - The upper open drawer can always be seen together with its contents
    - Items that are either in the drawers below or in closed drawers will not be seen

- All closed drawers that are above the bottom open drawer can be seen
- All closed drawers below the top open drawer can only be seen when the user is not in the immediate vicinity of the entire Drawer.

A drawer was considered closed, when it was either pulled out less than half, or it was completely closed. Whereas a drawer was considered open, once it has been pulled out at least halfway. The remaining data sets were imported into Excel, filtered and totaled by viewing time and number of interactions. The number of times an object was viewed was counted in Excel based on the individual viewing times. These data were calculated not only for the individual participants, but also for main and subgroups and the total number of participants. In addition, the results of the individual days were also added together.

5 Results

This chapter lists the results of the experiment that was carried out. As a first step, general participant data are given. The results for the dependent variables social presence, social perception, and the relationship between users and the virtual environment are as follows. In addition, the effect of traces of use on social behavior is shown at the end.

The study was conducted with a total of 16 participants, seven of whom would self-identify as female (43.75%), seven as male (43.75%) one as diverse (6.25%) and one subject preferred not to say (6.25%).Participants ranged in age from 22 to 32 years with an average of 25.44 and a standard deviation of 2.87.
When evaluating questions about experiencing 3D worlds and VR headsets, participant P07 was not considered because his answers were inconsistent. 40% of 15 participants stated that they had often experienced 3D worlds, such as 3D movies or computer games, 46.67% between two to ten times and 6.67% only once. The remaining 6.67%, on the other hand, have never experienced 3D worlds. When asked “How often have you already experienced virtual reality headsets?” 20% answered often as well as once, 46.67% two to ten times and 13.33% not at all.
Figures 8.1 and 8.2 attached in the appendix illustrate the end states of the individual days of each group. If the conditions of the respective subgroups are compared with each other, the daily chaos of G4B is striking. As a member of this subgroup, P03 has expressed in several open questions that uneasiness was felt including the diary entries. In general, the participant’s responses were rather negative which was also noticeable in the general presence. The difference in the answers from the first and last day were between three and four points per question. As this is an isolated case, P03 is considered an exception in the following general presence analysis and excluded from the calculation. On the first day, 14 out of 15 participants felt present in the shared office, seven of whom felt a high level of presence. In comparison, on the last day, all of the participants considered felt present. In this case, ten people had a high level of presence. When the responses of the A and B groups are considered individually, it becomes clear that the increase in the high sense of presence was due to group A. This can be deduced from the fact that the entire group felt present on both days, but the high sense of presence increased from five to eight participants. Meanwhile, in B, the high presence count remains at two, instead the sense of presence generally increases from five out of six members to a maximum of six people.

5.1 Social Presence

One of the aspects examined in this work was the extent to which traces of use influence the perception of social presence and social awareness. In this section, the analysis results of the social presence are presented in the first step, followed by findings of the social awareness questionnaire.

A positive total score on all social presence questions means that social presence was felt, while a negative score negates the sense of social presence [18]. On the first day, four out of 16 participants felt social presence. Of these, three were assigned to group B and one to group A. The remaining eight subjects from A and four from B did not feel any social presence. The total of subjects sensing a social presence increased to 13 on the third day, eight from A and five from B. Thus, three cases felt no social presence. However, the number of sensed social presences decreased by one at the end of the experiment. It can be stated that this is due to P09, considering the individual participants. The corresponding explanation could be found in the last diary entry of P09 which stated “I have totally different feelings compared with last week. I suspected others are artificial this week. Last week, I believed real humans entered the room. Because I assumed others wouldn’t try to clean the room and tried to prove my thought is correct. So every time, I entered the room, I would mass it up and put some particular items in some unreasonable places and check if they resumed back to original places the next time.”.

The social presence datasets analyzed below were first tested for normality using the Shapiro-Wilk test to determine methods for calculating significance accordingly. Social presence was tested for

M1: Social Presence	-	M2: Social Presence	Test	Statics	z	df	p
Day1	-	Day2	P. T-Test	-3.912		15	<.001
Day2	-	Day3	P. T-Test	-0.680		15	0.253
Day3	-	Day4	P. T-Test	2.353		15	0.984
Day4	-	Day5	Wilcoxon	15.500	-0.829		0.219
Day1	-	Day5	P. T-Test	-3.816		15	<.001

Note. For all tests, the alternative hypothesis specifies that Measure 1 (M1) is less than Measure 2 (M2).

