EFFECTS OF SCALING SHOULDER WIDTH IN VIRTUAL REALITY ON REACHABILITY AND PASS-THROUGH-ABILITY AFFORDANCES

SAFA ANDAÇ

BOĞAZİÇİ UNIVERSITY

2021

EFFECTS OF SCALING SHOULDER WIDTH IN VIRTUAL REALITY ON REACHABILITY AND PASS-THROUGH-ABILITY AFFORDANCES

Thesis submitted to the

Institute for Graduate Studies in Social Sciences

in partial fulfillment of the requirements for the degree of

Master of Arts

in

Cognitive Science

by

Safa Andaç

Boğaziçi University

2021

DECLARATION OF ORIGINALITY

I, Safa Andaç, certify that

- I am the sole author of this thesis and that I have fully acknowledged and documented in my thesis all sources of ideas and words, including digital resources, which have been produced or published by another person or institution;
- this thesis contains no material that has been submitted or accepted for a degree or diploma in any other educational institution;
- this is a true copy of the thesis approved by my advisor and thesis committee at Boğaziçi University, including final revisions required by them.

Signature ....

Date ....

ABSTRACT

Effects of Scaling Shoulder Width in Virtual Reality on

Reachability and Pass-through-ability Affordances

Perceiving affordances, the action-possibilities of a system in an environment, is a survival key for the system (Gibson, 1966). Changing invariants for the system shapes its affordance perception (Warren & Whang, 1987). Pass-through-ability of an aperture, as a perceived affordance, is determined by the fit between the apparent aspects of the environment (e.g., perceived gap) and the perceived body scale. Changing body perception in real life depends on using tools such as a wheelchair or a long stick (Higuchi, Cinelli, Greig, & Patla, 2006; Higuchi, Cinelli, & Patla, 2009). Here, in order to understand the effects of body scaling on the affordance of pass-through-ability and reachability, we conducted a virtual reality and a simulation study. Participants were assigned to different virtual shoulder widths scaled to their real size (narrow, normal and wide). In the experiment, they were asked to walk naturally to pass through an aperture without colliding and reach a target on a table. The success rate of passing through an aperture and the speed were similar in all conditions, which implied that participants adapted their virtual bodies. We also showed that participants were closer to the target when assigned narrow compared to a normal-size shoulder, suggesting that participants thought their body became smaller, so they moved closer to the target. In order to control the adaptation for conditions, we also conducted a perceptual judgement experiment. Also reflected in the perceptual judgements, participants with narrow virtual shoulders thought that they had smaller shoulder width, an effect not observed in the wide shoulder condition, which together demonstrate an asymmetry in the effects of body scaling.

ÖZET

Sanal Gerçeklikte Omuz Genişliğini Ölçeklendirmenin Erişilebilirlik ve Geçilebilirlik Sağlarlıkları Üzerine Etkisi

Bir sistem için çevresindeki olası eylemleri tanımlayabilmesi, başka ifadeyle sağlarlık algısı hayatta kalabilmesi açısından önemlidir. Sistemin, çevrede var olan bazı değişmeyen parametreleri üzerinde değişiklik yapmak sistemin sağlarlık algısını da değiştirmektedir. Geçilebilirlik sağlarlığı sistemin algıladığı aralık ile kendi beden algısı arasındaki ilişkiye bağlıdır. Gerçek hayatta beden algısının değişikliği tekerlekli sandalye veya uzun bir çubuk kullanımına bağlı olarak değiştirilebilmektedir. Bu tez çalışmasında ise, vücut ölçeklendirmenin geçilebilirlik ve uzanabilirlik sağlarlığı üzerindeki etkilerini anlamak için bir sanal gerçeklik ve simulasyon çalışması gerçekleştirilmiştir. Katılımcılar, gerçek omuz büyüklüklerine göre ölçeklendirilmiş farklı sanal omuz genişliklerine (dar, normal ve geniş) atanmıştır. Deneyde, bir aralıktan doğal bir şekilde çarpmadan geçerek bir masa üzerindeki hedefe sağ elleri ile ulaşmaları istenmiştir. Tüm deney durumlarında aralıktan devirmeden geçme oranları ile aralıktan geçerkenki hızlar benzer bulunmuştur. Bu sonuç, katılımcıların atanan sanal bedenlerine uyumlandığının bir göstergesi olmuştur. Ayrıca, katılımcıların normal durumlarına göre daha dar omuz atandıklarında hedefe daha yakın bir mesafede durduğu gösterilmiş, bu sonuç katılımcıların vücutlarının sanal ortamda küçüldüğünü düşündüklerine işaret etmiştir. Koşullara uyumu kontrol etmek için yapılan algısal yargı kontrol deneyi de dar sanal omuz durumundaki katılımcıların daha küçük omuz genişliğine sahip olduklarını düşünerek karar aldıklarını, geniş omuz koşulundakilerde ise bir etki olmadığını, sanal bedene uyumda bir asimetri olduğunu göstermiştir.

ACKNOWLEDGMENTS

Throughout the thesis writing process, I have received a great deal of support. I would first like to thank my thesis advisor, Dr. Inci Ayhan, for sharing my excitement in this study and assisting me at all stages. I would also like to thank my thesis co-advisor, Assoc. Prof. Emre Uğur, for identifying critical points and making valuable advancements in the methodology.

