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THE EFFECT OF PRIMING ON PHYSICS PERCEPTION IN SMALL-SCALE VIRTUAL ENVIRONMENTS

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ABSTRACT

For humans, it is difficult to understand how physics would work in an environment in which they are not the size they normally are, but their size has been altered. A good way to experience it is in a simulated virtual environment run by a computer, and with a virtual reality headset. What humans think physics and the environment should look and feel like often differs from what would happen in a similar situation.

This thesis focuses on whether priming the participants' experience in a virtual environment before altering their size affects their perception of physics, specifically, rigid body dynamics. The hypothesis is, that priming would make participants feel that real-life physics is how objects in virtual reality should act, instead of how small-scale phenomena are usually depicted in media. To test the hypothesis experimentally, a VR environment was developed. This environment contained many different perception clues to inform the participants they have been shrunk tenfold and that this environment corresponds to reality. In the experiment, the representation of rigid body dynamics played a huge part as it affects how participants perceive the environment when interacting with physically simulated objects and items. More specifically, the participants experienced two different physics representations; one in which objects behaved similarly to what would be realistic at that scale, and another one closer to what is usually shown in movies and television. The participants were surveyed, and their answers were analyzed, giving insights into their physics perception in the virtual environment.

The study found that priming the participant gave them a point of comparison to real life. They felt that it helped them choose the correct scenario when they were presented with scenarios with realistic physics and physics usually seen in movies and other media. Although they felt that the priming helped, the participants nevertheless considered the physics representation corresponding to movies and television to be the more realistic one. This was further confirmed by statistically comparing the results of this study to a similar, previous study in which no priming process was utilized.

Keywords: Virtual reality, virtual reality environment, user experience, thesis, gravity.

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TIIVISTELMÄ

Ihmisille on vaikeaa havainnoida fysikaalisia ilmiöitä, kuten kiinteiden kappaleiden liikeratoja, tavallisista poikkeavissa mittakaavoissa. Paras tapa kokea se on tietokoneen simuloimassa virtuaaliympäristössä virtuaalitodellisuuslasien luoman immersiivisen kokemuksen kautta. Se, mikä vastaa ympäristöön ja fysikaalisiin ilmiöihin liittyviä ennakko-odotuksia voi monin tavoin poiketa todellisuudesta. Esimerkiksi kymmenen kertaa pienemmässä mittakaavassa realistisesti kuvatut kappaleiden liikeradat näyttäytyvät ihmisille äkillisinä kiihtyvyyksinä ja lyhyinä lentoratoina, kuten aiemmassa tutkimuksessa on osoitettu. Sen sijaan, epärealistiset fysikaaliset mallit joissa liikeradat vastaavat normaalia mittakaavaa suhteessa käyttäjään itseensä vaikuttaisi näyttäytyvän realistisena simuloidusta mittakaavasta huolimatta.

Tässä opinnäytetyössä pyritään selvittämään, voiko virtuaalitodellisuusjärjestelmän käyttäjiä perehdyttää fysikaalisten ilmiöiden suhteen siten, että se muuttaisi heidän käsitystään simuloitujen fysikaalisten ilmöiden suhteen virtuaaliympäristössä. Työssä kuvataan tutkimus jossa koehenkilöille esitettiin perehdytysvaihe jossa havainnollistettiin erilaisten esineiden liikeratoja jonka jälkeen heidän tuli valita oikea fysiikkamalli realistisen ja väärän mallin välillä.

Tätä tarkoitusta varten kehitettiin virtuaalitodellisuusympäristö, jossa oli lukuisia erilaisia havaintovihjeitä, joiden tarkoitus oli havainnollistaa käyttäjälle fyysisesti simuloitujen kappaleiden liikeratoja. Koehenkilöt käsittelivät fyysisesti simuloituja esineitä kahdessa eri mittakaavassa realistisessa painovoimassa. Tämän jälkeen he käsittelivät simuloituja esineitä sekä realistisessa, että epärealistisessa painovoimassa, jonka jälkeen heidän tuli valita kumpi simulaatioista vastasi paremmin todellisuutta.

Tutkimuksessa havaittiin, että koehenkilöiden perehdytys näyttäytyi heille hyödyllisenä antaen vertailukohdan todellisuuteen. Vastausten mukaan he kokivat, että perehdytys auttoi heitä valitsemaan oikean fysiikkamallin. Tästä huolimatta epärealistinen fysiikkamalli näyttäytyi heille todellisempana merkittävästi useammin kuin realistisesti simuloitu malli. Tämä voitiin vahvistaa myös vertaamalla tilastollisesti tässä tutkimuksessa kerättyä aineistoa aiempaan vastaavaan tutkimukseen jossa perehdytysvaihetta ei ollut. Tästä voidaan päätellä, että koeasettelussa käytetty perehdytysmenetelmä ei pystynyt muuttamaan koehenkilöiden ennakkokäsityksiä fysikaalisten ilmöiden havainnoimisessa.

Keywords: Virtuaalitodellisuus, virtuaalinen ympäristö, käyttäjäkokemus, opinnäytetyö, painovoima.

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FOREWORD

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Aleksi Sakari Sierilä

LIST OF ABBREVIATIONS AND SYMBOLS

VR	Virtual reality
VE	Virtual environment
HMD	Head-mounted display
PI	Place illusion
PSI	Plausibility illusion
MCVE	Multi-scale collaborative virtual environment
UI	User interface

1. INTRODUCTION

1.1. Virtual Reality

Virtual reality or VR as it is often shortened to, is a simulated reality made with computers and usually viewed through a head-mounted display (HMD). A good definition is given by Steven LaValle, who is one of the founders of Oculus VR, in his book: *"Definition of VR: Inducing targeted behavior in an organism by using artificial sensory stimulation while the organism has little or no awareness of the interference"*. [1]

1.1.1. History

VR's history reaches further back than one might think as the first commercially available HMDs and the computers that could render the environment for them are about a decade old.

The First VR device as it could be called, came from Morton Heilig who in the 50's dreamed up a way to experience theatre plays in full immersion with all senses, which he build a prototype for in 1962 called 'Sensorama' and five short films that could be played on it [2]. Sensorama was a fully mechanical VR device and didn't use computers to render the environment.

How VR became what it is in the 1960s it became with small steps. With the development of computer-generated graphics technology, VR began to use it to generate the scenes, and in 1973 Ivan Sutherland developed a graphics scene generator, which could generate a primitive low-polygon low-fps VR scene. The first VR HMD with an LCD screen was developed in 1981 by NASA; it was called VIVED. With being the first to use LCD screens VIVED had also head tracking with technology called Polhemus non-contact tracking. [3]

Before HMDs became commonly used, other methods were being experimented with as well, to find viable alternatives to be used when creating virtual environments. One of them was called "Audio-Visual Experience Automatic Virtual Environment" or as they called it "CAVE". CAVE is a cubic area, where the VE is generated with screens surrounding the user, sometimes also combined with head-tracking devices. [4]

As previously mentioned first commercially available VR HDMs are only about a decade old and started with Oculus Rift. That statement is almost true and could be restated as the first "commercially viable" as the first device developed for gaming came from SEGA in 1991 but quickly flopped because of its bad graphics stemming from the lack of computing power of its time. The same fate awaited other devices of the time such as VictorMaxx's developed headset and Sony's Japan-exclusive headset in 2002. [5]

1.1.2. General

In VR, HMD produces stimuli that override the senses of the user. The user is given visual information through two small screens, one for each eye, while the HMD at the same time also provides the position and tilt of the head to the computer through head-tracking sensors; this is needed to adjust the view relayed to the screens when the user moves his head and thus changes what he sees [6]. HMDs often come with attached headphones to relay audio information about the environment, but sometimes additional headphones are needed. As HMD provides information to the senses, controllers, (or more recently, new generations of haptic gloves that have matured enough to become consumer hardware) are used to interact with the environment, usually by pressing several buttons, which are used to grab and manipulate items [7, 8]. Sometimes even a full motion capture body suit is used to give more touch sensory information, but these are largely still in development [9].

In VR, the simulated reality can try to portray reality as close to the real world or veer completely away from it. Even though the simulated reality can be created to match something that does not or even can not exist, some 'rules', as much as they can be called such, must be followed and those are how we as humans perceive the reality around us. How people perceive reality is through the use of different kinds of cues that can give the perception of how far, how big, how different objects around us or how they move [10]. More about the cues are explained in an upcoming section titled 'Perception of size' but the most important cues for this thesis are the cues that help us perceive the size of the objects compared to the user.

