Perceived Affordances: Why do people wear virtual cooking pots on their heads?

Kirsten Albrecht[1], Kristopher J. Blom[2], Steffi Beckhaus[2]

[1]im.ve, [2]University of Hamburg, Germany
{kirsten-albrecht@gmx.de, blom@informatik.uni-hamburg.de, steffi.beckhaus@uni-hamburg.de}

Abstract

It is crucial to understand users' perceptions of virtual environments, if they are to be adopted as a platform for other research. Existing research has focused primarily on the user's reaction to the environment as a whole and to physical display qualities, but rarely on differences of user perceptions between real and virtual content. In this paper, we present work that indicates that simple virtual and real objects are perceived very similarly, but with a few critical differences. A method for directly comparing user perception of virtual and real environments is developed, based on perceived affordances of individual objects. The results of a study using this method indicate that critical differences exist in certain aspects of object perception across virtual and real spaces. Notably, users perceive more destructive actions with virtual objects than real and are more playful with the virtual objects. Additionally, the study indicates that perceptual differences exist across certain demographics, namely gender and gaming experience. These results indicate that performing perceptual based research with virtual environments is viable, but needs careful consideration.

1. Introduction

Immersive Virtual Reality provides a technical solution to the presentation of a computer generated environment, such that the users experience the environment as an alternative reality. This acceptance of the virtual environment (VE) as a temporary reality is an important factor in the expanding adoption of Virtual Reality as a technology. That the users find themselves present in the VE, makes VEs interesting to use as a research platform. In addition to training environments, VE usage for studies in the sciences, e.g. Psychology, Sociology, and Neuroscience, has been expanding recently. Implicit to these usages is the assumption that results achieved in a virtual environment can be transferred to real environments. User presence is a major component supporting this assumption. However, there is as yet little formal evidence that supports the assumption that the user's perceptions of virtual environments and their components are the same as those in real environments.

In contrast to the idea of presence, it is commonly understood within the Virtual Reality (VR) community that users understand that the VE is not the "real" environment. This is manifest in the user's willingness to do things they could not or would not do in real life, for instance flying through an environment or walking over an edge. Presence and this knowledge of it not being real seem to be contradictory. How could the user accept the VE as a momentary reality and, at the same time, understand that the VE is not the "real" world? We believe the answer is that the user's expectations of the VE are not those of the real world. Because they do not expect the VE to behave as the real world, they can accept the VE as a momentary reality (a mirroring of the concept of "the suspension of disbelief" that is often used to help explain presence). The important question is: what truly are their expectations of that environment? This question has to be answered to understand the effect of VEs and also to assess under which conditions VEs can be used for learning and as environments that test perceptual based concepts.

This paper presents work that addresses the question of whether differences exist between user expectations of virtual and real environments and what those differences might be. Since little formal work has explored these questions, an exploratory study is developed. In particular, the study investigates the differences in perceived interaction possibilities of simple objects. These perceptions are those that Norman refers to as perceived affordances [11]. If differences in the ways people perceive virtual and real exist, the perceived affordances of even simple objects should also indicate these differences. The presence phenomenon leads us to believe that perceived affordances should be minimal between the two environments; however, the internal knowledge that the world is virtual indicates that not all perceptions will be the same. We conjecture that the perceived affordances of simple objects are largely the same in real and virtual settings, but that differences will exist. The study presented provides initial work on verifying the general similarity and identifying those important differences.

The following section presents the perceived affordances concept. Section 3 describes the most relevant research to our work. The methods developed for our investigation and the design of the study are presented in Section 4. The results of our study are presented in Section 5. The results and potential impacts of the work are discussed in Section 6.

2. Perceived Affordances

The term affordance is familiar in the areas of Cognitive Science, Human-Computer Interaction (HCI), and beyond. However, there are many differences in its meaning and understanding among different groups. All affordance concepts seek to explain how people manage to interact with the millions of objects encountered, both familiar and unfamiliar. We use a definition of affordances that stems from Donald Norman, who has suggested renaming his interpretation as "Perceived Affordances." Perceived affordances are the actions that the user perceives to be possible with/to an object [10]. For interaction, this entails what interactions are expected as possible and in what ways they can be performed.

Affordance concepts have largely been philosophical exercises and little formal work has tested their existence. One direction investigating affordances has used methods of gripping objects to verify their existence. Humans have five basic grip types; this provides an interesting way to test whether objects afford certain interactions, i.e. ways to hold them [4, 5, 22]. A single work has been performed using virtual objects viewed on desktop displays [19].