Table 5.1: Significance test for social presence (total of all participants)

significance by first comparing two consecutive days and then the first and the last day. This procedure was used for the total number of participants and also for the A and B groups. With $\alpha = 0.05$ using the Paired Samples T-Test, there was generally a significant difference between

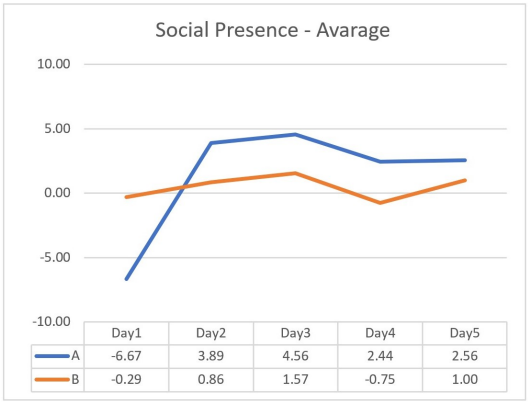


Figure 5.1: Development of the average social presence perception of group A and B

the first two days (t = -3.912, p = <.001) and the first and last day (t = -3.816, p = <.001) (see Table 5.1). In other words the social presence on the first day was significantly smaller than on the second as well as the last day. The same result could be found when comparing the same days in group A. Also in this case, day one was significantly smaller than the second (t = -5.803 and p = <.001) and the last day (t = -5.458 and p = <.001). In contrast, there were no significant differences in group B. This behavior can also be seen in Figure 5.1. While the mean values of group B were in a somewhat constant range, the increase in group A's mean from the first to the second day (+10.56) as well as to the fifth day (+9.23) was extreme in comparison.

Day 1	U	p
1. I perceive that another person was in the room before me.	4.000	0.001
2. I feel that another person could enter the room and become aware of my presence.	34.000	0.628
3. The thought that the previous person is not a real person crossed my mind often.	13.500	0.027
4. The previous person appears to be sentient, conscious, and alive to me.	15.000	0.041
5. I perceive the previous person as being only a computerized image, not as a real person.	24.500	0.241

Note. For all tests, the alternative hypothesis specifies that *group A is less than group B* .
Note. Mann-Whitney U test.

Table 5.2: Significance test for questionnaire components of social presence, comparing A and B (Day 1)

Furthermore, both groups were compared with each other regarding the individual questions per day. Since none of the data sets were normally distributed, the Mann-Whitney U test was applied. Table 5.2 shows that statements one (U = 4, p = 0.001), three (U = 13.5 , p = 0.027) and four (U = 15, p = 0.041) had a significant difference. The values of the statements in group A were therefore significantly smaller than those in group B. When comparing the remaining days, there was another significant difference. Namely, on the second day, A was significantly greater than B concerning the statement "I feel that another person could enter the room and become aware of my presence.". The corresponding values U = 47 and p = 0.039 were calculated with the Mann-Whitney U test.

The study participants were asked four questions about the observed side dependency of social awareness, which had to be answered on a five-point Likert scale. As these questions were not drawn from a standardized questionnaire, they were assessed individually. As before, the datasets were tested for normality using the Shapiro-Wilk assumption test in order to subsequently calculate the significance using the appropriate methods. For the first question "Knowing that I am not

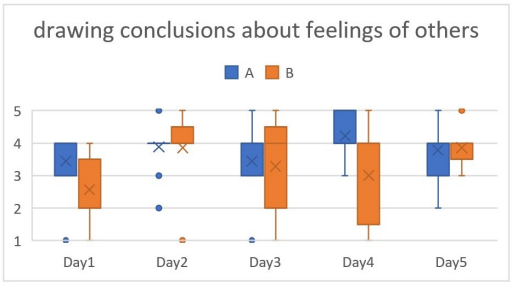
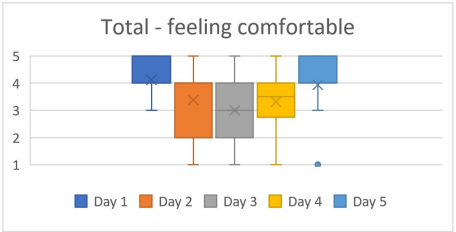
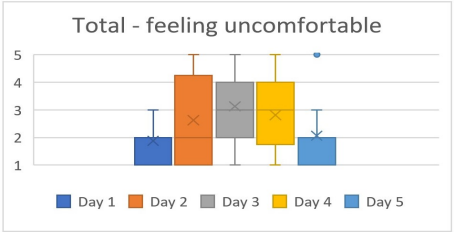


Figure 5.2: "In the room I can draw conclusions about how other users felt in the room."

the only user of the room changes the way I look at the room." both the median and the mode were three for all participants and increased to four by the last day. According to the Wilcoxon test, there was no significant difference on any of the days for this question.
The next social awareness statement to be evaluated was: "In the room I can draw conclusions about how other users felt in the room."
Due to the normal distribution of data from two consecutive days, the Paired Samples T-Test was used to calculate the significance. In general, there was a significant difference between the first two days (t = -2.030, p = 0.030). The first day was smaller than the second. The same significant



(a) "I feel comfortable in the room."



(b) "I feel uncomfortable in the room."