I would like to thank all members of VisionLab. Our lab meetings were always inspirational and introduced me to the first steps of building things indistinguishable from magic.

I also want to thank my friends -Hamit and Didem-, who have always been a source of help and receiver of complaints when things would get a bit discouraging and stressful.

Finally, I must express my gratitude to my wife, Aslınur Andaç, forever and ever being there for me.

DEDICATION

To my wife, who keeps telling me she loves me

TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION 1
1.1 Perception of the body schema and body embodiment 2
1.2 Effects of manipulating actions on affordance perception 5
1.3 Pass-through-ability affordance 6
1.4 Reachability affordance 8
1.5 Perception in virtual reality 9
1.6 Motivation of the study 10
CHAPTER 2 VR EXPERIMENT 12
2.1 Participants 12
2.2 Stimuli and apparatus 12
2.3 Procedure 13
2.4 Results 20
2.5 Discussion 31
CHAPTER 3 SIMULATION EXPERIMENT 33
3.1 Participants 33
3.2 Stimuli and apparatus 34
3.3 Procedure 34
3.4 Results 40
3.5 Discussion 47
CHAPTER 4 GENERAL DISCUSSION AND CONCLUSION 49
APPENDIX A ETHICS COMMITTEE APPROVAL FOR VR EXPERIMENT 54
APPENDIX B ETHICS COMMITTEE APPROVAL FOR ONLINE SIMULATION 57
APPENDIX C BODY OWNERSHIP QUESTIONNAIRE (ORIGINAL TURKISH VERSION) 58
APPENDIX D BODY OWNERSHIP QUESTIONNAIRE 59
REFERENCES 61

LIST OF FIGURES

Figure 1 Models for T-position and standing position 15

Figure 2 One trial in a condition 18

Figure 3 Instantaneous speed near the aperture (x = -0.05 cm) 22

Figure 4 Psychometric thresholds with 75% success 23

Figure 5 Psychometric functions of AT in aperture task 24

Figure 6 Head position data of one participant from post-narrow group 26

Figure 7 Absolute perceptual thresholds of two participants in post-narrow condition 30

Figure 8 Mouse calibration scene in the simulation 37

Figure 9 Psychometric thresholds with 75% success in simulation 42

Figure 10 Psychometric functions of FWD in aperture task 43

CHAPTER 1

INTRODUCTION

In order to engage correctly and safely with the environment, biological systems perceive the environment with respect to their bodies. Thus, survival in the environment depends upon the body perception and bodily interactions with the environment. These interactions can be described in terms of the system or agent's action possibilities. Gibson coined the term “affordances” to explain what the environment offers to the system (Gibson, 1966). If we consider the system-environment relationship through the concept of affordances, instead of using metric measurements and features that depend on metric evaluations to describe the objects in the environment of the system, an agent can perceive affordances that objects offer with respect to its body through the fixed quantities (invariants) determined by the environment. To give an example, in order to act on a cylindrical shaped mug with a handle on a table, a human does not evaluate features of it, such as its shape and size. It rather perceives affordances the mug affords, such as to be touchable, graspable, fillable and rollable. If the object starts to be bigger than the hand, the grasp-ability of the object with respect to the person disappears. If it is too small, it begins to lose its fillability affordance.

Affordances of objects can vary with respect to the body of the biological system (Gibson, 1979). Throughout the development, for example, whereas a solid object at a certain height is an obstacle for a nine-month-old baby, it is “climb-able” by the age of two and ceases to be an obstacle by the age of seven. An adult agent perceives the affordance of such an object as “jump-over-able”. When considering different biological systems, we can also see that affordances of the same object can vary. For instance, a mug is graspable for a person but climbable for an ant. These possible ways of interactions are determined by the relationship between an agent and the environment.

The aim of this thesis is to investigate the effects of scaling of shoulder widths on two affordances, namely the pass-through-ability and the reachability, in a VR environment. So, the thesis has mainly three different components. The first component is about body perception. The second one is about affordance perception. The last one is the relationship between body perception and affordance perception in the VR setting.

1.1 Perception of the body schema and body embodiment

The plasticity in the somatosensory cortex allows us to have a flexible perception of our body parts. The homunculus representation to represent flexibility that comes with plasticity was proposed by Lanier (2006), suggesting that each body part is represented in a different somatosensory area, but the representations can be altered (Ramachandran & Hirstein, 1998; Ramachandran & Blakeslee, 1999). For instance, limb losses in accidents lead to a change in the somatosensory area such that the representation of the lost limb is replaced by the representation of another body part. The homunculus figures that show motor and somatosensory mapping of the body parts were originated from Penfield & Boldrey (1937). In these figures, body parts are represented in a way that the body part size corresponds to the neuronal representation in the somatosensory or motor cortex.