VR is mostly seen as being used for entertainment purposes in the form of video games, movies, and virtual social environments but is also used for educational and several other purposes [11], [12]. VR can be used to study psychology and neuroscience, for example, a lot of studies have been done to see how the body distinguishes between your real body and a virtual body. VR can be used to help rehabilitate spacial abilities after injury. In a VE a person can get a new view of data visualization as the data can be shown in an interactive, 3D manner and as humans are very sensitive to patterns, there is a difference between viewing data on screens and being able to immerse yourself into it via VR. Moreover, VR can be further used in education via the previously mentioned immersion; for example, human anatomy can be walked through in VR, and surgeons can be trained in simulations done inside a VE. Other than education and study, VR can also be used in sports and other physical training as visual experiences in VR can often be transferred to real life, and by simulating sports by the user moving their bodies, they also get the physical benefits of the sport. VR can also be used to study social behavior, for example, proxemics (study of how much space humans need for themselves), discrimination, authoritarianism, cultural heritage, and moral behavior. All of the examples mentioned in this paragraph and more detailed explanations for them can be found in an article called "Enhancing Our Lives with Immersive Virtual Reality" by Slater et al. where they have compiled a list of comprehensively different applications of VR other than the usual entertainment. [13]

1.1.3. Devices

VR is developed with computers using many different kinds of software, which are touched upon in the next subsection. Before the development of HMDs VEs was viewed through computer monitors, but VR, as we know it today, is viewed through HMD, as is briefly described in this chapter above. Interaction in a VE is done through controllers, traditionally one for each hand, with many different button presses or hand gestures. HMD and the controllers, most of the time, come as a package deal through their different developers

According to multiple sources, the most popular HMDs and their developers are the Valves "Valve index", Sony "Sony PlayStation VR", Oculus' "Oculus Quest 2", HTC's "HTC Vive Cosmos" and Samsung's "Samsung Odyssey+" [14, 15, 16, 17]. Each headset has its strengths, whether it be usability, graphical fidelity, controller quality, and total cost, which ranges from hundreds to way over a thousand euros.

1.1.4. Development

VR scenarios and environments are developed with a computer by using a multitude of different development software, alone or together, depending on the available features of the different software and their possible limitations. VEs are put together by using pre-made assets from other people or assets that the developer made themselves via 3D modeling software. The assets can be anything from tables to alien lifeforms. These assets are then made to interact or be interacted with by writing scripts for them. The language the scripts are written in depends on the developing software, for example, Unity mostly uses C#.

Unity is a popular game engine first developed for Apple-only games, but now supports many platforms from a traditional personal computer (PC), mobile, console, and VR. Many popular games have been developed with Unity, such as the hardcore platformer 'Cuphead', the popular survival and player-versus-player game 'Rust', and the eery, immersive, and scary 'Subnautica'.

Unity was chosen to be used in this thesis project mainly because of previous experience with it in previous courses and the researcher's bachelor's thesis. Unity is also simple to use and navigate with easy to understand user interface (UI). It has a plethora of information available on the internet from other users, which helps a lot in development. It has an easy-to-use version control, for example, if you have assets that only work with a specific version of Unity, you can easily choose which version of Unity to use with its desktop application. Unity also has its asset store where assets can be downloaded for money and for free. An important aspect that Unity has is that it has easy-to-use settings for fiddling with physics settings, for example, gravity can be changed with a simple numeral value, which is straightforward gravity's acceleration in meters per second squared (m/s^2). Also, Unity is completely free.

1.1.5. Problems in VR

For some people, it is possible to suffer from motion sickness when using HMD to view VR environments, which happens when the user expects that they are moving when in reality they are not. This can appear with symptoms such as feeling nauseous, being dizzy, vomiting, headaches, or cold sweats, the symptoms can appear alone or a combination of all of them, depending on the severity that the user suffers from motion sickness. [18]

As the 'Declaration of Helsinki' states, when doing research with humans as test participants "the participant's welfare must always take precedence over the interests of science and society (article 5)" [19]. So motion sickness needs to be kept in mind when developing VEs, especially when researching as participant health is a high priority and severe enough motion sickness may affect the test participants' experience and thus affect the results gained from the said participant, this may require for the environment created for this thesis' research that the test participants movement is limited to only standing or minimal, slow movements. The possibility of motion sickness and the possibility withdraw from the study at any time should be mentioned in the consent form given to each study participant.

1.2. Place and Plausibility Illusion

In his article, Slater describes PI as a feeling of "being there" as in being in a VR environment instead of being, in reality, wearing HMD or in his words *"It is the strong illusion of being in a place despite the sure knowledge that you are not there"*. PSI on the other hand refers to the perceived realness of what is happening. Take for example a VR scene, in this scene there you are on a basketball court with a basketball in front of you. PI is about feeling that you are in the VE and not in the physical location wearing HMD. The level of PI depends on the immersion level of the system, in essence, how well the system can render stimuli according to the user's natural sensorimotor actions. Those things do not necessarily need to be perfect but must match the expectations of the viewer. Now in this scene, the basketball is thrown at the viewer and the viewer reacts by trying to catch the ball. The VR scene made the viewer react so that on some level they perceived the ball coming at them as real; this is PSI, meaning how right the events in the VE feel [20].

To maintain PI, VE should react correctly to the actions of perceiving the VE. Slater et al. called these sensorimotor contingencies for perception and in their word include it includes "turning the head, moving the eyes, turning around, bending down, stretching up, looking around, looking over, looking under, turning our head to hear a sound better, touching, pushing, smelling" [21]. PSI is about reacting to external stimuli for example as mentioned before: trying to catch a virtual ball thrown at you. Another example given by Mel Slaters' article about PI and PSI is where the user is affected by a smile with shyness or fear by public speaking [22]. An important part of PSI is a concept called coherence, which Skarbez et al. introduces as "The degree to which the virtual scenario behaves in a reasonable or predictable way" [23]. What is reasonable and/or predictable behavior is of course subjective, which can be seen later in this thesis as coherence is a central concept that is being studied.

1.3. Virtual Reality at Different Scales

A participant area where using and understanding scale is multi-scale collaborative VEs (MCVEs). MCVEs are VEs where multiple participants in the same environment use and observe objects from different point-of-views where the scale levels may differ hugely. For example, a building can be viewed by a person from a birds-eye kind of view where the observer is significantly larger than in real life and sees the building in its entirety and how the building fits its environment. At the same time, as the previously mentioned person is looking at the building at the scale where he gets to view the whole building, another person can be scaled down where their view is that of a normal person or even smaller. This other person can then view the building in detail and can, for example, assess that the building is made correctly from layouts of the rooms or design the electrical layout of the building [24]. MCVEs have been studied by Langbehn et al. where they described how the type of environment, avatars of our bodies, and bodies of others have an effect on the estimation of scale or as they describe "the scale level relative to which we make spatial judgments, plan actions and interpret other users' actions in MCVEs" [25]. The effectiveness of MCVEs has been studied by X. Zhang and G.W. Furnas and in their study they concluded that MCVEs indeed are an effective tool to use but they also mentioned that it is necessary to consider how the collaborative aspect is built so that people can use its advantages in full [26].

What the user feels when their size has been tampered with in VR has been studied previously by having their experiences documented when presented with two different kinds of physics; those that follow reality and those that follow how physics are presented in movies and media [27]. In the study, they concluded that when a person is shrunk, they feel that the physics dubbed as *"Movie physics"* are seen as more fitting of reality than when they were presented with physics as they would be in that situation. In this study, what is dubbed *"Movie physics"* means, as the name suggests, physics that can be observed in movies; where the character is shrunk down and is interacting with objects, and when the objects move, the objects move as they would while they were "normal" size, as-if the tiny person was normal-sized and the environment enlargened instead. An example of movie physics can be seen in the study design of the aforementioned article, where the test participants drop soda-can pop-tabs on the floor and the fall time is comparable to the time they would need to drop from a height of normal sized person dropping them when in reality the time should be much, much shorter. Again as the name suggests, *"True physics"* is the physics as they should be in real life when the observer is shrunk down. While viewing *"True physics"*, objects seem to fall too fast or fly too short of a distance when thrown. The distinction of *"True"* and *"movie"* physics is needed as the only experience a normal person can have as a shrunk-down person is the movies they see. This aforementioned study is the academic motivation for this Thesis and is kind of its prequel as this Thesis will try to understand how the user can be led to feel like real life physics would be more realistic than *"Movie physics"*. [27]

Understanding the cues that the user needs to feel and experience the "real physics" will be useful in developing future designs of VEs when the user is presented with a scenario where their size has been altered to be smaller than normal.

1.4. Motivation

In everyday life, people do not get the chance to experience the world in different scales than their bodies can provide. Certainly, they can climb high or fly on planes to see the world from a giant's point of view or they can squat down and feel like they are knee-high. Changing perspective can only do so much as it only changes how you see things but it does not truly give them a realistic experience without being able to see how not only are there visual differences but differences in how they and how objects they interact with move around when physics are not what they might experience.

In this thesis, the focus is small-scale VR, with a further focus on physics in it. In this thesis, a study in this small-scale VR will be done and it will be a follow-up study to the Pouke et al. study called "The Plausibility Paradox for Resized Users in Virtual Environments" [27]. In the aforementioned study, Pouke et al. devised two experiments with users experiencing both large- and small-scale VR and the study done in this thesis is a follow-up to the small-scale experiment done in that study. Where the studies will differ is that in this thesis, we will investigate whether we can affect participants' expectations by introducing a priming phase to take place before the interaction task in which the physics models are assessed. By giving the users time to get used to VR, and rigid body dynamics at different scales, we might be able to perceive 'True physics' as the realistic physics representation, unlike in previous studies.