Affordances have also been proposed by Lepecq et al. as an objective method for testing presence [8]. They used a door opening smaller than the user's shoulder width to test whether the users made physical adjustments – a rotation of the shoulders – necessary to pass through the virtual door. They theorized that if the users were present, they would make the adjustment. This implies that the present people would perceive the affordance of the opening for walking through it and those who were not present would not.

3. Comparing Virtual and Real

At the heart of this work is the question of whether virtual and real environments are equivalent in the perception of the user. In this section, we review relevant works that have looked at this issue on some level. The comparison of virtual presented worlds to the real world in terms of sensory input to the users is well researched. In contrast, research that indicates the user's perceptions of the environment presented is very limited. Perceptual based research generally falls into one of two categories: those that look at specific deficiencies of perception of VEs and those that look at the validity of VEs as a platform.

Using VEs as a platform for experimentation has been expanding across various sciences. Numerous advantages are to be found through their usage: the control of the environment, reproducibility, and cost. However, caveats that can influence the results of studies have also been noted. Loomis et al. provide an overview of the most covered topics [9]. Well known issues include: navigation difficulties [3, 21] and spatial awareness [16], estimation of distances and sizes [14, 3], lack of stimulated senses [17], and effects of the fidelity of the models and graphics [18]. These issues show that differences in virtual and real do exist and that certain aspects have to be considered.

The question of the validity of VEs as a platform has also been of interest to various educational related areas. These areas are primarily concerned with learning transfer, i.e. the question of whether skills learned in a VE can be/are applied to the real world. Rose and Foreman provide a survey of this area [15]. Early studies imply that learning transfer of procedures might not occur. However, later works have called into question their methods, and newer studies have indicated that a transfer occurs [20, 7]. Peruch et al. [13] discuss two extensive studies that found that learning transfer from virtual to real settings does take place. The application of processes learned in VEs in real settings implies that the perceived affordances of virtual objects and real objects are at least similar enough to enable the perception of actions learned with virtual objects on real objects.

Only a single study known to the authors looks directly at differences in perceived affordances across real and virtual environments. de Kort et al. compare the user's reaction to real and virtual environments and how they internally process those environments [3]. Although their goal is to compare the differences of performance in evaluation of and in cognitive mapping of the environments, they considered a wide spectrum of factors. They examined approximation of heights (doors and height of rooms), self reported factors (evaluation, ambience, arousal, privacy, and security) and perceived affordances. Their study supports existing results in regards to height underestimation and poorer cognitive mapping in the VE. In response to questions on their perceptions of the environment in regards to what activities where afforded by the locations, the users more frequently associated the real world with social meetings, while the virtual was more often tied to formal activities.

4. Methods

A method to explore into the question of whether the user's perceptions of simple virtual and real objects are the same and identify differences in those perceptions is developed in this section. An experimental methodology based on the action perceptions is proposed. Through our method an impression of the perceived affordances of objects is captured. The experimental method is explained in the next subsection. Thereafter, a study is proposed, based on the method developed. The environments and objects used in the study are presented in Sections 4.2 and 4.3. Section 4.4 details information about the study participants. Section 4.5 explains the experimental procedure.

4.1 Experimental Method

For the purposes of investigating the differences between real and virtual perceptions we propose using affordances. Using affordances we attempt to capture the perceived interaction possibilities of the room or objects. Differences in the affordances in real and virtual environments would provide insight into general perceptual differences in virtual and real. The initial question to answer is how to test for perceived affordances. Optimally, we would like to use the method with which the affordance concept itself has been verified; unfortunately, as seen in Section 2, the affordance concepts has yet to be tested in a generally applicable way. By confining ourselves to Norman's perceived affordances, we gain the advantage of needing only to identify action potentials that people are aware of; therefore, a method that allows recording the response of people to an environment is required. To that end, we propose use of the "think aloud" user study method.

The "think aloud" method is well known in the HCI community. There, participants verbally express what they are doing/thinking [2]. In HCI contexts, the user is asked to voice what they expect to happen when they interact with an interface, e.g. I expect to see the help screen when I press the button with a question mark. The think aloud method is usually used in the context of a specific task. This limitation is necessary to constrain the discussion to points of interest. In order to avoid getting very general results, as those in de Kort et al, we also need a more constrained context. What is required is a smaller context for the participants to focus on, without reducing the openness required. We propose constraining the user's attention to single object at a time. Additionally priming should be given in the form of suggesting to the participants that they speak of what actions could be done with and/or to the object in question.