When perceiving our body parts, we use different sensory information which come from different modalities. Disrupting visual information may lead to phenomena in which people perceive objects as their body parts. One of such phenomena is the Rubber Hand Illusion (RHI) (Botvinick & Cohen, 1998). In RHI, people see a rubber hand which is stroked with a brush while their corresponding hand - which is not in their visual field - is also stroked at the same speed. Following this adaptation period, people perceive the rubber hand as their real hand. The phenomenon appears not only with a rubber hand but also a virtual one (Slater, 2008). The index for the RHI is the proprioceptive drift of the perceived hand position. The studies demonstrate that the perceived hand position shifts toward the rubber hand position (Botvinick & Cohen, 1998; Slater, 2008). Even though the proprioceptive information signals the unbiased position of the hand, these results suggest that people rely on the combination of both visual feedback and proprioceptive feedback while perceiving their body parts in space. In the RHI, change in the visual feedback leads to a change in the perception of the position of the body part. The phenomenon was also replicated in a virtual reality study (Aldhous, Hetherington, & Turner, 2017). Moreover, the effect was found was to be similar with the original RHI.

When it comes to the embodiment of the avatars in VR, there are many studies that investigate the relationship between an avatar and a user. Depending on the body type and shape of an avatar, an adaptation period, where users interact with the virtual environment with immerse sensory feedback allows them to embody the body of the avatar. Sensory feedback does not only depend on the visual information but also the tactile information that can be used in the virtual reality. In other words, interaction in a virtual environment becomes similar to the one in the real-life. In fact, people perceive that the body they use in the virtual reality environment as their real body even when using avatars with different identities than their own, with different age, gender or race (Banakou, Groten, & Slater, 2013; Salmanowitz, 2018;

Slater et al., 2010). Moreover, people can also adjust their behaviors when controlling an avatar which does not have a facial expression to express their feelings (Roth et al., 2016).

Body embodiment is not just a phenomenon with virtual bodies that can have a particular form. People can also adjust their movements within an avatar which pushes the limits of homuncular flexibility. After Lanier (2006) proposed the homuncular flexibility, he started using different avatars, which shared similarities with animals in his informal studies. He observed that people could find new action-motor mappings to control extra limbs assigned in virtual reality. In a formal study conducted by Won et al. (2015), the authors showed that people with novel virtual avatars could remap their movements into the real world to perform better in a task in the virtual reality. For instance, people assigned to 3-armed avatars adapted to the avatar and performed better than those who controlled 2-armed avatar in a virtual task in which using the third hand had an advantage.

Studies on body image are not limited to VR. With the use of different objects and tools, we can alter the body perception of people. In order to investigate such adaptations, researchers conduct studies about affordance perception. For example, the stick held to reach an object causes dramatic changes in the body perception (Sposito, Bolognini, Vallar, & Maravita, 2012). Macaque studies have also suggested that there is a change in the somatosensory region of the macaques to represent the tip of the stick (lriki, Tanaka, & Iwamura, 1996). There is also an extension in the peripersonal space (PPS), which is the area in which an agent can reach or be reached by a tool to an object, affecting the judgment of whether to reach to an object. These studies demonstrate that an agent constantly updates the representations of the outer world with respect to their bodies and base their perceptual judgments on the interaction with the environment instead of using fixed metrics when perceiving their own bodies

VR and tool-use studies show that the perception of body is dynamic and flexible as discussed above. Thanks to this flexibility, people can succeed in tasks in the virtual environment by adapting to a new virtual body and learning to use limbs they don't have in real life. One thing that needs to be considered during the adaptation process, though, is that the new virtual limb or the tool they are adapted to use should be relevant to the task.

1.2 Effects of manipulating actions on affordance perception

As seen in a human's developmental progress, affordance perception changes, and objects start offering new types of affordances, while losing some to the agent. When having an older body, a heavier or a shorter one, people perceive stairs as steeper (Eves, 2014). Physical conditions also affect affordance perception. When people are exhausted or have low physical fitness, they judge slopes steeper. Carrying heavy loads also has similar effects (Bhalla & Proffitt, 1999). Moreover, participants perceive jumpable gaps longer when wearing ankle weights, whereas the judgments are not affected for the un-jumpable gaps (Lessard, Linkenauger, & Proffitt, 2009).

Affordance perception is also changed by the tool use but in an indirect way. When using a tool, the representation for the related body part and peri-personal space (PPS) representation are updated. For instance, Canzoneri and his colleagues (2013) found the PPS is extended along the tool use axis. Moreover, the body part used for the tool is perceived as narrower and longer like the shape of the tool. However, in order to have such an effect, active tool use is necessary. Another condition for such an effect is that the function of the tool must be relevant to the action during the task (Bourgeois, Farnè, & Coello, 2014). So, tool use reshapes not only the body representation but also the PPS that encodes the close-distance environment.

Tool use changes the reachability affordance and depth perception, but only when the subject plans for a reaching action (Witt, Proffitt, & Epstein, 2005). This suggests that representation of the environment depends on the intentions and abilities to act. Moreover, somatosensory mapping of the body parts and their positions are constantly updated by the interaction between the agent and the environment (Sirigu, Grafman, Bressler, & Sunderland, 1991). The neuroscientific study conducted by Irıki and his colleagues (1996) showed that the neural representation of the hand of a macaque in the somatosensory cortex was reshaped after the tool use. During the action phase, the visual receptive field was also adjusted to cover the expanded reach area accessible by the tool.