From a previous section above, called place and plausibility illusions, a concept called coherence was introduced [23]. Coherence was defined as "the degree to which the virtual scenario behaves in a reasonable or predictable way". Coherence is a central concept in motivating this study because when the user's perspective is dramatically altered, what constitutes reasonable and/or predictable behavior, for the user that is experiencing that perspective can and will differ greatly from what is realistic and is based on real physics. This breakdown in coherence can be seen in the results of the study mentioned previously from which this thesis' study is a follow-up from [27]. In that study users interacting when they were shrunk down believed that "movie physics", as that study defines it, is the way objects should behave instead of how they behave when physics is as they are in reality [27].

1.4.1. Research Questions and Methods

This thesis reports the results of a study in which a sizable group of human participants was put into a VR environment, which presented them with different cues to real-life physics. The participants were primed with interaction tasks with everyday objects before and after being shrunk down. After this, the participants performed a similar interaction and physics realism estimation task as described in Pouke et al. [27]. The participants' experiences were evaluated using questionnaires.

The research question can be encapsulated: Does priming the test users help them realize which scenario has physics that corresponds to reality after they have been presented with scenarios that have realistic gravity and another with gravity ten times smaller than in reality? In the Pouke et al. they used terms 'true physics' to mean realistic a gravity scenario and 'movie physics' to mean a scenario with altered physics that look like they do in movies [27]. In this thesis' these scenarios are named 'normal-gravity' and 'low-gravity' respectively.

Hypotheses:

- **H1**: For a scaled-down participant, after priming, 'normal-gravity' is more likely to feel realistic than 'low-gravity'
- **H2**: For a scaled-down participant, after priming, 'normal-gravity' is more likely to match the participant's expectations than 'low-gravity'.
- **H3**: Participants experiencing a priming phase are more likely to consider 'normal-gravity' to feel realistic than participants who did not experience a priming phase.
- **H4**: Participants experiencing a priming phase are more likely to consider 'normal-gravity' to match their expectations better than participants who did not experience a priming phase.

1.5. Thesis Structure

The thesis structure follows a standardized format presented by the University of Oulu [28]. As presented in the format, the first pages of the thesis include a title page, abstracts, table of contents, foreword, and list of abbreviations and symbols.

The main bulk of the thesis starts with a description of related work, which describes related literature, the available VR technology, and the reasons for choosing those technologies that were used in the study in this thesis. The related work also describes via academic sources the ways humans perceive reality and physics and how those methods were chosen to be part of the thesis. Lastly, different human participant study methods will be covered with reasoning as to why the specific ones were chosen.

The next chapter, named 'Implementation' will describe in detail the methods used in the creation of the VE that was created for the study. The chapter will list the used software in the environment's creation, the methods used on the study participant, and methods used on the environment to make it feel like the participant has been shrunk.

The implementation chapter also describes the experiments done in the environment. The experiment is described in detail how the testing was done with detailed test protocol, tasks that the participants were assigned, and answers that the participants gave to the questions on their experiences.

The results of the study are compiled into the chapter named 'results'. In this chapter, the resulting data is presented in its raw form after analysis without further discussion of what the results could mean. Provided data is also visually presented with figures and tables.

In the discussion chapter, the results of the work done in the thesis are condensed, discussed what the results mean, and compared to similar work done in the past and how this thesis added to it. The results of meeting the thesis' objectives are reflected upon. Lastly, possible limitations of the study and implemented work are also reflected upon

The thesis is concluded with a summary chapter where the main and the most important parts of the thesis are laid out concisely.

2. RELATED WORK

2.1. Perception of Size

We as humans use a large number of different cues to discern the size of other objects in our environment and the size of ourselves, meaning our bodies, compared to the environment. The different cues can be used alone or together with other cues. When a person is shrunk, the cues that inform them of that can be primarily divided between cues that come from the person themselves and outside of the person. Cues that come from the user themselves are perspective and body cues. Cues that come from the outside are the cues from the environment and the physics perceived in that environment.

Langbehn et al. found that the cues, which we use to observe the size of ourselves and the environment around us, are primarily body cues, body avatars in the study. The study showed that when presented with other avatars (people) the test participant used them as reference for size over the avatar of their bodies. When body cues were not enough we use additional cues from the environment. [25]

2.1.1. Perspective Cues

To make a person feel like their height has been tampered with, the first and easiest cue pertaining to their own body is to change the height of their perspective as in lower or increase the height of their eye level compared to the floor or ground. If the perception level is manipulated, the users' avatar should be proportionally either enlarged or shrunk down or it can mess with the perception of distance [29]. Change of perspective has been studied and it was found that manipulation of eye height influenced estimating egocentric distances and dimensions of the room around them [30]. Changing the height of the user's eye height in a VE is easily done by changing the location of the virtual camera, which determines the viewpoint of the user when they wear the HMD, which is usually a simple numerical value that needs to be changed.

2.1.2. Body Cues

When estimating the size of the environment or an object we very often compare the environment to our bodies i.e. torso, legs, or hands [31]. This works even when the perception of size has been tampered with by magnification [32]. This way of estimation is called body-based scaling, and perhaps the easiest and most studied way to implement this in a VR environment is to change the controllers in the environment from the basic controllers to a close representation of users' hands [31, 33, 32].

In their study, van der Hoort et al. aptly named study "Being Barbie", studied how people would perceive the world if they were shrunk to the size of a Barbie doll. What their study found was that when people were shrunk and shown the world around them as doll-sized in VR, they used their bodies to relate to the outside world and so found that rather than them being shrunk, they felt that everything around them was scaled up in size. Interestingly their study also found that when given real-life stimulus at the same time as perceived in VR the users felt that the doll bodies were their own even though they were differently sized compared to their real-world bodies. What they also found out was that given that when the user's virtual body is scaled, regardless of its larger or smaller size, it does not matter how much the size is altered as long as it is altered proportionally, then they can alter the size as much as they want to. [29]

Another study in being in small-scale VR is by Banakou et al. Where they studied body ownership where the user was scaled down and given a virtual body. Their study had two scenarios, one with a scaled-down adult body and another with the body of around four-year-old child. What they found was that users did not have problems with identifying with being a scaled-down person or a child but interestingly when in their child avatars their size over-estimation was off by a larger amount than how they normally over-estimate sizes when scaled down. [34]

In another study, Linkenauger et al. studied how people use their bodies to figure out the scale of the environment. In this study the changing variable was the size of the user's hand in VR [35]. What they found was that when their hand was made larger, the participants estimated objects as smaller than they really were, and with smaller hands, they estimated the objects as larger than in reality. To further study the effect of hand size in estimating object size, they conducted a study where again hand size and object size were varied and the sizes of the objects were asked to be estimated. What was different from their previous study was that this time the hands were not their own but another avatar. This time there was no significant fluctuation in estimations of the size of the objects regardless of the other avatars' hand sizes. Based on this they concluded that it is our bodies that we use to perceive the scale in the environment and not the bodies of others. In another study with hands and sizes in VR Ogawa et al. also studied how the size of our hands relates to the perceived size of the environment. What this study added was that not only are our bodies used to find the size of objects around us, but familiar-sized objects inversely can be used to figure out the size of our bodies [33].

2.1.3. Environmental Cues

Environmental cues or depth cues come from the environment around us and give us information about the size and distance of objects around us. These cues can be further divided into monocular and binocular cues, as in cues that use one eye and cues that use both eyes. Regarding this thesis' research, the distinction is not important. The environment does not need to include many cues for the observer to be able to make size estimations [36].

There are a plethora of depth cues, but the most relevant ones are [10]:

- **Motion parallax**: When the observer moves, the objects with different distances, compared to the observer, move at different rates.
- **Relative size**: When observing two objects, which are known to be the same size, the one that takes more space on the screen is the one closer to the observer.
- **Object interposition**: When observer objects overlap in vision, the object further away is blocked by an object closer to you.

- **Familiar sized object**: When objects in the environment are familiar and their approximated size is known beforehand they can be used to estimate the sizes and distances of other objects.

As Langbehn et al. found when populating a VR environment with avatars of other people we tend to sift our perception of size from our own body to the size of familiar-sized objects (in this case other people) [25]. A similar thing was found by before mentioned Ogawa et al., who found that with familiar-sized objects in the environment, their test participants used those objects to figure out the size of their avatars [33]. From these two studies can be deduced that when playing with the scale of the environment and trying to have the viewer deduce that scale, familiar-sized objects become exceedingly important, especially when the other cues come from their bodies or avatars in the case of VR.

2.1.4. Perception of Physics

Previous studies show that we humans have some kind of internal process to estimate how physics should work, for example, J. Hamrick et. al. found that their test participants could fairly accurately tell how stable different structures were, even when they were virtual and not real structures [37]. P. Senot et. al also found that humans could anticipate the effects of gravity on moving balls by having the test participants intercept balls that flew with different speeds and would accelerate at different speeds [38].