Figure 5.3: Well-being of all participants within the virtual space

difference could only be found in group B, with the values t = -2.274 and p = 0.032. In addition, day one was also significantly smaller than day five, considering the total number of participants

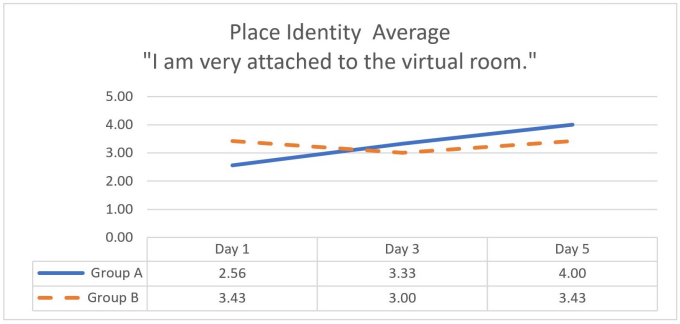
(W = 5, p = 0.038) as well as for B (W = 0 , p = 0.049), calculated with the Wilcoxon-Signed-Rank-Test. These differences can also be seen in figure 5.2, which illustrates a box-plots diagram of both groups in relation to the individual days. Group A's response range shows little change compared to B's.
The last two questions dealt with the well-being of the participants within the virtual space. the two statements that were analyzed were "I feel comfortable in the room." and "I feel uncomfortable in the room.". According to the box-plots, the answers of both statements were proportional to each other (see Figure 5.3). As a result, an abnormality in the distribution of responses between the first and last two days could be determined for both statements. These abnormalities were also confirmed with the significance test using the Wilcoxon-Signed-Rank-Test test. For the first statement, day one was significantly bigger than day two (W = 26.5, p = 0.019) and day four was significantly smaller than day five (W = 3, p = 0.037). The opposite was the case for the second statement: day one was significantly smaller than day two (W = 0, p = 0.010) and day four was significantly bigger than day five (W = 33.5, p = 0.017). There were no other significant differences, such as the direct comparison of A and B with regard to the individual days.
After the last two statements on the Likert scale, there was an open question in which the participants were asked to explain why they felt the way they indicated on the scale. The answers of the test subjects who felt comfortable varied in general. Despite this, five participants shared the same statement that the virtual environment or its objects were realistic. For example, P08 wrote "It seems very real. It's more memorable than the real life". Answers related to realism were also given in the question regarding negative and positive discoveries in the room. In addition to realism, four participants also gave the characteristics of the room, such as "cozy" and "small", as a reason. The room characteristics was also cited as a reason in the following days. Another reason for positive well-being was changes made by others. For example, one of these statements was from P05 "I consciously search for changes in the room that I did not make. I can then draw conclusions on what others may have found interesting (indicated through changes).". In addition, the subjects felt comfortable because they became more familiar with the shared office over time. On the last day, it was noticeable that the clean state of the virtual space was mentioned five times. Of the four participants who reported negative well-being on the second day, three of them cited destroyed items as the reason. The fourth person (P16) stated that it "looked as if someone robbed the place or was at least looking for something very specific". The reason that it was messy was given a total of eight from day two to day five.

5.2 User-Virtual Space Relationships

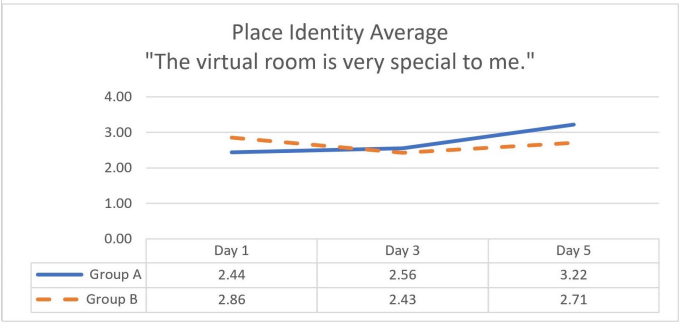
This chapter examines the results of a Place Attachment questionnaire in the form of a six-item scale. By including analytical values for some open-ended questions, partial aspects of diary entries, and the sense of time spent in the shared office, it will be possible to discuss the impact of traces of use on user-virtual space relationships later.

The abbreviated place attachment scale is divided into two subcategories, place identity (PI) and place dependency (PD). The first three points measure the place identity and the last three the place dependency.[22] Since the focus of this work is on place identity, a overview of place dependency results are provided first, followed by a detailed analysis of PI dataset.
The first item of the PD asserted that "The virtual room is the best place for what I like to do.". The average response of all participants to the item remained constant at 2.38 across all three days measured. The average response to the next place dependency item, "No other place can compare to the virtual room.", decreased from 2 to 1.94 over the entire time period. In contrast, the average of the last item " I would not substitute any other area for the activities I do at this virtual room." increased. On the first day the average was 1.94, on the third day it rose to 2.38 and finally on the last day it was 2.5. In addition, the significance for the latter item, which was calculated using the