4.1.1 Study Design Having settled on a method, a study design had to be considered. Viewing the same object more than once is unlikely to provide good results; therefore, a direct comparison of "performance" by the participants in both environments cannot be done. We propose instead a repeated measures design for the study. A comparison of perceived affordances of different objects can be done, but the validity of this is questionable, even for very similar objects. However, different categories of perceived affordances should be possible to compare. For instance, vocalizations about an objects color could be a categorized together. We propose a study where participants view a fairly large set of objects, so that a broad comparison of object affordances can be performed. In order to collect general enough information, we propose having each participant view objects in each environment. To reduce any affects of order, the order of objects and the order of viewing of environments are handled as dependent values. The grouping of objects used is explained in Section 4.3.

4.1.2 Expectations The study we are proposing is largely exploratory in nature, as we are not completely sure what results to expect. We hypothesize that the overall impression of an object will be the same for the virtual and real manifestations, but that certain specific perceived affordances will occur more frequently in the virtual environment. However, we are uncertain exactly what those differences will entail. Two areas that we expect to see differences are in terms of discussion of material composition of the objects and 'playfulness' with the objects.

Figure 1: The physical (real) and virtual environments used in the study.

It is to be expected that the visual properties of virtual objects will be discussed more frequently, as VEs typically only stimulate the visual sense. In particular, we expect that this will be more prominent for unfamiliar objects. This should manifest itself as increased occurrences of discussion of color and material properties in the virtual setting. In our physical world the material makeup of an object is mostly easy to observe. In contrast, in a VE it is often hard to guess the correct material, because of the incomplete information provided (e.g. lacking weight and tactile sense).

Another difference we expect to find is in terms of the user's "playfulness." This is based on the premise that users realize that the virtual is not "real." We suspect that this frees them to think more creatively. This should manifest itself in terms of coming up with more actions that are possible and actions that go against the rationality of the real world. Even more, we suspect that prior experience with virtual environments, either gaming or VR experience, may increase the likelihood of such perceived affordances. In particular, we suspect players of games genres such as adventure games will be more creative with perceived affordances of the objects. This may additionally manifest itself in the form of longer times per object in the virtual settings, as a more creative approach is taken leading to more perceived affordances.

4.1.3 Data Collection The final point for this method that needs consideration is the data to be collected. The data collected in the study falls into three categories: demographic data, timing information, and a protocol of the expressed perceived affordances. The demographic information collected from the users was largely standard for such a study and is detailed in Section 4.4.

Timing information was recorded during the testing. The total time of exposure to each object was measured. Additionally, the time until the participant identified the object was recorded. The identification was either by correctly naming it or by indicating knowledge of it through mention of explicit usages; for instance, well known objects such as the hammer might never be vocally "named" though obviously recognized though the actions mentioned, like "hammering a nail."

Naturally, the collection of the content of the think aloud method was of critical importance. This consisted of recording whatever the participants mentioned. In particular, verbs and actions were of interest, as they are the best indicators of perceived affordances. This information was recorded exclusively by the lead investigator. A short-hand notation was used and was transferred to an electronic version on the same day. Additionally, almost all participants agreed to video recording, so that the notes could be verified.

4.2 Environments

The study required two test environments, one real and one virtual. To ensure that the results were as comparable as possible, the virtual environment was created as a replica of the physical (real) room used. To ensure that the affordances of the room interfered as little as possible, a simplistic room with little decoration and simple furniture was chosen. The room is shown in Figure 1.

The room has a window with plain curtains, which were always closed for the study. In front of the curtains were two tables, placed so they created a single, large space. The objects were presented on the tables, such that they were at a convenient height (73cm high). Near the entrance to the room was a series of wardrobes. They were behind the participant when facing the tables and were used as a holding area for the test objects, such that the user could not see them.

4.2.1 Virtual Environment The virtual room was a recreation of the physical room. The virtual components were produced to be as close to the real counterpart as possible. High resolution models were created, using high resolution textures taken from the original environment.

The virtual room was presented in our "L-Shape" immersive VR display system. The L-Shape is a projected display system with co-joined surfaces: a floor and a single wall. The display is stereoscopic, using circular polarization. The floor projection is 3m x 2.25m and the wall projection is 3m x 2m. The user is tracked using an ART ARTrack2 optical tracking system with 8 cameras. The VR system can be seen in the left hand side of Figure 2.

4.2.2 Interaction with the Virtual Environment Several decisions of importance had to be made with respect to the interactions possible in the virtual environment. These include whether the user should be able to travel freely through the room or not, whether interaction with the objects should be allowed, and when interaction is allowed, which techniques and devices should be used.