When the observer is scaled down and allowed to interact with the VR environment to play with and experience the physics closely, they feel like physics, often shown in movies, would be more accurate than what physics would be in reality when they are smaller and as such objects fall a shorter distance and so feel faster. [27]

2.2. Experiments

When doing experiments that involve a human participant there are things that need to be taken into consideration.

2.2.1. Ethical Concerns

One of those things is the previously mentioned "Declaration of Helsinki" [19, 39]. Declaration of Helsinki is a list of ethical principles for research involving human participants, it is a declaration for medical research but can be largely broadened to be used in all research with human participants.

How these principles are acted upon during this research is when the participants are made to sign a consent form and in this form, they consent to be a participant in the experiment, have their experience recorded, and that data stored securely, possible health risks and their ability to withdraw their consent and terminate the experiment at any time during their participation.

Possible health risks during this experiment where participants have limited mobility and are wearing a VR headset are low but not non-existent, the possible health risks as previously mentioned are that some percentage of users experience motion sickness when using VR and test participants must be made aware of this possibility. In addition as the responsible party, when developing the experiment steps must be made to mitigate the possibility of motion sickness and that can be partially achieved by limiting the movement of the participants so that they move about the environment only as much as is needed. The way the participants move is also a factor, having the participant teleport around instead of moving the whole way using the controls is a way to reduce the instances of motion sickness, which has added benefit of removing extra conditions that can have an effect on the study's results. [40]

2.2.2. Other Concerns

When doing a study where the studied participant and the person conducting the study are human there will exist a degree of human error, which the researcher must try to mitigate during the process of the experiment.

Rosenthal effect or experimenter expectancy effect is a type of experimenter effect in which the person who is conducting the research and is guiding the participant may either consciously or unconsciously have an effect on the study participant where they hint at the wanted result of the study and the study participant may notice this and alter their answers to the asked questions. The way the researcher might affect the participant might be through body movements, gestures, and facial expressions [41, 42].

The participant-predisposition effect is an effect where the test participant may skew the results of the experiment in a different way by not giving truthful answers to the experiment questions, this might be intentional or not, depending on the participant, and are affected for example by past experiences and personality. "The SAGE Handbook of Quantitative Methods in Psychology" lists three groups of participants to give examples of this effect. [42]

The first group is concerned with pleasing the researcher and striving to be good participants. This is called the cooperative-participant effect. This first group might try to give answers in a way that they perceive that the researcher wants to be answered, whether it is the way they would answer or not when answering truthfully.

The second group is the opposite of the first group where they are uncooperative and might even try to sabotage the experiment. They might give answers that they think the researcher isn't looking for or just answer untruthfully to the questions given. In the handbook, this effect is aptly called the "screw you effect".

The third group is apprehensive about being evaluated. They don't really care about the hypothesis of the experiment or what the researcher wants to hear as an answer. What they want is to get a positive evaluation from the researcher, they want to appear smart, cooperative, confident, and so on, while they try to hide undesirable characteristics i.e. stupidity, shyness, and so on.

3. IMPLEMENTATION

3.1. Experiment Implementation

Implementation for the study was done by designing a virtual environment using the Unity game engine (editor version 2020.3.26f1). VR interactions and movements were done with Valve VR and its library of scripts.

At the beginning of the test, the participants were instructed to do a priming phase. In this phase, the participants interacted with different everyday objects, while keeping the objects and the environment as realistic and normal as possible, without altering the participant or the physics of the environment. They were given five different sets of objects to interact with at this point: two sets of soda cans, a hammer, three dice, and two plates. The priming phase then moved to its second stage when the participants were shrunk down to a tenth of their regular size and asked to again interact with some objects, this time with two soda cans, three dice, and a hammer. After the priming phase, there was an interaction test where the participants were asked to perform a physics estimation with soda can pull-tabs. In this physics estimation phase, the participants interacted with a set of five pull-tabs alternating dropping them on the floor or throwing them away. There were two almost identical interaction tests, first with nothing but the participants' size altered and second where gravity was made ten times weaker to match the amount the participant was shrunk. These interaction tests were given to the participants in a counterbalanced order.

The VE was based on the main halls of the University of Oulu, near popular and often-seen lecture halls L5 and L6. This location was chosen for a specific reason, as this is a very popular location on the campus, to give the test participants easy environmental size cues as all of the test participants were either students or faculty of the University of Oulu. This location contained plenty of familiar size cues, such as a staircase, windows, and doors, each of which is seen by the staff and students almost daily.

To the environment were added two simple gray blocks from the original 3D object library from Unity, which were resized to be two identical-sized tables on top of which objects were placed to be interacted with by the test participants during the test. One of the tables was placed at approximately waist height of an average-sized person and the other table was placed on the floor. The first table was for the first phase of the priming where the test participants are at their normal size and the second table was placed on the floor, where the remaining priming phase and remaining two test scenarios were completed after the test participant was shrunk to a tenth of their original size.

The different objects, which were placed on the first table Figure 1 were in the following order: two sets of soda cans (four empty and four full ones), two hammers, three dice, and two plates. The second table Figure 2 had a full and an empty soda can, three dice, a hammer, and five soda can pull-tabs. These objects were downloaded from Unity's official asset store. Each of the objects was made interactable by Valve's *"interactable"* script and all but the soda cans were made throwable by Valve's script called 'throwable'. Each of the items was sized and weighed as closely as possible to their real-life counterparts using measurements found on the internet. The items were chosen based on them being familiar objects that everybody had most likely seen numerous times. This allowed participants to picture their size dimensions and weight without having to interact with their real-life counterparts. This also eliminated the possible need for priming the test participants with real-life items, (although that could be an interesting part of a future study).

In the experiment, the participants didn't have to move large distances; movement between different key locations within the VE was handled by a researcher with a keyboard. The researcher moved the participant to six preassigned locations next to the different item sets. These locations can be seen in the images below, where spots are numbered in Figure 1 and Figure 2

The experiment was separated into three executable unity files. The first executable had the priming part where the participant interacted with different items with physics left close to reality, by leaving Unity's physics settings as they are originally set. The priming part itself has two distinct parts in itself, in the first half, the test participant is normal sized Figure 3 and in the second half, they are shrunk to a tenth of their normal size Figure 4. The second and third executables contain the physics estimation phase, simulating 'normal-gravity' and 'low-gravity', respectively. Participants were located in the same place as where the priming took place. These phases were significantly shorter, as the test participant only interacted with five soda can pull-tabs Figure 5 similar to the interaction task described in the article that this research is a follow-up of [27]. The phases are identical to each other, except for gravity. In 'low-gravity' scenario, gravity was set to be ten times lighter than Unity's default physics settings, which matches gravity outside of VR. This later part of having the participants interact with five soda can pull-tabs was part of which the participants' experience was noted and later analyzed with additional questions of if the priming part was helpful.