1.3 Pass-through-ability affordance

The pass-through-ability affordance helps the system to change its location without any collision between obstacles in the environment and the body. In other words, the ability to perceive the pass-through-ability of apertures helps one follow another secure and efficient trajectory. Navigation through such environments needs some adjustments in the body posture and gait so that a biological system can pass through narrow apertures or follow a different trajectory if passage is not possible. So, in order to select an efficient and safe trajectory for a task, the ability to perceive the pass-through-ability of apertures in advance is necessary.

Studies about pass-through-ability affordance in humans started with Warren and Whang (1987). They asked participants to walk at their natural speed when passing through apertures. They found that participants made some adjustments in their posture and gait when the ratio between aperture width and shoulder width is smaller than 1.3. This implies that people leave some safety margin to account for lateral body sway during their movements. The strategies that people follow when passing through narrow apertures are slowing down to reduce body sway, rotating the shoulders, or passing sideways (Higuchi et al., 2006).

The perception of pass-through-ability can be achieved across a wide variety of conditions, but these perceptions may differ. For instance, Warren and Whang asked participants to judge whether they could pass or not through an aperture from a fixed distance. The threshold ratio between aperture and shoulder width for such judgement is 1.15, which is smaller than the critical 1.3. Furthermore, the threshold increases when running, carrying an object or walking with another person (Chang, Wade, & Stoffregen, 2009; Wagman & Malek, 2007; Wagman & Taylor, 2005). Disabled people who use wheelchair extensively and so that have experience for locomotion can take into account their extended bodily dimensions for pass-through-ability affordance (Higuchi et al., 2006; Higuchi, Takada, Matsuura, & Imanaka, 2004).

Warren and Whang (1987) found that changing eye-height information in the system led to some errors in pass-through-ability perception. This suggests that people make their judgements based on their fixed ratios with the environment. Fath and Fajen (2011) considered three sources of visual information used in the system to determine the pass-through-ability of apertures and its perception. These three sources were eye height-scaled information, head-sway-scaled information and stride-length-scaled information. All this information was body-scaled. Their study found that even when the eye height-scaled visual information is not available, the system can still make good perceptual judgements.

1.4 Reachability affordance

Reachability affordance refers to how far an agent can extend its reach; thus, reachability perception provides a metric for agents to scale close distances. The perception of reachability changes after tool use or manipulating the visual feedback of the hand position of an agent. For instance, when using a tool, targets which are out of the reach by hand appear to be closer (Witt et al., 2005). A tool which helps an agent extend its reach reshapes the perception of the agent so that it leads to a decrease in the apparent distance to the target object. In other words, tool-use changes the representation of the reaching limb of the agent so that it represents the entire tool or the end-effector (Ackroyd, Riddoch, Humphreys, Nightingale, & Townsend, 2002; Berti & Frassinetti, 2000; Pegna et al., 2001).

When it comes to reachability studies in VR, Day et al. (2019) compared the usage of normal avatars and altered body avatars, which have longer arms than the normal ones, for a reaching task. Their results showed that participants adjusted to an altered avatar only when they got feedback during their actions to complete the task. Moreover, calibration took place more quickly if there was feedback such as tactile or visual to have them feel the transition from the normal to the altered avatar. Another worth to mention study conducted by Joy and her colleagues (2021) shows that the participants do action planning faster in a reachability task when they control hands which offer less affordances than normal hands after an adaptation period. Overall, people can adjust to novel body limbs and update their actions and motor planning accordingly.

1.5 Perception in virtual reality

Affordance perception studies depend on external tools and objects to manipulate the agent body to investigate the perception in a controlled manner. However, since using external objects is a limited method to study affordance perception, as seen in the literature, there are some cases in which affordance perception cannot be investigated without changing the agent’s body. So, in such cases, virtual reality offers a precious tool. With the developing technology and possibilities, Using VR paradigms in studies helps us control some variables in a way that it is not possible in real life. With the increase of hardware and users that support virtual reality environments, it has become much easier to control the desired variables by designing a completely different environment than the reality. Virtual reality not only allows us to manipulate the environment but also modify an agent’s virtual body and see its effects through the embodiment of the avatar.

If the reality of the environment in an experiment performed in VR is properly adjusted, a participant's actions are closer to reality as they interact better with all the stimuli in this environment. In this way, participants have an experience independent of their real environment. Thanks to the tracking devices used in VR which transfer the actions of the agent’s body directly to the VR environment, it is also possible to conduct action and perception studies in a better way.

In VR, not only can we change the body and environment but also, we can manipulate effects of actions which participants perform in real life. However, there are still issues to be considered when conducting an experiment in the virtual environment. Apertures that afford pass-through-ability in virtual reality environment are larger than in real world (Fath & Fajen, 2011). Moreover, people perceive distances in virtual reality as closer than normal in real life (Knapp & Loomis, 2004; Thompson et al., 2004). Therefore, the ranges used for control are chosen wider than normal. If participants perceive that the environment in virtual reality is similar to the one in real life, the distance perception in the former is similar to the one in the latter (Geuss, Stefanucci, Creem-Regehr, & Thompson, 2010). In order to match the environments, Geuss and his colleagues created a 3D virtual replica of the experimental setting. They measured perceived affordances with judgments of distance and size. They found that affordance judgments were not significantly different for the virtual environment and the real world.