The size of the immersive display did not permit the display of the entire room at once. However, the participants were free to move about the room, to the extent of the physical display via head tracking. A virtual travel method was not used, as movement beyond the range physically possible in the display was not necessary for viewing the objects. This had the additional benefit that it removed potential distractions due to the difficulties of virtual travel.

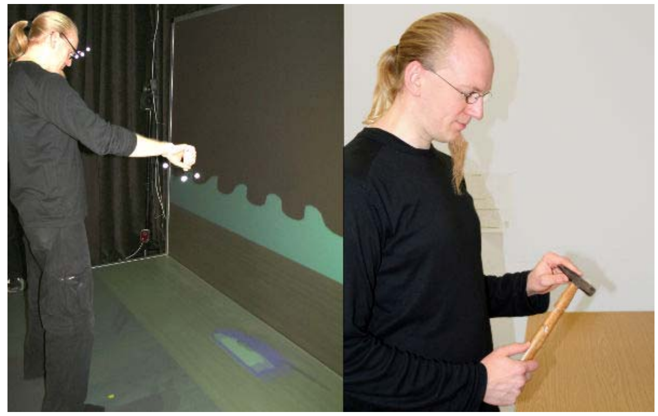

Figure 2: Interaction with virtual and physical objects.

Because of the inequality of interactions between the real and physical environments, the ideal for the study would be to disallow all interaction with the objects. However, this has two critical detractors. First, hindering interaction with the object in the real setting would be very prohibitive. The users would likely be frustrated by this and constant reminders of not being allowed could hinder the freedom of thought required for the think aloud protocol. Second, in the virtual, it was difficult to investigate the objects without interaction. This was partly due to the narrow field of view of the display. For instance, to view the back side of an object would not be possible. Therefore, we decided that interaction with the objects was necessary.

A pointer based metaphor of interaction was selected. The implemented method allows the participant to move and rotate objects. Only the object being investigated could be interacted with. The "wand" device used was built from a "Wii Remote" from the Nintendo Wii™ and a tree target from the tracking system attached to the front of the device (seen in Figure 2). A virtual ray extended out of the Wii-Remote's tip approximately 20cm to assist the selection. When an object was selected for interaction, the participant could interact with the object as long the button was held. The interaction methods used mapped the change in physical movement of the wand device during interaction to a corresponding virtual movement. To eliminate occlusion issues, the virtual ray was turned off for the duration of the interaction.

4.2.3 Software The virtual environment was developed in-house. The VE was developed using VR Juggler [1] and OpenSceneGraph (OSG) [12] for the graphics display. The interactions were implemented using the ACTIF framework [7]. The modelling was done using the Softimage's XSI modelling program by an experienced modeller and imported into the scene graph using the Collada format.

“Familiar” Objects		**“Unfamiliar” Objects**	
Apple	Walnut	Designer Hole-Punch	Roulade Fastener
			
Book	Glasses	Etching Needle	Head Massager
			
Iron	Hammer	Planting Device	Nail Holder
			
Pot	Teapot	Magnesium Firestarter	Silicon Backing Brush
			
Telephone	Flashlight	Large Bobbin	Orange Peeler
			

Table 1: Photos of the real objects used in the study.

4.3 Objects

The selection of the test objects was critical to the studies effectiveness. A number of factors needed to be considered in this decision. The selection was based on the following criteria:

- objects should be “everyday” objects,
- objects should be as diverse as possible,
- objects should be a balance of well known and (potentially) unfamiliar,
- objects should be a size appropriate for tabletop display and approximately handheld size,
- objects should be from various different fields, with different applications, and
- pairs of similar objects should be found where possible.

Objects that are used daily have specific actions for which they are used and everybody should know these actions. These objects are included to provide insight into whether our everyday experiences carry over into the virtual space. Unfamiliar objects provide a way to get some insight into the differences in ways people approach the discovery process and the differences in the ways affordances are perceived in the two environments. Since the same object could not be used in both settings, objects that are similar in terms of expected perceived affordances were sought out. These paired objects were split between the virtual and real. Examples of this are the apple and the walnut and the pot and the teapot. These pairs permitted a limited ability to directly compare the differences in perceived affordances of a single participant.

To effectively be able to say something about perceived affordances of simple objects, a relatively large number of test objects were required. This had to be balanced with the time required for the tests. We settled on twenty (20) objects. In this way each participant would see ten (10) objects in each environment. We also balanced the number of familiar/unfamiliar objects. Table 1 shows the objects selected for the study with images of the real objects used.

Figure 3: Participant Demographics

The left hand side of the table shows the objects that we expected everyone in Germany to recognize readily.