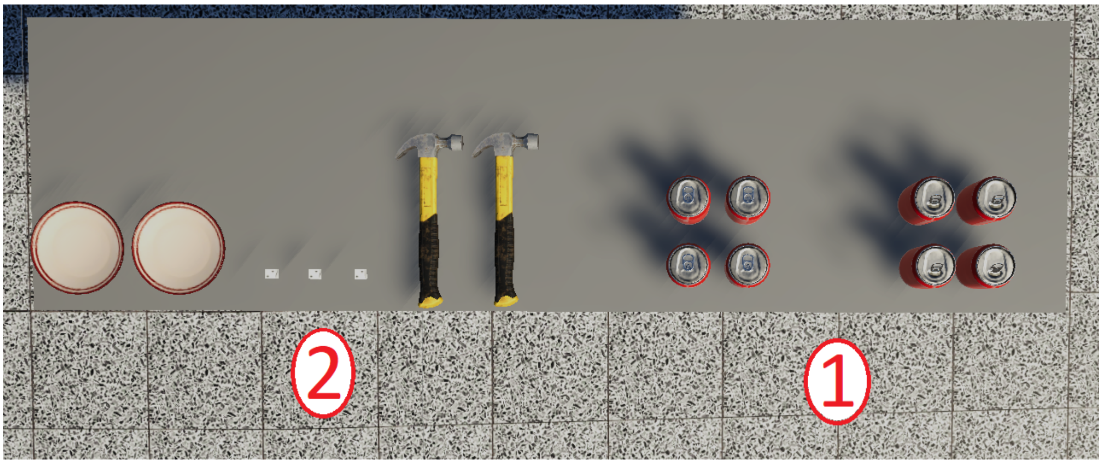

Figure 1. Interaction locations 1 and 2

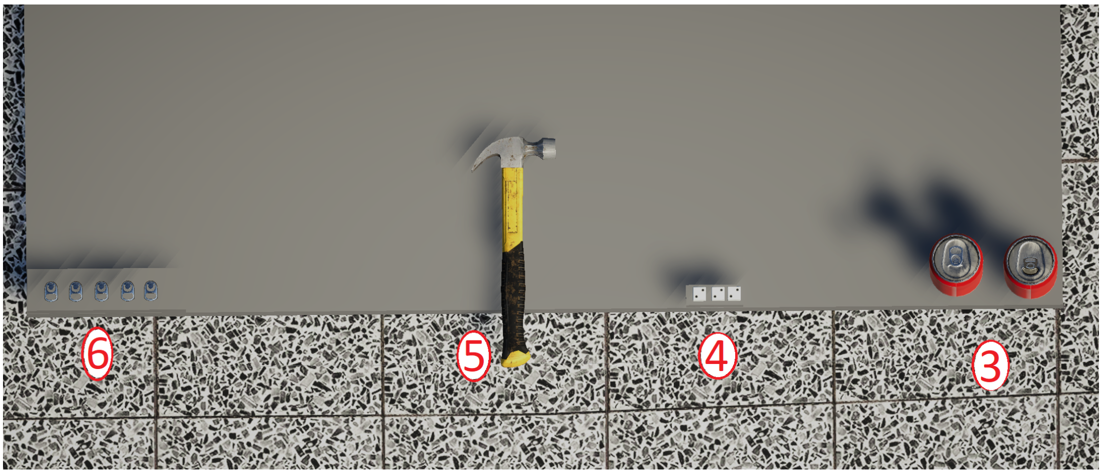

Figure 2. Interaction locations 3 to 6

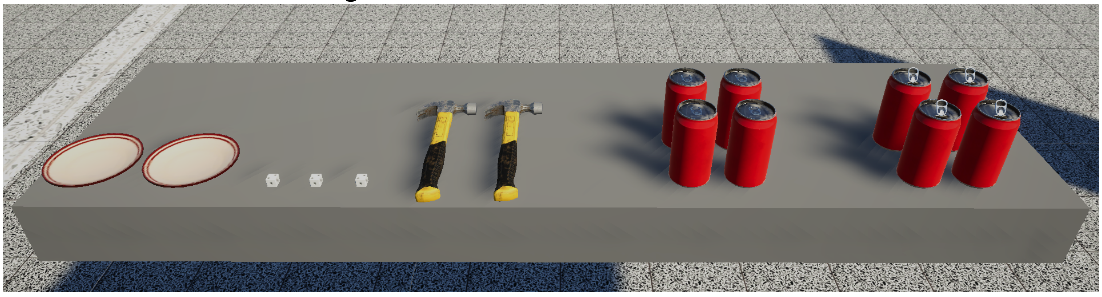

Figure 3. Table for priming as normal sized

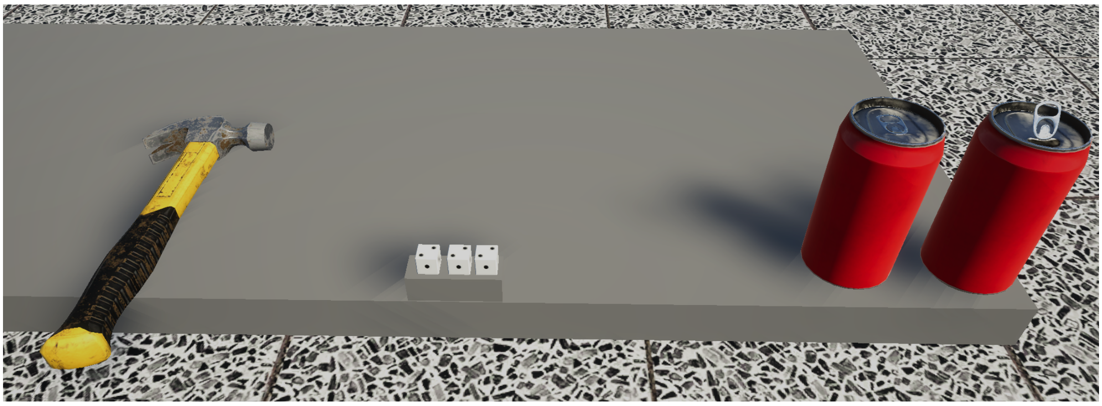

Figure 4. Table for priming after being shrunk

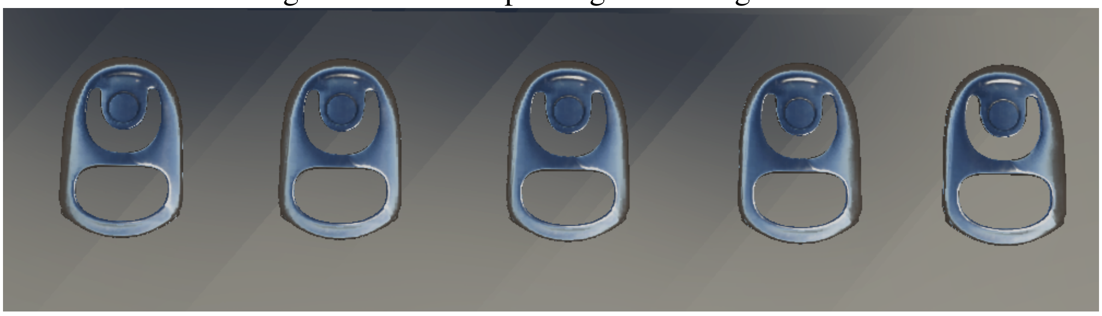

Figure 5. Pull tabs

3.1.1. Methods

Test participants were gathered by using an internet browser-based research participation system called 'sona-systems' (https://oulu-ubicomp.sona-systems.com/), where willing test participants could register to be a participant in the study. Sona-systems also handled scheduling by giving each test participant a 30-minute time slot in which the test was to be done. 48 participants were gathered and tested, but only the results of the first 44 were included in the analysis in the end. The number of wanted participants was set to 44 on the research preregistration because some of the results in this study will be compared with the previously made small-scale experiment that also had 44 participants [27].

Out of 48, 12 participants were female and 36 were male, with an average age of 26, ranging from 21 to 46. Based on the background questionnaire given to them at the end of the experiment, almost half (22) wore glasses. Of the participants, more than half reported playing video games more than weekly: Once or twice a month 22,7%, Several times a week 27,3%, and daily 15,9%. Deviating from the majority participating in playing video games often, the test participants that had used VR systems previously before the study only 15,9% reported using it weekly and 50% reported having used VR systems only once or twice before in their lives.

3.1.2. Experiment Process

At the beginning of the study, the test participant was directed to read two documents that gave some general info for the participant. The documents were named 'Information for Participants' and 'Information for Research Participants'. Both documents are standard versions that are used in the University of Oulu, Perception Engineering group at the Center for Ubiquitous Computing. The first document included basic information about how the study would progress, and how the data that was being gathered was going to be used and stored. The document also included information regarding the health and safety of the participant. They were told that using a VR headset has the possibility of causing motion sickness and they were also given information on precautions for COVID-19. The second document gave information purely on how, when, and where the data was stored, who has access to the data, who is responsible for making sure it is being used responsibly, and in case of misuse who to contact.

After reading the documents the test participants were made to sign two paged informed consent forms in which they gave their consent to being the participant of the study, to store their data, and to use it in studies. They also signed that they were given the two documents mentioned above.

When the test participant finished signing the consent forms they were taught how to use the VR HMD and its controllers. They were told how to use the controllers while in the VE by informing them that the controllers will appear as their hands and that to interact with the different objects they will need to move the controllers as they would move their hands in real life, they were also told how to pick up, drop and throw the objects.

After teaching the participants how to use VR equipment they were instructed to move to a predetermined position in the room and to put on the HMD. With the HMD on they were given information on the VE itself, they were told that as they could see they are in the hallway of the university near popular lecture halls. They were also informed on how to behave while in being inside the VE. They were told that the only movement that they had to do was to take one or two steps and they would instead be teleported around to predetermined positions and to only interact with the objects after explicit order was given to interact with them. They were also instructed that they should pay attention to how all the objects behaved when they were interacted with i.e. how fast they fell on the floor, how fast they flew, and how far after they were thrown.

As mentioned previously, the interactive part of the experiment contained two parts. In the first part, the test participants were primed on how objects behave in VE. The purpose of this part was to have the test participant see that how the objects behave in VE is the same or very close to as they would in behave real life. In this first part, the test participant was first moved to stand near the table where they could easily interact with the objects in front of them. The test participant was then told to interact with the objects before they were again moved near the next set of objects. Interacting in this experiment meant that they would drop some of the objects on the ground and throw others The objects came in sets of two or more so half of them would be dropped and half would be thrown. Objects that didn't follow previously mentioned interactions were the first sets of four soda cans, which they were told to only push onto the floor.

The priming part of the experiment could be seen as being in two halves. In the first half, they interacted with the objects as their regular selves and in the second half, they were shrunk to a tenth of their regular size. Objects that they interacted with can be seen in Figure 1 and Figure 2 above. The second half of the priming was the more important half and what made this important is that this was the scenario that the test participants couldn't have experienced in real life: they saw how the objects would behave when they were a lot smaller than they normally are.

After priming the test participants on how the objects should behave in real life the second part of the experiment began in which they were told to interact with five soda can pull tabs while they were shrunk down. Again, they were told to drop some on the ground and throw the rest, in this case, three were dropped and two were thrown. This interaction was done twice: once, with gravity that matched real life and once with gravity lowered to a tenth of its normal strength. The order in which these scenarios appeared was switched per test participant, half interacted with normal gravity first and half interacted with lessened gravity first.