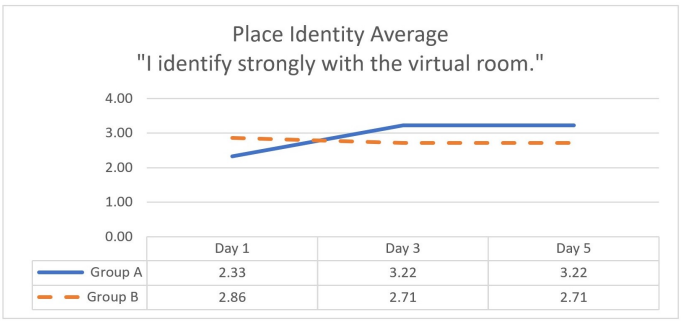
Wilcoxon-Signed-Rank-Test, showed that day one was significantly less than day five (W = 6, p = 0.026). The individual groups and subgroups were not tested for significance.
In contrast to the PD, an increase in the average response of all participants can be observed for each item of the PI. The average of the statement “I am very attached to the virtual room” rose from



(a) First item of Place Identity



(b) Second item of Place Identity



(c) Third item of Place Identity

Figure 5.4: A/B evolution of APAS items

initially 2.94 to 3.75 at the end of the experiment. Both averages of the two other items increased from 2.63 (“The virtual room is very special to me.”) and 2.56 (“I identify strongly with the virtual room.”) respectively on the last day to 3. However, the significance test revealed a difference only for the first item. The value calculated with the Wilcoxon test corresponded to W = 5 with p = 0.021 and thus day one was significantly smaller than day two.
In addition, groups A and B were individually checked for significance of all place identity items. For all items, A’s tests showed that the first day was significantly smaller than the last. Both the first (W = 0, p = 0.027) and the last item (W = 0, p = 0.047) were tested with the Wilcoxon-Signed-Rank-Test. Due to the normal distribution of the data collected in the second item, the significance was evaluated using the Paired Samples T-Test. This resulted in t = -1.941 with p = 0.044. In B, on the other hand, there were no significant differences. In addition, the A and B groups were tested for significance with the Independent T-Test and Mann-Whitney-U Test, as well as the four

subgroups with each other using ANOVA. There were no significant differences in any of the cases. These results are reflected in the development of the mean responses of the individual main groups (see Figure 5.4). While the average for B is more balanced, compared to A, an increase can be noticed for A within five days.

From the second session onwards, the diary entries asked about the connection between the individual user and the virtual room. Responses in two subgroups remained unchanged throughout the period. Across G1A, consistently 75% of members felt connected to the shared office, while 25% felt no connection. The 25% was represented by P15, explaining the lack of connection as follows “its still just a place i visited in my head and the people dont seem real”. In G2B, 100% of members felt a connection daily. In contrast, G3A did not reach its maximum of 100% until the fourth day. On the second day, 40% felt connected, 40% felt not connected, and the remaining 20% felt neutral about the room. The following day, the proportion of those who felt connected to the room rose to 60%, the proportion of non-connected cases remained at 40%. On the second day there was exactly one case (25%) in G4B who felt connected to the room, the remaining three (75%) did not feel connected. The remaining days divided the opinions in half. Half of them felt a connection to the shared office, the other half didn’t. The reason was the daily chaotic state of the room (see Figure 8.2), as already mentioned at the beginning of this chapter. On the third day P11 wrote “It’s kind of odd, as it definitely feels like a shared room... But it’s like a room where I would have played as a kid to wreck the room, not as something I would like to spend more time on nowadays as it’s such a mess. So I feel quite disconnected from both the room and the other user as I’d like to distance myself from them”. When it comes to the total number of participants, the proportion of subjects who felt connected to the shared environment increased from 56.25% to 81.25% at the end of the experiment. The proportion of 6.25%, which was neutral to the room, dissolved on day three. And the six cases (37%) who felt disconnected from the room, ended up halving to three (18.75%). In addition, statements were made that it bothered them to see the room become “destroyed” or “messy” because they felt connected to the room. For example, P05 wrote “I felt very connected with the room. Nearly possessive. Which is why I felt less positive towards the other users as they had invaded my space.”.

In terms of the data tracked by the program, figure 8.3 shows the ten objects viewed the longest, most frequently viewed and most frequently interacted with out of 34 objects placed in the shared office, during the entire study period. Objects whose characteristic could be changed (see Table 8.1) as a trace are marked, thus non-reversible traces of use [13]. In the virtual room, the post-its were also realized as such, since they could be crumpled up but not restored to their normal state. For this reason, they are also marked on the list. It is noticeable that every object that can change the characteristics, except for the protective mat, is always included in the list in group A as well as in B and therefore also in general. From the second day, these changes were noted at least once as a negative point to the question “What have you noticed particularly positively or negatively?”.