The objects were modelled in the same manner as the virtual room. The most complex model was the teapot, which contained of nearly 20,000 polygons before triangulation; the lowest complexity was the etching needle, with only 192 polygons before triangulation. 1024x1024 pixels textures were used for all objects. With this level of detail, it was possible to display a lot of small details, while still allowing their display in real-time. As with the room, no advanced computer graphics techniques were used.

4.4 Participants

33 participants were invited to take part in our study. Participants were found per fliers distributed on campus and via personal contact. The participants were not paid and gave consent prior to taking part in the study. One participant was unable to complete the full test due to difficulty in VR – an inability to converge the images. The data for that participant is not considered further.

Demographic data about age, sex, favored hand, experience with 3D computer games and with virtual environments was collected. Additionally, participants were questioned about known difficulties with stereoscopic sight and color blindness. None of the users reported known visual difficulties. The users were between 17 and 56 years of age (mean: 28.81, std dev: 8.6). The distribution of the users on other factors can be seen in Figure 3.

4.5 Experimental Procedure

The experiment followed the standard method for a repeated measures study design. All participants were exposed to both the real and virtual conditions. The order of the exposures was controlled to account for any possible learning effects. Prior to the first exposure, the participants were explained the procedure and what would be expected of them. They also filled out the demographic questionnaire.

Each participant viewed all twenty objects, ten in each space. Two different object sets were created, leading to four (4) conditions (two sets of ten objects that were either in the virtual or real setting). Therefore, four (4) participants were exposed to the same objects in the same order and locations.

The think aloud method was explained to the participant, before being exposed to the test environment. A test run was made on first exposure. A special object that was not used in the study was presented to the user. They were told this was a practice object to become familiar with the think aloud protocol. On first exposure to the virtual environment, an additional training phase was incorporated with another unused object. The participant was clarified how the interaction methods available worked and could practice them. It was explicitly clarified that the interactions methods available were strongly controlled in this study, but that they should not limit their ideas to these methods, but rather say anything they could think of.

After the training object(s), the test objects were presented to the participants one at a time. In both environments, the objects were brought into the participants field of view covered in a box. In the physical environment, the test object was brought hidden in a cardboard box and on a board from the back of the room by the assisting investigator. After placing the box and board on the table, the box was removed and the time started for the test. In the virtual environment, a box came down from the ceiling, placing the object on the table.

The participants were encouraged to first interact with the object after they felt they no longer had ideas about the object. The exposure to each object was limited to three (3) minutes. On either saying they could not think of anything else or after a period of silence, the object was changed before the three minutes ended. The maximal exposure time was thereby limited to 30 minutes per environment, for a total of 60 minutes per participant.

5. Results

The results of the study lend support to our hypothesis that virtual and real objects have mostly the same perceived affordances, but with significant differences in some regards and shed some light into how the perceptions differ. A statistical analysis of the data generated in the study is presented here. Some of the additional, observational evidence from the study provides support for our conclusions is also presented. Further observations from the study are presented in the discussion of Section 6.

The following subsection explains the way in which the raw data was prepared for analysis. Section 5.2 introduces the statistical methods used. The results are then presented in three parts: the general, overall results in Section 5.3, the differences in the perceived affordances categories and per demographic group in Section 5.4, and the inter-group interactions in the data in Section 5.5.

5.1 Preparation of the Data

In order to obtain data that could be evaluated statistically, the raw data generated (described in Section 4.1) had to be encoded. This was done by classifying the vocal expressions of the participants into different categories of perceived affordances. In the first phase, the classes of perceived affordances had to be identified. Then, the vocalizations were encoded into those categories. The prepared data quantified the number of occurrences of perceived affordances of each category. A count of the total number of vocalizations was also generated.

Categories of perceived affordances were found in three ways: those identified in the design phase, those that became apparent during testing, and those found by inspecting the data. Seven categories of perceived affordances were identified:

Color: mention of the color of the object

Material: mention of the material properties of the object, e.g. wood, or rough

Interaction with environment: expression of desire to/performance of interactions with other objects in the environment

Object destruction: expression of desire to destroy the test object itself

Destructive actions: expression or performance of destructive actions with the object, i.e. the object is used to destroy something else

Non-social conformity: expression or performance of actions that fall outside the social norms of the society, e.g. wearing the pot as a hat

Personal association: expression of personal affect of the object, e.g. “I would throw it away”, “I like it”

5.2 Statistical Methods

The encoded data was tested across the different factors using appropriate statistical methods. Except for the data on the length of time per object, all the data was in the form of the number of occurrences of a specific category of perceived affordances. Three distinct sets of data required analysis, requiring three different statistical methods.