After this, the VR part of the experiment was done and the test participants were told that they could remove the HMD and fill out two questionnaires. The first questionnaire handled questions mainly about how the pull tabs behaved in the two scenarios and which one of them felt more realistic, the scenario where gravity matched real life or the scenario where gravity was ten times smaller. They were also asked about their experience in the VE and how they perceived it and if they felt that priming was helpful, this was done with seven-point Likert-scale questions. The first questionnaire was about the background information of the test participants: gender, age, if they needed glasses or not, and amount of previous experience with VR and playing video games.

Lastly, they were given a debriefing on the experiment where they were told how this experiment was about studying the perception of physically simulated objects in

VR while scaled down. They were told that if they had friends interested in this study, they could register but not to tell them about the study. They were also told that they could contact the researcher if they had questions in the future or if they wanted to know about the results of the study.

3.2. Questionnaire

Below are listed all the questions used in this research. All of the results shown in this chapter are based on them. The questionnaire is comprised of two forced-choice questions about realism and expectations, followed by two open-ended questions, six 7-point Likert-scale questions about the interactions tasks, three forced-choice, and open-ended questions, and again six 7-point Likert scale questions about Place illusion [22]. The questions about Place illusion utilized the 'extended Slater-Usoh-Steed' questionnaire [43, 44]. The questionnaire was done in "webropol.oulu.fi", which compiles the answers in an easily readable format and has its analysis tools that were used in the upcoming open-ended questions section.

The questions below are in the aforementioned order. The research participants were shown the 'normal-gravity' and 'low-gravity' scenarios in different orders, this can be seen in the questionnaire as some questions are asked twice with additions of "(1st time)" and "(2nd time)" after the questions.

Realism and Expectations

- C1. Thinking back on how the pull tabs were behaving in the experiment, which felt more realistic (like what would happen in the real world if you had been shrunk down), the first or the second time?
- O1 Why?
- C2. Thinking back on how the pull tabs were behaving in the experiment, which matched your expectations (similar to what would happen in the real world if you had been shrunk down), the first or the second time?
- O2 Why?

Pull-tab behaviour

- L1 How did you perceive the speed at which the pull tabs fell? (1st time). Too fast - Too slow
- L2 How did you perceive the speed at which the pull tabs fell? (2nd time). Too fast - Too slow
- L3 How did you perceive the distance at which the pull tabs flew when thrown? (1st time). Too far - Too near
- L4 How did you perceive the distance at which the pull tabs flew when thrown? (2nd time). Too far - Too near

- L5 How did you perceive gravity when interacting with the tabs? (1st time). Too weak - Too strong
- L6 How did you perceive gravity when interacting with the tabs? (2nd time). Too weak - Too strong

Priming and perception

- I1. Did you feel that being able to interact with objects at normal size (before being shrunk down), was helpful in choosing which time felt more real?
- O3. Why?
- C3. After being shrunk, which of the following sensations better matched your experience? I felt normal-sized and the environment looked enlarged or I felt scaled down and the environment looked normal-sized. (1st time)
- C4. After being shrunk, which of the following sensations better matched your experience? I felt normal-sized and the environment looked enlarged or I felt scaled down and the environment looked normal-sized. (2nd time)

Place illusion

- L7 Please rate your sense of being in the virtual environment, on a scale of 1 to 7, where 7 represents your normal experience of being in a place. I had a sense of "being there" in the virtual environment: not at all to very much
- L8 To what extent were there times during the experience when the virtual environment was the reality for you?
- L9 When you think back to the experience, do you think of the virtual environment more as images that you saw or more as somewhere that you visited?
- L10 During the time of the experience, which was strongest on the whole, your sense of being in the virtual environment, or of being elsewhere (in the VR laboratory)?
- L11 Consider your memory of being in the virtual environment. How similar in terms of the structure of the memory is this to the structure of the memory of other places you have been today? By 'structure of the memory' consider things like the extent to which you have a visual memory of the virtual environment, whether that memory is in colour, the extent to which the memory seems vivid or realistic, its size, location in your imagination, the extent to which it is panoramic in your imagination, and other such structural elements.
- L12 During the time of the experience, did you often think to yourself that you were actually in the virtual environment?

4. RESULTS

4.1. Confirmatory Questions

When questioned about which felt more realistic when interacting with the soda can pull-tabs, the 'low-gravity' or 'normal-gravity', the vast majority answered 'low gravity'. This answer remained the same regardless of which gravity scenario they were shown first. Out of 44 participants, 13 answered that 'normal-gravity' felt more realistic, which is 29,5% of the test participants.

When again asked about their expectations about how the pull-tabs should behave, the answers remained the same, with 7 out of 44 (15,9%) having answered that 'normal-gravity' matched their expectations. The results were also analyzed with a one-tailed binomial test, which gave respective p-values of 0.9982 and 1. Based on the answers and the analysis above, it can be concluded that support for hypotheses H1 and H2 was not found.

As mentioned in the introduction chapter, this thesis is based on the study portrayed in the article by Pouke et al. [27] where similar interaction tasks with soda can pull-tabs were done. Results from the questionnaire in both studies, this thesis and the previous study, were analyzed together with a two-proportions Z-test.

Comparison between the studies was done with the questions about realism and expectations, meaning questions one and two in the list above, which were: *"Thinking back on how the pull tabs were behaving in the experiment, which felt more realistic (like what would happen in the real world if you had been shrunk down), the first or the second time?"* and *"Thinking back on how the pull tabs were behaving in the experiment, which matched your expectations (similar to what would happen in the real world if you had been shrunk down), the first or the second time?"*.

Test participants answered with 'normal-gravity' (term used in this thesis) and *"true-physics"* (term used in the previous study) 13 and 12 times, respectively, for the first question and 7 and 4 times, respectively, for the second question. Both studies were done with a total of 44 research participants, which gives results of 29,5%, 27,3%, 15,9%, and 9% success rates for answers sought based on hypotheses. As can be seen, the results for both studies were extremely similar. Analysis results from the two-proportions Z-test gave p-values of 1 and 0.52 for both questions, which is further proof that the results are similar in both studies.

Based on the questionnaire results and two-proportions Z-test, it can be concluded that support for hypotheses H3 and H4 was not found.

4.2. Exploratory Results

Results for the first two questions about realism and expectations were analyzed with a two-sided binomial test. According to the analysis results with p-values of 0.00956 and 5.3e-06, the 'low-gravity' scenario was statistically a significantly more likely choice.

4.2.1. Likert Scale Questions

Results of the Likert-scale part of the questionnaire again show how the test participants' answers do not support hypotheses H1 and H2. Medians for the questions regarding their experiences in 'low-gravity' are 4 for every question. Medians for questions asking about their experience in 'normal-gravity' are all close to or exactly 7 or 1, meaning too much or too little depending on the question, which supports the fact that 'normal-gravity' is not how the pull-tabs should act according to the participants. Likert questions were also further analyzed with Wilcoxon Signed Rank test, which gave p-values lower than 0.05 for all questions L1 to L6.

Results for the questions can be seen in Table 1 and Figure 6, which show answers in the Likert-scale and their average and median values. In Figure 6, each horizontal column represents a question, and the different colors in the bars represent the answers to the question on Likert-scale one to seven. Before mentioned questions were done in three pairs of two, as each three questions separately asks their experience first in 'normal-gravity' and second in 'low-gravity' scenarios. The questions are represented as L1 to L6 in Figure 6 and Table 1 below.

L1 & L2	
Average	Median
Normal gravity	
2,5	1
Low gravity	
3,9	4

L3 & L4	
Average	Median
Normal gravity	
5,9	6
Low gravity	
3,5	4

L5 & L6	
Average	Median
Normal gravity	
5,8	7
Low gravity	
3,6	4

Table 1. Average and Median answer results of Liker scale questions L1 to L6

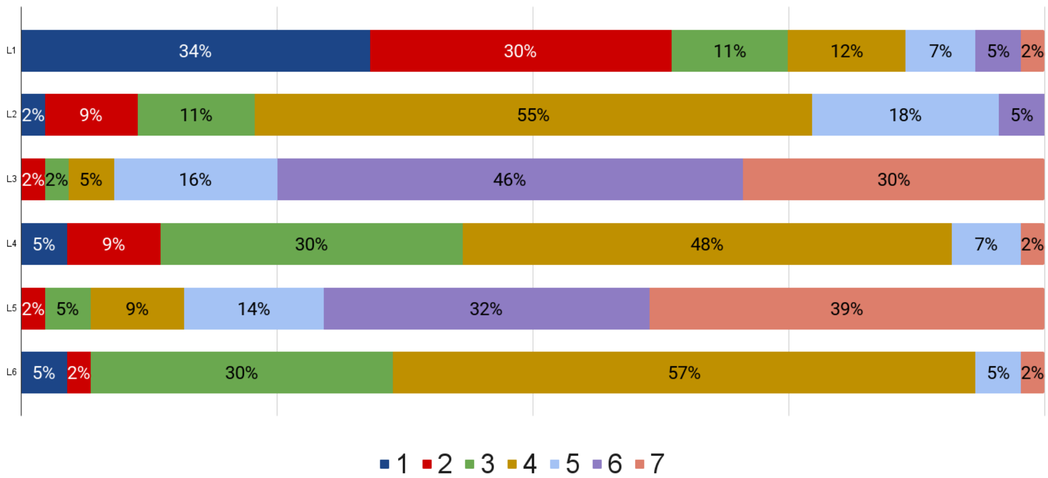

Figure 6. Combined answer results for likert scale questions

4.2.2. Perception of Presence in VE

In addition to Likert scale questions about hypotheses, the test participants were asked six questions, in the style of Slater-Usoh-Steed questionnaire, (L7 to L12 in the Figure 7 and Table 2) about their perception of actually being present in a VE and not just having an HMD on and looking at its screens, i.e. Place Illusion. Questions were such as if they felt that they were in the VE or just images that they saw or did they feel like they were in the VE or in the laboratory where the test was being conducted.