We can perceive distances with respect to the horizon that exists in the real world and optical flow created by movements of either an agent or an object. When we remove an invariant such as horizon line in a virtual environment, it has been observed that people can pass through apertures in the virtual environment even without the eye-height information, which is important in the perception of pass-through-ability (Fath & Fajen, 2011). Other information used in the study are invariants that emerge dynamically depending on body movements. Thanks to the dynamic stride-length-scaled and head-sway-scaled information, an agent can find whether an aperture affords pass-through-ability. In this way, the perception of the ability to pass through an aperture using dynamic information, which is obtained from the environment in different ways, and scaled according to the body, can be achieved without the knowledge of eye-height, which is statically processed.

1.6 Motivation of the study

This study aimed to investigate the effects of scaling shoulder widths on the reachability and pass-through-ability affordances. The novelty in our work was to directly change the body morphology, rather than using external tools to change the affordance perception as has been done in the previous studies. In order to do that, we designed a virtual reality experiment, where we assigned participants different virtual shoulder widths scaled to their real shoulders. The task of the participants was to pass through apertures which were scaled to virtual shoulder widths and reach a target on a virtual table. In order to check whether participants had an understanding of their new body dimensions, we conducted a perceptual threshold experiment similar to the one in Warren and Whang (1987) study.

In the second part of the study, we conducted a simulation experiment to test the replicability of the results in the VR experiment on a 2-dimensional gaming platform. Due to the COVID-19 pandemic, the experiment was implemented in a simulation and published online. This simulation experiment also allowed us to check the effect of horizon on the pass-through-ability and reachability affordances.

CHAPTER 2

VR EXPERIMENT

2.1 Participants

Twenty participants (14 male, 6 female) participated in the VR Experiment. Participants were mostly undergraduate students from Özyeğin University. They were recruited via convenient sampling on a voluntary basis. They received 3 extra course credits in exchange of their participation. All observers had normal or corrected-to-normal vision (the VR headset has the required space inside to be worn with eyeglasses) and were naive to the purpose of the experiment. Ages of participants were in the range between 20 to 35 years old with a mean of 23. There were 4 participants who reported that they had VR experience before; the number of hours they experienced, however, was less than an hour except for one of them. Eighty-five percent of the participants were right-handed, and the rest were left-handed. The study was compliant with the university research ethics requirements and approved by the Özyeğin University Ethics Coordinating Committee (see Appendix A). Confidentiality and anonymity were ensured by saving data using the initials of participants' names. The consent form and instructions were given in Turkish.

2.2 Stimuli and apparatus

Stimuli were 3D models, most of which were downloaded from the Unity Asset Store and Sketchfab. Two side-by-side walls were used to create an aperture in the virtual environment. The bricks that made up these walls were created using the Blender 3D modeling software. Stimuli for the VR experiment were presented using an HTC Vive Pro Full Kit. The system was connected to a desktop computer, MSI Aegis 3 with hardware specifications of Intel i7-7700 CPU, 16GB DDR4 RAM and 1070 GTX 8 GB graphics card.

Paradigms for the VR experiment were implemented in Unity 3D Game Engine, version 2019.1.0f2 with C# programming language. To control the headset and remote controllers, we used SteamVR 2.0 Unity Plugin. Unlit shader types allowed stimuli to have the same perceived color from different angles.

Stimuli were presented from a head-mounted display. The virtual environment lacked the horizon line to disrupt the distance perception of the participants (Fath & Fajen, 2011; James J Gibson, 1979). In each trial, participants saw two building blocks and a table without legs behind the blocks. For participants to interact with the environment, such as with building blocks, a box collider was assigned to participants. The reference point of the collider was the position of the head mounted display with respect to the origin of the virtual environment. The width of the box collider represented the shoulder width in the virtual world. Participants reached the target on a virtual table with a right-hand controller.

2.3 Procedure

Participants were given an informed consent form prior to the experiment. They were assigned into four different experimental groups. The group naming convention depends on the order of the shoulder-length conditions that the participants took; namely the normal-narrow, narrow-normal, wide-normal and normal-wide. In the VR experiment, in a virtual open environment, in which there was no horizon, participants saw an aperture between the walls. Behind the walls, there was a virtual table without legs. In each trial, the aperture between the walls was scaled to the virtual shoulder width, which was also scaled to the shoulder width of a participant. There were three different virtual shoulder widths as conditions in the experiment. Participants were instructed to walk naturally to complete the task, which consisted of two stages: The first part was to pass through the aperture without colliding to the walls. After passing through, the second part was to stop nearby a table and reach a target on the table with the right hand. The important thing here was that participants could not get any visual feedback for their reaching to the target, which meant that they couldn't see any virtual hand or a model that represented their right hand. In blocked trials, the aperture width and the target location (near, middle and far distances) were manipulated. Those two variables were determined as independent variables. At each rendering frame of the Unity Game Engine, the virtual positions of the head mounted display, and the right and left remote controllers of HTC device were collected together with the rendering time.