To test for differences in the perceived affordances between the virtual and real objects we needed a method that compared occurrence data from the same group. For this a Wilcoxon Matched-Pairs Signed-Ranks (WMP) test was performed. We also wanted to test for effect across user groups, i.e. experience with virtual reality and computer games. For this, a Kruskal-Wallis one-way analysis of variance was used. The Kruskal-Wallis analysis tests whether the data points all come from the same group and can be used in cases where a normal distribution cannot be expected. It is useful when testing data that comes from more than two groups. In the case where the data points came from two unrelated groups, e.g. gender, a Wilcoxon Rank Sum test (WRS) was used. A critical (p) value of 0.05 was used for all tests.

5.3 Overall Results

Observing the testing from a broad point of view, the most obvious thing from the observer’s point of view was that there is little difference between how the participants reacted to virtual and real. In most cases, they quickly classified and named objects. The interactions that could be expected with each object where generally, quickly mentioned. What was surprising on this level was how well the participants recognized objects in the virtual environment. While the objects were recognized less often in the virtual, the difference was less than expected and not significant. In total, 54% of the objects were unrecognized in the VE (174/320) and 63% in real environment (202/320).

The other overall data to be analyzed was the time taken per object. We had conjectured that the time spent per object would be larger for the virtual objects than for the real. However, no statistical difference was found and no evidence of a trend exists. Likewise, the difference in the time taken to recognize an object was not significant.

5.4 Perceived Affordances per Category

Differences in the perceived affordances were obvious to the study observers when considering certain ideas. Inspection of the different categories of perceived affordances showed significant differences exist between the virtual and real. This section presents an analysis based on the specific categories of perceived affordances developed in Section 5.1.

Table 2 lists the main results of the statistical analysis of perceived affordances occurrences per categories and per group. The marked concept and groupings had significant differences (at the $p < 0.05$ level or less) between the virtual object and real objects.

First, we look at the results for all participants together, as listed in the first column. After that we will look at the results for subgroups. The first column shows that significant differences were found in all categories but materials for all participants. Excepting ‘personal association,’ more occurrences of the categories were found in the virtual than real environment. In every one of those cases, the expressions occurred roughly twice as often in the virtual as in the real.

The statistical results show that the participants reacted more playfully and in ways that they would not in the real world. These differences were fully experienced by the observers and were quite pervasive. Various instances highlight these differences. One instance is the teapot. In the VE, the main investigator was offered a tea three (3) times by the participants. Each case occurred after the participant had explicitly commented that nothing came out of the teapot when tipped (usually concluding that it was empty). No such cases existed in the real environment. Other activities that were performed include a number of childhood activities. In the VE, the participants often “placed” the pot on their heads (or their head into the floating virtual pot). In the real environment, this activity was mentioned, but never done. Similarly, the head massager was only “used” in the VR environment. Also of note was that a number participants tried to put the glasses on, even though the earpieces were halfway closed and immovable in the virtual environment.

	all	female	Male	gamers	non-gamers	VR experience	no VR experience	recognized	un-recognized
color	x		x	x	x		x	x	x
material									
interaction	x		x	x			x	x	
object destruction	x		x	x		x		x	
destructive actions	x	x	x	x	x		x	x	x
non-social conform	x		x		x		x	x	
personal association	x	x						x	

Table 2: Perceived affordance differences Virtual and Real per concept and participant group. Tests with a significant difference on the WMP test with a critical value of (p<0.05) are indicated with an x.

Another perceived affordance difference that quickly became apparent was the propensity to destroy objects or use them for destructive activities. The most common example was using the hammer; however, this was not the only case. Globally viewed, all objects were perceived by different participants in these ways. One participant was particularly remarkable in this regard. The participant showed very destructive tendencies, particularly in the virtual environment; for every object, object destroying actions were mentioned (28 times in total). In contrast, this participant only expressed affordances that would destroy the object 12 times for 7 objects in the real environment. When questioned afterwards, the participant responded that the objects were only virtual, so he could break everything, without any lasting negative effects. This question was posed in such cases and roughly the same answer was given by each participant. This pervasive destructive nature in the virtual environment needs to be further explored. In particular it needs to be considered with respect to using VEs for studies exploring participants' behavior.

The remaining columns of Table 2 investigate sub-groupings of the data for the same effects. Striking in the table is that many sub-groupings did not have significant results for various categories. On closer inspection we found that many of these holes seem to rather indicate a failure to achieve significance than indicating a true difference. In particular, the VR experience, female, and 'none to little gaming experience' groups had small sample sizes that may have caused the test failure. In general, they showed similar patterns, leading us to believe in most cases they would hold true with a large enough sample size. However, there are still a few interesting points revealed in the table.