The question of how long the participant thinks they have been in the virtual space was estimated 18 times as longer than the actual length of stay, which corresponds to 22.5%. 26.25% of the sessions were correctly estimated and 51.25% as less. The participants’ feeling of discomfort, which was reported in the social awareness question, had nothing to do with their estimation of the time. Instead, participants with self-defined tasks (e.g. tidying up), which were mentioned in the open-ended question “What have you done in the room?”, estimated their residence time correctly or less for the most part. The exceptions were P17 on days four and five with a higher time estimate and P03 on day five as well.

What was also striking was the common responses of the participants to various questions. Some mentioned towards the end of the experiment that they were sad about not being able to enter the room anymore. Some participants indicated that they became curious about how the

space was changing or who the other people were. At least four participants stated that they would have liked to have clean up more, from the second day onwards. And some of the participants tried to personalize the space or add personality to the shared office.

5.3 Social Behavior

In addition to the dependent variables of this bachelor thesis, further data was collected through the diary entries and the open-ended questions of the questionnaires. The information obtained can be summarized as social behavior. For this purpose, the remaining results of the diary entries are analyzed first. This is followed by some aspects of the general questions, including the intimate space evaluation.

In addition to the question of how connected the test subjects felt to the virtual space, the diary entries also asked about the connection to their fellow users. In general, the proportion of participants who felt connected to other users increased from 25% to 68.75% over the course of the study. Meanwhile, the proportion of those who did not feel connected decreased from 62.5% to 25% and those who felt neutral from 12.5% to 6.25%. When looking at the individual subgroups, it is noticeable that the connection to other users was dependent on the condition of the room. For example, P05 from group G3A wrote “I feel more connected to the virtual room but less connected to other virtual room users (it feels like they do not respect the shared virtual space).”. P11 justified his disconnection from others by not pursuing the same goal as the room was always messy.
The second part of the diary entries dealt with how the users felt about sharing the space with others. The results of the subgroups were different. G1A was the only group that reached a full proportion of members who liked to share the space, from the second half of the study period. In contrast, no one from either group G2B or G3A said they liked sharing the virtual room. P01 member of G2B wrote that “Sharing could be cool, if the others would be more responsible and could do cool things instead of demolishing the room”. As for G4B, initially there was no one who liked sharing the space. That changed in the last two days so that 50% did like it and the other half didn’t. One of the participants from this group who didn’t like to share the room was P11 “I wouldn’t want to share the virtual room as all I did was clean during the two weeks I was in the virtual room. I never got to ’enjoy’ the room.”. In addition, it was generally mentioned that sharing the room with people you knew would be more comfortable, as well as considering the room as property.

The general questions of the questionnaire also asked if participants felt like their intimate space was invaded by others. Looking at the participants individually, P07’s responses stand out. The participant belonged to the group G4B and was the reason why the room was always devastated. Comparing all of his responses and behavior, the participant himself was having fun and felt comfortable as long as it was his own mess. P07 found that his intimate space was invaded as soon as parts of the mess were not his own. In general, it can be observed that the feeling that others had invaded the participants’ intimate space rose and fell with the state of the space. This means that if the participants found a room that is neat comparable to the previous day, they no longer felt invaded in their intimate space and vice versa.
Responses to other open-ended questions revealed that in the last two days, three participants started hiding objects or throwing them on the closet so that other subjects couldn’t reach them. The reason was that they wanted to avoid further chaos. Other participants, on the other hand, tried to prepare something for the other group members, such as events or other surprises.
On the second day, two subjects who were assigned to the control group, mentioned as a positive aspect to the question whether they had noticed something particularly negative or positive, that they had discovered new things because of other users. Another positive point was mentioned by

P17, it was about the common interests that they could derive from the traces of use by others. Conversely, disorder and broken objects were the main negative points, mentioned. Another point of criticism from two participants was the changes made by others.

6 Discussion

In connection with the dependent variables examined in this bachelor thesis, the results revealed a significant increase in social presence and the user-virtual space relationship. A significant increase in the side dependency social awareness was only partially observed. Thus, the initially defined hypothesis “Evolving traces of use enhance social awareness, user-virtual place relationship and social presence in permanently shared virtual environments.” was confirmed for social awareness as well as the virtual place relationship and partly social awareness. In addition, the results indicate social behavior that is similar to that in the real world. These points are discussed in more detail below.

6.1 Effect of Traces of Use on Social Presence

The results show that the social presence was increased by the traces of use. Comparing the experimental group and the control group shows that the increase in social presence depends on the presence and absence of the traces and not on the duration in which they are experienced. This can be deduced from the fact that from the second day of the study, both groups experienced the virtual space under the same conditions and from then on there were no significant differences. However, a significant difference was seen when comparing the two groups on day one. Traces are unavoidable in the real world.
In terms of social awareness, the ability to draw conclusions how participants felt was significantly increased over the study period. In contrast to social presence, however, the reason was not the presence or absence of the traces, but the extent to which and the type of traces left behind. A high level of traces left behind meant that participants were more likely to draw inferences about feelings and actions. For example, P12 wrote “looked like someone had fun in it!”. However, conclusions were also drawn about negative emotional states of others.
The well-being of the participants was determined by the condition of the room. Depending on how messy the room was left by previous occupants, individual subjects felt comfortable or not.