According to the answers, the test participants largely felt that they experienced being present in a VE, and they felt that they were in a VE so they did feel that they were somewhere else realistic, the place illusion was strong enough to fool that the participant was not in a lab, wearing HMD but that they were visiting a VE. The median for all the questions except L12, was above 4 while for L12 it was 4. The summary of these questions can be seen in Table 2 Figure 7.

4.2.3. Perception of Self

In addition to Likert-scale questions, the participants were also asked after they were shrunk if they felt like the environment grew or that they themselves shrunk. Depending on if the test participant was in 'normal-gravity' or 'low-gravity' scenario first, their answers differed. For the participants that experienced the normal gravity scenario first, the answers were approximately even, i.e. half felt that they shrunk, and the other half felt that the environment grew. When the participants experienced the 'low-gravity' scenario first, 32 out of 44 (72,7%) felt that the environment grew, and 12 out of 44 (27,3%) felt that they shrunk.

L7	
Average	Median
5,4	5,5

L8	
Average	Median
4,8	5

L9	
Average	Median
5,6	6

L10	
Average	Median
5,3	6

L11	
Average	Median
5,3	6

L12	
Average	Median
4,2	4

Table 2. Average and Median answer results of Liker scale questions L7 to L12

4.3. Open Ended Questions

Within the questionnaire, in between other questions, the test participants were asked open-ended questions to explain their reasoning to a previous question in the form of a "Why?" as can be seen in the list of questions in this chapter above. The responses to the open-ended questions O1 and O2, after questions about realism and expectations of how the pull tabs behaved in the 'normal-gravity' and 'low-gravity' scenarios,

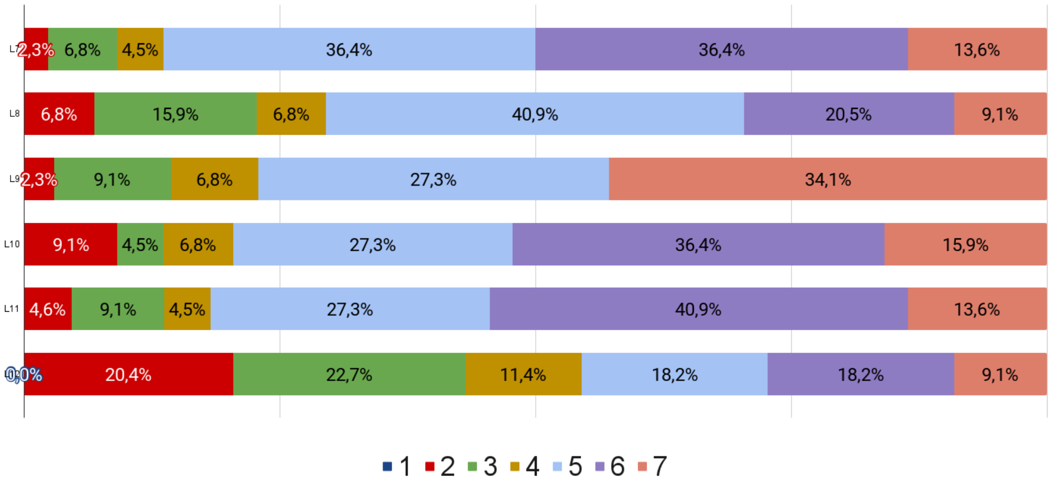

Figure 7. Combined answer results for likert scale questions

show that the responses to those questions are based on the perceived physics of the scenarios. Open-ended questions were analyzed with tools from "webropol.oulu.fi".

Using the Webropol analysis tool for text mining to find code words in responses shows that the realism of physics was mentioned in some way every time. Most of the time fall speed of the pull tabs, their weight, or gravity was mentioned in some way. For O1, gravity was mentioned 11 times, weight six times, physics four times, pull-tabs being too heavy or too light 12 times total, six times for each heavy and light. For O2 gravity was mentioned four times, pull tabs being heavy five times, them being too light seven times, and throwing the pull tabs was mentioned 14 times. For both O1 and O2, when physics was not mentioned, the questions either weren't answered at all or the answers were ambiguous.

Examples of answers:

- *"I feel like the second time the gravity felt too strong. Of course when you are shrunken down the pull tabs would feel more heavy but it was a bit too much in my opinion"*
- *"I feel like the second time the gravity felt too strong. Of course when you are shrunken down the pull tabs would feel more heavy but it was a bit too much in my opinion."*
- *"In the second experiment* (normal-gravity scenario) *they seems too heavy and are too fast in falling down, also when I throw then I expected that they go far while rotating (like in the first experiment)"* (low-gravity scenario)

For O3, answering if and why priming was or wasn't helpful 29 out of 44 (65,9%) answered in the positive. When giving reasons for when priming worked, the test participants mentioned how it gave a point of comparison to when they were shrunk down afterwards, it also helped them get used to how the different objects should move when interacted with. Test participants who answered that priming helped, 11 of them were those that felt than 'normal-gravity' scenario matched reality and 18 were of those that answered with 'low-gravity' scenario being the realistic one (according to close-ended question 1). For the 15 test participants that reported that the priming didn't help six answered that they based how interacting with the pull-tabs on their intuition based on real life, two answered that being shrunk down is too unique of a state that even priming wouldn't help.

Examples of answers given for those that felt that priming helped:

- *"It gave a better comparison how the gravity, distance and speed would feel at normal size and made it easier to see what was changed when shrunken down."*
- *"After being shrunk I already had a sense of what the weight of a certain object would be, so I could feel the difference"*
- *"It gave me a comparison point. Objects size related to me gives me an expectation of how it should move. I know how a can, a dice, a hammer and a plate behaves in normal life and giving me this reference point in VR sets the reference."*
- *"In the first time when everything was in the real size the dimensions of the object and the way the should have be pulled or dropped on the earth was so real. It helped me to connect the virtual world and get used to the environment."*
- *"I got to experience the "base level" of the interaction that the object had with their surroundings with the normal setting. My expectations were set to that level after being shrunk down."*

Examples of answers given for those that felt that priming did not help:

- *"I feel like I would have had the same experience either way since I feel like the shrinking did not change my expectations that much actually"*
- *"as the "shrunk state" was surreal in itself. it did not matter when thinking in gravities and falling objects"*
- *"I dont think think it changed the way "realistic" gravity would feel by intuition"*

5. DISCUSSION

At the beginning of this thesis, four hypotheses were defined as follows:

- **H1**: For a scaled-down participant, after priming, 'normal-gravity' is more likely to feel realistic than 'low-gravity'
- **H2**: For a scaled-down participant, after priming, 'normal-gravity' is more likely to match the participant's expectations than 'low-gravity'.
- **H3**: Participants experiencing a priming phase are more likely to consider 'normal-gravity' to feel realistic than participants who did not experience a priming phase.
- **H4**: Participants experiencing a priming phase are more likely to consider 'normal-gravity' to match their expectations better than participants who did not experience a priming phase.

In summary of all questions asked and answered, all of the four hypotheses can be rejected. Results show that the majority of participants when interacting in VE, after their size had been altered to be significantly smaller than normal, believe that physics should act as they do in movies and other media rather than how it is in real life. They believe that objects should fly proportionally as far, drop as slowly, and generally behave as they do when interacting with items as though they were proportionally the same as when the participants were regular-sized. The findings of this study align with the results of the study, Pouke et al. [27], which was the motivation for this thesis.

The results of the confirmatory questions show that only less than one-third of the participants felt that when they experienced a scenario with normal gravity, they felt that it was realistic and matched their expectations of how items should behave. These results were contradictory to the first two hypotheses, which posited that after priming and shrinking down the majority of people should feel that 'normal-gravity' was the realistic scenario.

According to the confirmatory questions (questions C1 and C2), the participants expected that objects should fly far and drop slowly, which they experienced in the study's 'low-gravity' scenario. They expected that the objects should behave as they did in that scenario, and they also felt that it was the more realistic one of the two scenarios. Only less than one-third of the participants' expectations and experience matched the 'normal-gravity' scenario, which was what the hypotheses expected that they would answer.