One demographic stands out for having no significant effect. For men, there was no significant difference ($p > 0.1$) in the expressions of 'personal association' to the object between virtual and real. However, for women there was a significance difference ($0.01 < p < 0.02$, with a sample size of 9). This seems to indicate that women were less likely to accept the object as real enough to develop personal feelings about the object in the virtual setting, where men accepted both virtual and real equally. Interestingly, this same lack of significance is found in the gamer category (16 of the 19 were men). That the VR experience category achieves significance in the category of object destruction is also interesting, as the "no VR experience" group did not.

A look at how unrecognized and recognized objects were handled across the virtual and real conditions is also worthwhile. For a number of categories no significant difference ($p > 0.1$) was found between the real and virtual in the unknown grouping. Closer investigation of the data shows that the data seems to follow the same trends of the others, but fails to achieve significance. However, in contrast to the female and non-gamer groupings, there are enough data points for the "unrecognized object" grouping that the lacking significance must be at least considered further.

Looking at how unrecognized and recognized objects were perceived within the virtual and real conditions is also of interest. Table 3 shows those areas that were significant and whether known or unknown occurred more often. With real objects the participants spoke significantly more in terms of color and 'personal associations' for those objects they recognized than those they did not. No other differences were found. The virtual objects showed more interaction between known and unknown. In the cases of color, 'non-social conformity,' and 'personal association' to the object, the participant was more apt to thinking in terms of those categories. The participants associated material properties with the unknown objects in the virtual environment more often than with known objects.

5.5 Inter-Group Interactions

We expected to find certain effects, particularly those related to playfulness, between demographic groups. Testing for interaction between groups was performed for each of the categories. In the real environment, significant interaction across gender were found in the material ($p = 0.01$) and destructive actions ($p = 0.04$) categories with the WRS test. No interactions were found in the VE.

The analysis of the individual gaming groups showed no significant interactions using the Kruskal-Wallis test. This is likely due to the small sample size for the individual groups.

	real	virtual
color	known » unknown	known » unknown
material		unknown « known
interaction		
object destruction		
destructive actions		
non social conform		known » unknown
personal assoc.	known » unknown	known » unknown

Table 3: A comparison of the perceived affordances of recognized and unrecognized objects (known/unknown). Noted statistics were significant ($p < 0.05$) on WMP.

However, grouping the gaming experience into two categories, "no or little experience" and "experienced," yields an interesting result. Significant interaction between the groups was found with the WRS test for the area of 'non-social conformity.' This was found regardless of environment (real $p = 0.03$, virtual $p = 0.04$) and was the only interaction. No other significant inter-group interactions were found.

6. Discussion

A number of observations from the study fell outside of the statistical realm are important to discuss as well as discussing the results presented. A few observations to the user experience are important, as they indicate the virtual environment functioned well. Other observations provide suggestions on how and what for other modalities should be incorporated in VEs and also have impacts on future research directions. In this section we discuss some of the more significant of these observations.

Presence wasn't explicitly examined in our study. We felt think aloud protocol would constantly make the participants aware of their situation and likely make presence testing invalid. However, we observed behaviors that indicate that the participants were highly present in the virtual environment. A great number of the participant tried to place the interaction device on the virtual table at the end of the session; only quick intervention reminded the participants that the table was not physically present. Often, we observed participants attempting to feel the objects. This occurred particularly often for the tips of the etching needle and the wires of the head massager.

The testing sessions were relatively long, approximately one hour with a break at approximately 30 minutes. The user was in the immersive VR setting for 20-30 minutes. With such a long immersive session, at least some instances of cyber-sickness would be expected. However, not a single participant complained of any symptoms, nor did they show signs of difficulties. We believe this may be attributable to the fact that we did not use any virtual travel methods. This lends itself well to prevailing expectations within the community. That the participants had very specific tasks that focused them on the environment may be another factor.

The virtual environment was solely visual; this was something participants quickly noted and commented. Particularly for unfamiliar objects, participants expressed wishes to have other modalities simulated. The haptic sense was desired, as it is important in determining the material properties of objects, e.g. the metal and stone of the firestarter. One of the more interesting observations was the number of participants who expressed a desire for sounds. Beyond the typical wish for sounds when they hit the table with the hammer (a number added these "sound effects" themselves), a few interesting desires were expressed. The most interesting wish was to be able to drop an object and hear how it sounds. This was surprisingly universal and was presumably to provide a clue as to the object's material composition. This indicates that, if gravity is simulated, the sound of the object hitting other objects/surfaces should be included and modelled correctly. This also shows why the inclusion of physics might be detrimental; the users expectations of the simulation fidelity are likely to increase greatly with each addition.