6.2 Effect of Traces of Use on User-Virtual Space Relationships

The user place relationship was evaluated using a standardized questionnaire and open-ended questions. Based on the data measured with the abbreviated place attachment scale, a significance of the emotional or symbolic attachment to the shared office [22] could be determined. Traces of use indicate previous interactions in the real environment [25]. Therefore, a higher level of reality can be reached by using traces in a virtual environment as virtual reality tries to be an exact replica of the real world [14]. In addition, the immersion is positively related to the virtual reality place attachment [27]. From this it can be deduced that the connection to the virtual environment is strengthened by the traces. This statement is supported by the measured significance for the place identity of the control group and the non-significance of the experimental group. However, according to the results, it is not only the presence and absence of the traces that is decisive for the strengthened connection, but also how others have dealt with the traces related to the asynchronous context. An example of this is the statement of P11 “It was like the room exploded, I thought last 2 times were bad with the amount of mess but this was... well... lets say special. I would also question myself if I would like to share a (non) virtual room with these people given what they do to the virtual room. So I would say that I feel quite disconnected from both the virtual room and the other users.”.

6.3 Effect of Traces of Use on Social Behavior

Summarizing the results, it can be said that the human-to-human relationship in virtual environments can be positively or negatively influenced by traces of use, which also affects social beha-

vior. As a positive aspect, which strengthens the interpersonal relationship, it is possible to draw conclusions about the similarities between the users based on the traces, without having been in direct contact. The similarities are about preferences like keeping the room clean, habits like leaving the TV on, or common goals that were implicitly assumed.
It was also possible for participants to discover further interaction possibilities with the help of the traces left by other group members. This led to a connection between users.
In the real world, we submit to social norms to organize our coexistence. There are concrete ideas about how to behave towards strangers, how to greet friends or how we deal with outsiders.[11]
The study observed that the lack of these social norms in an asynchronously shared virtual environment can lead to negative interpersonal relationships. That was also detected by some participants, which stated in the diary entries that they would be more willing to share the room with other users if there was a certain amount of rules. The consistency of our real identity and the real world ensures that misconduct and the resulting consequences affect us directly and that we have to deal with them [11]. Since virtual space does not have such a consistency, there are no negative consequences in VR for actions that you would have to take responsibility for in real life. For example, during the whole experiment, P07 knocked over all the things in the room and deliberately broke them. In addition, the subject indicated that he wanted other objects to throw or break, such as furniture that could be demolished. In response to such behavior, other participants began to hide objects. In return, participants who have adapted to the behavior of others over time were able to avoid the negative effect of the traces and build a bond with the other users. However, this behavior of action and reaction points to the aspect of social awareness. Since social perception refers to the awareness of social relationships within a group [10] and is also a context for one's own behavior that can be derived from it [21].

6.4 Limitations

Despite the intention in this study to measure the effect of traces of use over a longer period of time, the duration was restricted to 2 weeks due to the limited time. In addition, the study was carried out with a small number of 16 participants.
Another limitation was the technical means. The head tracking system implemented in the study did not allow precise gaze tracking. However, there is no eye tracker integrated in the VIVE Pro, which means that the head tracking system had to be used.

7 Conclusion and Outlook

This work investigates the effect of traces of use in a mid-term asynchronously shared VE. For this purpose, a two-week laboratory study was carried out, which was supported by subsequent diary entries. Dependent variables were measured using qualitative and quantitative data collection.
The results show that both the social presence is significantly increased by traces of use by others, as is the emotional bond in the user-space relationship. Even if no complete significance of social awareness could be determined, the calculated significance of the claim “In the room I can draw conclusions about how other users felt in the room.”, as well as the results of social behavior, indicate that the ability to be aware of others is positively influenced.
Since this study deals exclusively with the effects in asynchronously shared VEs, the next step would be to analyze how the effect of the traces is in synchronously shared environment. Two different cases can be considered, one is working collaboratively and the other is working for oneself. That way, general conclusions could be drawn about the effects of traces of use in virtual environments.