After the block of an experimental condition was completed, participants took a perceptual judgement experiment. In this setup, the walls shown in the first part slid towards each other at a fixed speed in each trial. The walls were presented at three different distances (near, middle and far). Participants were instructed to press a trigger button on the remote controller when the aperture width between the walls was the minimum width that they thought they could pass through without colliding. Aperture widths when a participant pressed the button and the distances between the walls and the participant were saved in a data file.

There were three major parts in the procedure, one of which was the calibration of the system to a participant. Another part was related to tasks in which participants were instructed to pass through an aperture and reach a target on the virtual table. This part included three blocks for each condition, and each block had fifty trials. After one condition was completed, participants finished a perceptual judgment task in order to see the effects of manipulation in shoulder width.

2.3.1 Calibration

For objects and distances in the virtual environment to be compatible with the real body of a participant, we included a calibration phase to the experiment. Calibration phase was initiated after a participant wore the head mounted display and held the controllers. In order to get the height and the shoulder width of the participant, two humanoid models were shown. Before each block, participant was asked to do the same body postures as the models (Figure 1).

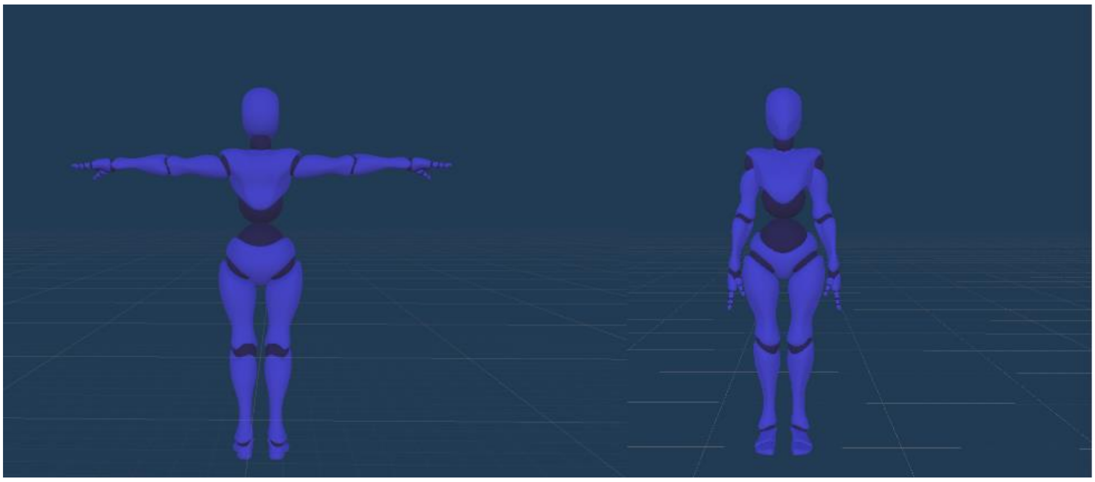


Figure 1 Models for T-position and standing position

The model on the left represents the T-position body posture and the one on the right represents the standing body posture. Participants saw these models in the calibration part. When they were doing the same postures as the models an algorithm calculated their height and shoulder width.

The model with the T-position body posture was used to calculate the height of the participant. When the participant was performing the T-position body posture, they were asked to press the trigger button of the left controller. After pressing the button, the arm-span was defined as the distance between the controller positions. Since the ratio between the height and the arm-span is approximately a one-to-one ratio for European people (Quanjer et al., 2014), the arm-span length was assigned as the height of the box collider. For the participant to reach the target on the table naturally, the height of the table was set to be the 5/8 of the arm-span length.

The model with the standing position was used to calculate the virtual shoulder width of the participant. Depending on the condition (wide, normal or narrow), 1.5 times, 1 time or 0.67 times the distance between the controllers in this position was assigned as the width of the box collider. The width of the box collider represented the virtual shoulder width in the experiment. The aperture widths between building blocks were generated using this virtual shoulder width.

2.3.2 Experiment

After the first calibration, for participants to understand the task, there was a practice session in which there were five trials. If participants did not understand the task, a few more trials were added to the practice session. In the practice session, participants were instructed to stand on a red area on the ground which indicated the starting position of a trial. When they thought that they were in the red area, they were asked to press the trigger button of the right controller in order to start the trial. After the button press, participants were presented with two building blocks and a table without legs behind the blocks (Figure 2). Their task was to pass through an aperture between sidewalls without touching the blocks and reach a target on the table with their right hand. Participants were also asked to move naturally and not to rotate their shoulders when passing through the aperture.

Participants approaching the table after passing the aperture stood near the table and reached the target with their right hand. Meanwhile, since a model representing the hand was not made available to the participants on purpose in the virtual reality, they were instructed to wait for 0.75 seconds in that position. This waiting period was used to keep the hand position fixed. After the waiting period was over, a new table with building blocks were generated behind the participant. The red area was also redisplayed to signal the start of a new trial.

Participants were asked to stand on the new area and turn towards the direction of an arrow. There were three reasons for using this arrow. The first reason was to avoid that the cable of the head mounted display disturbed the participant during the experiment and got caught in the feet of participants. The second reason was to avoid a possible damage to the cables due to the incorrect turns. The third and the most important reason was that the dimensions of the real space used for virtual reality were small (3 x 5 m); thus, the arrow direction helped the environment for experiment to work symmetrically so that the participant did not have to go back to the original red area in each trial.