As mentioned above, most of the participants felt that when presented with a 'low-gravity' scenario, the pull tabs behaved as they would in real life, these results can be easily seen in the Likert-scale questions, L1-L6, about pull tab behavior. The results show that the median response is exactly four in the 'low-gravity' condition, meaning that pull tabs behaved as they should and not too much in either direction i.e. falling too fast or too slow. These results were further proven with the statistical tests done, which were one and two-sided binomial tests.

The majority of the study participants (66%) reported that the priming phase helped them in choosing which scenario, 'normal-gravity' or 'low-gravity', felt realistic. Even though the majority reported that it helped, surprisingly more than the 66% answered incorrectly to the question of which scenario was the scenario with correct strength gravity. Perhaps a longer and more varied priming phase would have brought more correct results as a minute or two could be a relatively small time to get used to physics in a new environment. This could be a future avenue of study to investigate whether the time and complexity of the priming affect the results.

The open-ended questions brought clarifications as to why the scenario with 'low-gravity' felt so much more realistic than the 'normal-gravity' scenario. Most of the participants reported that the pull-tabs didn't fly far enough when thrown or fell too fast when dropped. When asked about the priming phase before pull-tabs, the participants felt that it gave them a point of comparison to real life, which should have helped them figure out, which physics scenario was the true one, but they still felt that the 'low-gravity' scenario was the realistic one. The inefficiency of priming can be further extrapolated from the results of comparison with the results from the article by Pouke et al. [27]. The results of the previous study are largely the same as this study, with 12 and 13 out of 44 answering that they felt that the 'normal-gravity' scenario was the realistic one whereas 4 and 7 out of 44 answered that the 'normal-gravity' scenario matched their previous expectations, answers being largely the same it can be extrapolated that no evidence was found that priming would be useful.

As Pouke at al. [27] mentioned in their study, the same was found in this study, scaling down the user and keeping the physic settings the same breaks coherence. As was defined in the introduction chapter coherence is "The degree to which the virtual scenario behaves in a reasonable or predictable way" [23]. And the degree to which the virtual scenario behaved in a reasonable or predictable way was when the participants were in the 'low-gravity' scenario, where gravity was lowered from normal, instead of realistic 'normal-gravity' scenario. This means that to keep coherence, the realism of the VE has to be put on the background and gravity has to be scaled proportionally to the subjects size. Based on the results of the study in this thesis, something other way than priming has to be found to get people to feel that normal, unaltered small-scale VE is realistic. Gravity can be altered and the VR users can keep high coherence with low realism while using small-scale VR in games and other entertainment, where reality doesn't matter, but not where it actually can matter.

This mismatch in keeping coherence levels acceptable while breaking realism can become a problem when multiple users are in the same VE at different scales. As Langbehn et al. described, MCVEs are an important application of VR, helping users to get new perspectives by working in the same environment at different scales at the same time[25]. While doing cooperative work in same MCVE the people working in smaller than normal scale will suffer with feeling that the environment becomes unrealistic as the gravity and other physics phenomena will not scale with them, as such coherence will suffer. These users will have to work in these unrealistic feeling conditions as manipulating physics settings for each person would be possible, but it would also break the usefulness of the VE, since while they felt that they were experiencing the environment in a realistic manner the realism of the environment would be broken as physics in that environment would no longer be realistic. This is specially important that if MCVE users use the same environment at the same time you can not use 'low-gravity' settings for everyone when people are viewing the events from multiple different scales as the settings would be only correct for some of them.

Even if realism was not that important in some specific MCVE, the experiences of the users could not be compared together as their experiences were done as almost in different environments because even though the environment stayed visually the same, changing physics alters it greatly.

The participant's experience was also assessed using the later Likert-Scale questions L7 to L12, which assessed PI i.e. the sensation of actually being in the VE versus being in a laboratory, wearing HMD playing a game. According to the answers, the participants strongly felt that they actually were in the environment they were presented with, and not just in a laboratory being shown images on an HMD. The median of answers to all the Likert questions was larger than 4, where 1 meant that they were not in VE and 7 meant that they were. While they felt that they were actually in a VE at the same time after they were shrunk down, they often that the environment became bigger instead of themselves becoming smaller. Interestingly, this mismatch of sensation of the environment becoming larger instead of participant shrinking down was more pronounced when the participants experienced the 'low-gravity' scenario first. After presenting the 'low-gravity' scenario first, 73% felt that the environment looked enlarged whereas 59% felt the same when the 'normal-gravity' scenario was presented as the first model. This meant that the first physic model that the participants felt had an effect on their experience for feeling wheter the environment enlarged or that they shrunk

5.1. Limitations and Future Studies

The experiment process in this study was relatively short, lasting only about 20 minutes. Out of those 20 minutes most of the time, perhaps as much as two-thirds, was spent doing the questionnaires, which means that the practical portion of the study only took about five to ten minutes. As mentioned in the previous chapter, where the study process was explained, the practical potion, where the participant was in VR interacting with different objects, could be split into two distinct portions. First was the priming, which was done by interacting with objects as a normal-sized person as well as shrunk down, and in a second portion the participants were asked to interact with soda can pull-tabs in two scenarios with two different physic settings 'low-gravity', in which the gravity setting was dialed to be ten times weaker than normal, and 'normal-gravity' where the gravity was let be as it is in real life.

As everything mentioned above was done in five to ten minutes, it did not leave a lot of time for the participant to get acclimated to how things work in a VR environment. It can be theorized that the results of this thesis' study, where participants answered wrong even though they reported that priming helped was due to the shortness of the priming portion. Possibly if the participants were given more ample time to get acclimated, their answers would have been different.

Additionally, the priming process in this study was to interact with objects in a simplistic manner by pushing, picking up, throwing, and dropping items from a table. Maybe the simplistic way of priming also contributed to not being good enough to shape the participants' expectations and experiences according to reality.

One more point against the process of this study is that the experience of becoming shrunken down was very abrupt, happening in a single frame. It could have helped them if the participants could have seen the shrinking happening continuously in a process lasting multiple seconds where they could have looked around as they became smaller and smaller, and everything else seemed to get bigger and bigger until they stopped shrinking.

All the points above could be investigated in separate studies. For example, having priming parts taking a variable amount of time could investigate the effect of time on priming efficiency. Another study could have multiple sets of tasks with differing amounts of versatility. In another study, all the limitations of this study could be combined into one where the participant could be made to play a game with different tasks and interactions with objects where half of the game would be played as their regular selves and another half while scaled-down.

6. SUMMARY

In this thesis a follow-up study was done to Pouke et al. study "The Plausibility Paradox for Resized participants in Virtual Environments" [27], which was expanded on by adding a priming phase to the original study design, and analyzing whether the priming affects the results.

The study was done by creating a VE in which the participants could interact with different everyday objects before they were given a task. Priming is a combination of different kinds of cues that were explored in the Related Work section. We hypothesized that having participants interact with familiar everyday objects in different gravity settings would have been helpful in learning how physically simulated objects should behave at different scales.

The thesis has an explanation of how the experiment was implemented, with related software that was used to create the environment, and a description of how the environment was created and what was added to it. In this study the environment was provided by the thesis supervisor and to it was added the different interactive objects.

The experience of the participants in this VE was documented by having them fill out a questionnaire that asked them about their feelings of how realistic they felt that the different scenarios were, and if they at all matched their expectations of how different objects should have behaved in those scenarios. They were questioned about how they felt that the pull tabs at the end of the experiment behaved, did they fly too far or not far enough, or did they fall too fast or not fast enough. They were also asked about how they felt while they were inside of the environment and of course, they were asked if the priming helped as that was the integral part of the research questions of this study. The specific research questions were as follows:

- **H1**: For a scaled-down participant, after priming, 'normal-gravity' is more likely to feel realistic than 'low-gravity'
- **H2**: For a scaled-down participant, after priming, 'normal-gravity' is more likely to match the participant's expectations than 'low-gravity'.
- **H3**: Participants experiencing a priming phase are more likely to consider 'normal-gravity' to feel realistic than participants who did not experience a priming phase.
- **H4**: Participants experiencing a priming phase are more likely to consider 'normal-gravity' to match their expectations better than participants who did not experience a priming phase.

The data gained from the questionnaire was then analyzed with different methodologies. The raw data and the analysis results were compiled fully into their own chapter, which shows the participants' answers step by step intermingled with the analysis methodologies and their results and descriptions of what the results meant generally. The 'Results' section was followed by a Discussion section further assessing what the results meant and how well they fulfilled the research questions. It could be concluded that based on the data and its analysis the research questions can be rejected fully. The main question that this theses' study went to answer was that if priming would help the participants acclimate enough that they would feel that how the objects should behave when scaled down was the same as they would behave. The results of this study was then compared to the study that this was a follow-up of and based on the results of both studies and the comparison of their answers it can be concluded that priming was not enough to help the participants.

It can be questioned if the priming phase in this study was not long enough or should have been more varied with more objects and different kind of tasks. More studies should perhaps be done before priming is wholesale rejected as a method of changing participants' experiences in VR.

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