8 Appendix

	Object setting	Object charachterisitc	Object state	Object context
Drawer	X			
Breakable Cube		X		X
GlassBoards			X	
Notebooks				X
RippedPapers		X		X
BallDecors				X
WaterGlasses		X		X
OfficeChair				X
Chair				X
Rulers				X
WineGlasses		X		X
Tv	X			
FloorProtectionMat		X		
CoffeeCup				X
MirrorPlate				X
Pillows			X	X
Pencils				X
TableVase				X
Whiteboard	X			
Basket	X			X
VaseGlas		X		X
Clipboard				X
WhiteboardMarker				X
WhiteboardEraser				X
Posters			X	
Cup				X
PostIts			X	X
Eraser				X
RoofLight	X			

Table 8.1: Classification of the objects used in the shared office in categorical levels of indicators of use

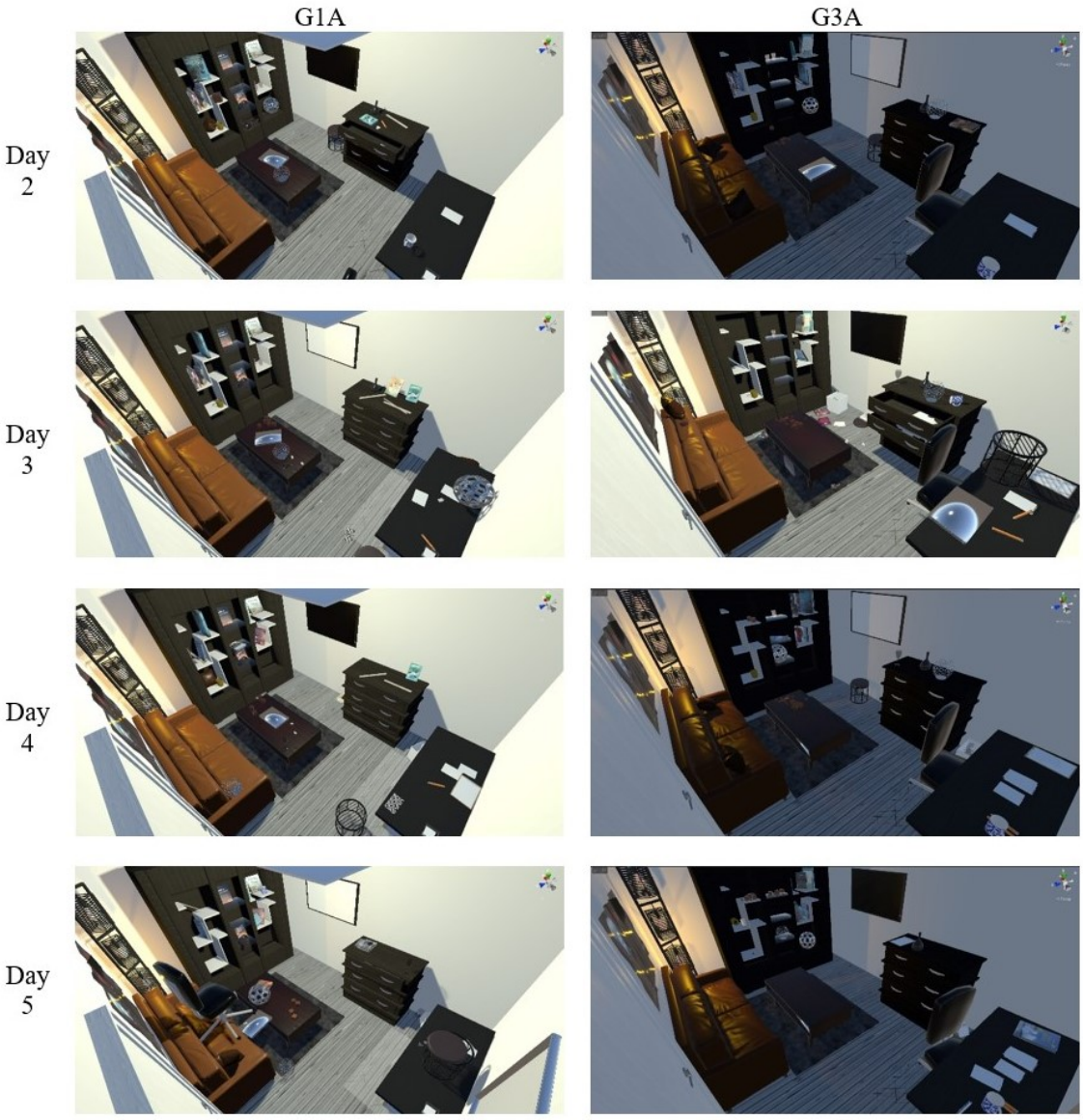


Figure 8.1: The shared office final states of the individual days: group A

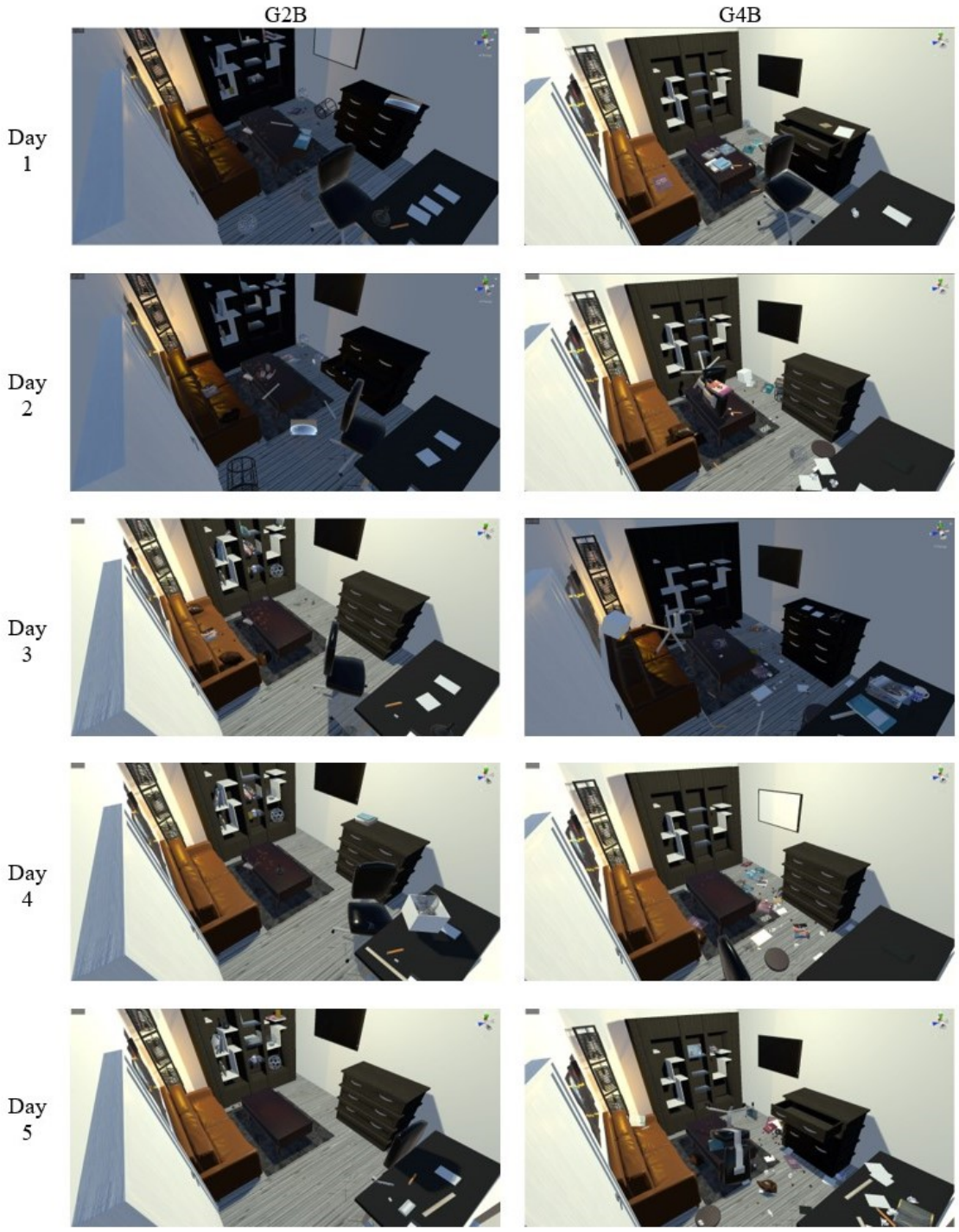


Figure 8.2: The shared office final states of the individual days: group B

	View Time			View Count			Interaction Count		
	Total	**Group A**	**Group B**	**Total**	**Group A**	**Group B**	**Total**	**Group A**	**Group B**
1	Books	Books	Books	Books	Books	Books	Books	Books	Books