After standing in the red area and turning in the right direction, participants pressed the trigger button on the right controller when they were ready. They went back and forth in virtual environment through physically moving in the real room and completed the practice session.

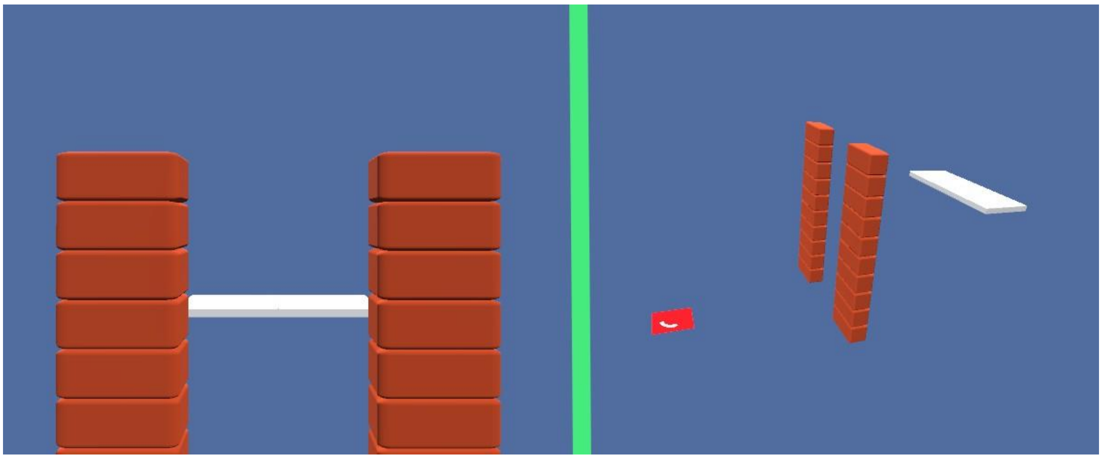


Figure 2 One trial in a condition

The view on the left side shows the first-person view. Participants saw all stimuli from that angle. The view on the right side shows the third person view of the environment. The starting point is indicated with the red area. The arrow points the direction of which participants should turn around before starting a new trial.

After the practice session, participants started with either narrow, normal or wide shoulder condition. Calibration took place before each condition. For any condition, there were three blocks and each block had fifty trials. Participants could give a break after a block was completed. Participants were informed of how many trials were left in half of each block and in their last ten trials. Ten different aperture widths were generated and scaled to virtual shoulder width for each condition. The scales were ranging from 1.1 to 1.55 by 0.05 increments. Each block had five trials for each different aperture width. So, there were fifteen trials for each aperture width in one condition. In each block, we ensured that the consecutive trials did not have the same aperture width.

There were also three different positions (near, middle and far) on the virtual table for the target and they were randomly assigned in each block. Since one block had fifty trials, the number of trials for different target positions was not equal to each other. Total number of trials for three different target positions were equalized in three blocks.

In the data recording of each trial, we saved the virtual positions of the head mounted display, right and left controllers for each frame, whether building blocks were touched, the ratio of the aperture width to the virtual shoulder width, the position of the target on the table, the time to complete the trial, and the time interval between two frames. Data recording was completed after the trial ended.

2.3.3 Perceptual judgement

After completing 150 trials for a condition, a perceptual judgment experiment was conducted to see the effect of shoulder width change. In this experiment, participants were shown two building blocks approaching each other at 0.2 m / s in virtual reality. The initial distance between these blocks was determined to be 1.5 m. In order for participants not to give same responses for one distance, 3 different distances were assigned for the distance between the participant and the walls. In each trial, participants could see the walls from either 1.5m, 2m or 2.5m away. There were 8 trials for each different distance with a total of 24 trials.

In the perceptual judgement experiment, participants were first asked to stand in the red area, as in the original experimental part. Afterwards, they were asked to press the trigger button on the controller in their right hand at the minimum distance that they thought they could pass through the aperture between blocks without rotating their shoulders. A new trial was generated each time they pressed the trigger button. In each trial, the distance between the walls when the participants pressed the button was recorded.

After the perceptual judgment experiment, participants took a break. They then performed the same tasks with a different virtual shoulder width, except for the practical session, depending on the group to which they were assigned. They also completed the corresponding perceptual judgement experiments.

2.4 Results

There were three main hypotheses in the experiment. The first one was about the novel shoulder width adaptation. To check whether adaptation took place, we compared the speeds of the participants as they passed through apertures. The second hypothesis was to see whether there is an adaptation transfer from the shoulder to the hand. In order to check the hypothesis, head data and right-hand data were analyzed. Finally, the last hypothesis was about the effects of novel shoulder widths on the perception of pass-through-ability. For this hypothesis, the perceptual judgement differences between the conditions were analyzed.