One of the largest impacts of this research is on the areas that are considering or already using VEs for research that bases on users' perceptions of the world. This encompasses many fields that are using VEs as a way to control the environment and experience. Our results indicate that perceived affordances of simple objects can be largely considered the same for real and virtual worlds, but with caveats that should not be ignored. In particular, the destructive tendencies and performance of actions that are outside of usual social norms need to be considered. The destructive tendencies results likely play some role in research on violence in games. Social research also needs to be careful to consider how users react even to simple objects, when using VEs a platform for testing.

When considering the work of Lepecq et al. described in the background section, new light might be shed on a phenomena they reported. They remarked that several participants in their study simply walked through the opening, without regard for the fact that the opening was narrower than their shoulders. This seems to fit nicely with the results we saw in regards to tendencies view the world as virtual and not to interpret it by real world rules. It seems such behavior should be expected from at least some of the users.

The inter-group effects found in gaming experience and gender are important to consider. Gaming experience seems to be a factor in our study, which would be in accord with various other VE studies. Unfortunately, the relatively small sample sizes made it difficult to find statistically significant results in our data. When grouping users by gamers and non-gamers, significant results did show up for gamers, but not for non-gamers. We are unsure whether this is an effect of sample size or really an indication of a difference. The data trends show the same tendencies. For 'personal association' there is a significant difference between the four levels of gaming experience (Kruskal-Wallis Test). The data shows that those who never played 3D games had the highest values, while ‘seldom gamers’ had the lowest rates. We also found that for the category of ‘non-social conformity’ there was a significant difference between the non-gamers and gamers in both the real and virtual.

Even more interesting are the gender differences we found. As evidenced by the Wilcoxon Ranked Sum test, gender differences in perceived affordances seem to be minimized in virtual environments. The ‘destructive action’ affordances are a good example of this. A significant gender difference (p=0.04, WRS) was found for the real environment, but no such difference was found for the virtual environment. 94% (15 out of 16) of the ‘destructive actions’ females expressed were in the VE. Similar results were found with the material affordances. These differences would seem to indicate that caution should be used with VEs as a platform for gender studies.

In addition to inter-group differences, the results of this study to some extent call into question the use of VEs as control environments for studies that investigate human nature. We do not believe that it invalidates usefulness of VEs, but rather that how they may be used needs consideration. The issues here need to be investigated more deeply. Currently, the biggest issue is the potential for misinterpreting results, based on the implicit assumption that the virtual and real are equal in aspects of perceived affordances.

We believe that the results are representative of the user’s perceptions of the environment; however, this study was a very simplified work for initial testing and had a relatively limited sample size. There are many avenues to take for future work. We expect that increasing the fidelity of the environment will also make the expectations of the user correspond more closely to the real world. In prestudy work, we had implemented collision detection. The expectations of the world did seem to be increased, but caused enough issues with consistence and user frustration that we removed it for our initial study. We expect that performing testing with a high fidelity collision detection implementation would show that expectations would converge somewhat. In particular, the playfulness factor will likely be reduced and the destructive tendencies may be reduced, though we suspect the differences such as the gender and gaming effects will remain. In contrast, we expect that more complex objects may introduce other expectations to the world. In particular we would like to investigate the perceptions of dynamic objects, as we suspect there will be interesting results in terms of “play” with those objects.

Another good starting point for further work is to more intensely investigate the differences found. One aspect is to more precisely define where these differences lie, so that users of the technology can make informed decisions on how to design their environments or experiences. Another aspect is to understand specific findings, like the gender difference in terms of personal relationship to objects and destructive actions. These differences are intriguing and vital for us to understand.

7. Conclusion

Any differences in the user’s perception of virtual and real environments are critical for the applicability of VEs as platforms in other areas. This paper has directly investigated whether differences exist. We developed a method to test for differences, by testing the perceived affordances of simple objects using the think aloud method. We presented a study based on this method that shows that the perceived affordances of simple objects are largely the same; however, some significant differences were found between the virtual and real when considering particular perceptual concepts. Users were more playful and destructive with virtual objects. Also, indications that differences related to gender and gaming experience exist were found that need further investigation. These results call into question the universal applicability of VEs for perceptual based research, while supporting the general case. The differences indicated in this work require further and more detailed investigation to be fully understood. Future work should to look at more complex objects and settings, as they may have other or greater effects.

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