2	BreakCube	Drawer	BreakCube	Drawer	Drawer	BreakCube	BreakCube	BreakCube	BreakCube
3	Drawer	BreakCube	Drawer	BreakCube	BreakCube	Drawer	Drawer	Drawer	OfficeChair
4	GlassBoards	GlassBoards	ShatteredGlasses	ShatteredGlasses	GlassBoards	ShatteredGlasses	OfficeChair	ShatteredGlasses	RippedPapers
5	ShatteredGlasses	ShatteredGlasses	GlassBoards	GlassBoards	ShatteredGlasses	GlassBoards	ShatteredGlasses	OfficeChair	Drawer
6	RippedPapers	Notebooks	RippedPapers	OfficeChair	Notebooks	RippedPapers	RippedPapers	UsedPostIts	ShatteredGlasses
7	Notebooks	RippedPapers	OfficeChair	RippedPapers	OfficeChair	OfficeChair	UsedPostIts	Notebooks	GlassBoards
8	OfficeChair	BallDecors	UsedPostIts	Notebooks	BallDecors	UsedPostIts	GlassBoards	Chair	UsedPostIts
9	WaterGlasses	WaterGlasses	Notebooks	BallDecors	RippedPapers	Notebooks	Chair	RippedPapers	Rulers
10	Chair	OfficeChair	Rulers	UsedPostIts	MirrorPlate	Rulers	Notebooks	GlassBoards	Pencils

Figure 8.3: Top ten list of Unity tracked data: 1.View time, 2.View count and 3.Interaction count

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