2.4.1 Instantaneous speed

For the analysis, we used instantaneous speed of the head at the relative position x = -0.05 cm away from the center of an aperture. To calculate the instantaneous speed at this specific position, the first step was to calculate the instantaneous speed using the time difference between the subsequent position records for each head data point. The second step was to find the time at which the participant was located at that specific position using the linear interpolation method on the head data positions. Having found this time point, we applied another linear interpolation on the speed data calculated in the first step. In order to compare the instantaneous speed between conditions, we applied a linear mixed modeling (LMM) with the equation (1) in Wilkinson notation, instead of an ANOVA,

$$\text{speed} \sim \text{ratio} * \text{condition} + (\text{ratio} + \text{condition} \mid \text{participant}) \tag{1}$$

where, the “ratio” variable refers to the ratio between the aperture width and the virtual shoulder width of a participant. Since there were 10 different ratios, the variable was considered as a categorical variable with 10 factors. The “condition” variable is a categorical variable which represents the shoulder width conditions in which participants completed the experiment. The “participant” variable indicates different players and is also a categorical variable.

There were several reasons why we applied LMM. One reason was that since we collected more than one sample for one condition, the data consisted of dependency such that it was not possible to apply ANOVA directly because one of the assumptions of ANOVA is that the data should be independent of each other. The second reason was that our experimental paradigm did not have a conventional independent variable, which was the variable representing shoulder width. The shoulder width condition variable is a within subject variable when we consider the normal and narrow conditions or normal and wide conditions, but it is a between subject variable when considering narrow and wide conditions. In order to take into account those issues, we needed to apply LMM. After having a model for the data, we could apply ANOVA into the model so that we investigated the effects of independent variables.

ANOVA was applied on LMM with Satterthwaite approximation. Satterthwaite approximation was used for effective standard pooled variance estimation, which means the effective degrees of freedom. The results of ANOVA showed that there was not any speed difference between the conditions ($F(2, 11.548) = 2.90$, $p = .09$). There was a main effect of ratio on speed ($F(9, 48.733) = 4.13$, $p < .01$). Post-hoc analysis also showed that participants were faster when passing through the aperture with a 1.55 ratio than when the aperture had a ratio of 1.1 ($p <$ .01). Analyzing the instantaneous speed, no interaction was found between the ratio and the condition ($p > 0.05$).

A non-significant result for speeds in different conditions may suggest that participants successfully adapted to different shoulder widths (see Figure 3). The main effect of ratio on instantaneous speed demonstrates that participants walked faster when the aperture was wider.

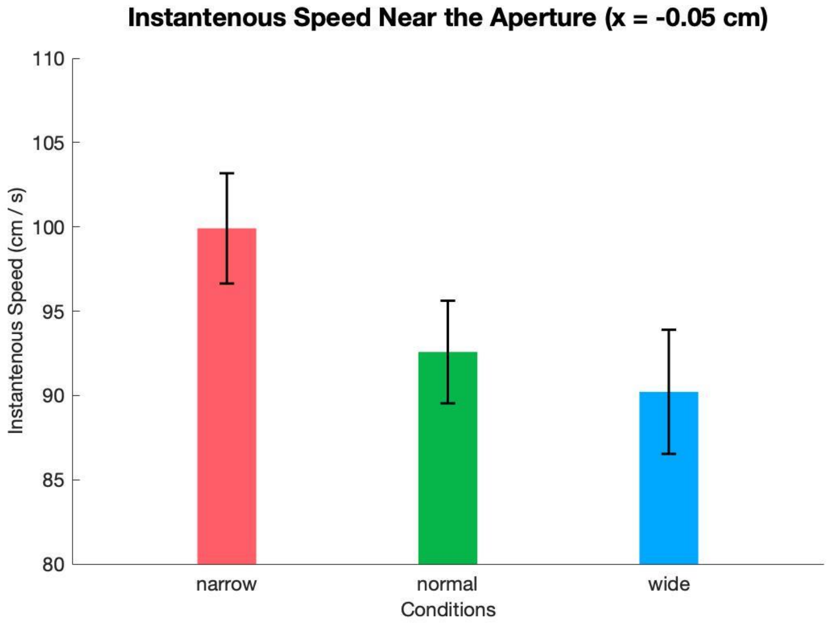


Figure 3 Instantaneous speed near the aperture (x = -0.05 cm)

The y axis of the figure shows the ratio between the aperture width and the virtual shoulder width while the x axis shows all conditions. The figure shows speed bars and standard error bars for all conditions.

2.4.2 Aperture threshold ratio

Aperture threshold ratio is the ratio between the width of an aperture and the shoulders of a participant such that the participant can successfully pass through the aperture without colliding the side-walls in 75% of the trials. In order to calculate the threshold for each participant, psychometric functions were obtained using the psignifit (Schütt, Harmeling, Macke, & Wichmann, 2016) library in MATLAB. LMM was used with the equation (2).

$$\text{threshold} \sim \text{condition} + (1 \mid \text{participant}) \tag{2}$$

ANOVA with Satterthwaite approximation showed that there was not any difference across the different shoulder width conditions ($F(2, 21.588) = 2.54$, $p = .10$).

In addition to the speed analysis, similar thresholds when passing through the apertures in different conditions supported the idea that the participants adapted to the different shoulder widths and, that their performances were similar in different shoulder width conditions (see Figure 4 and 5).

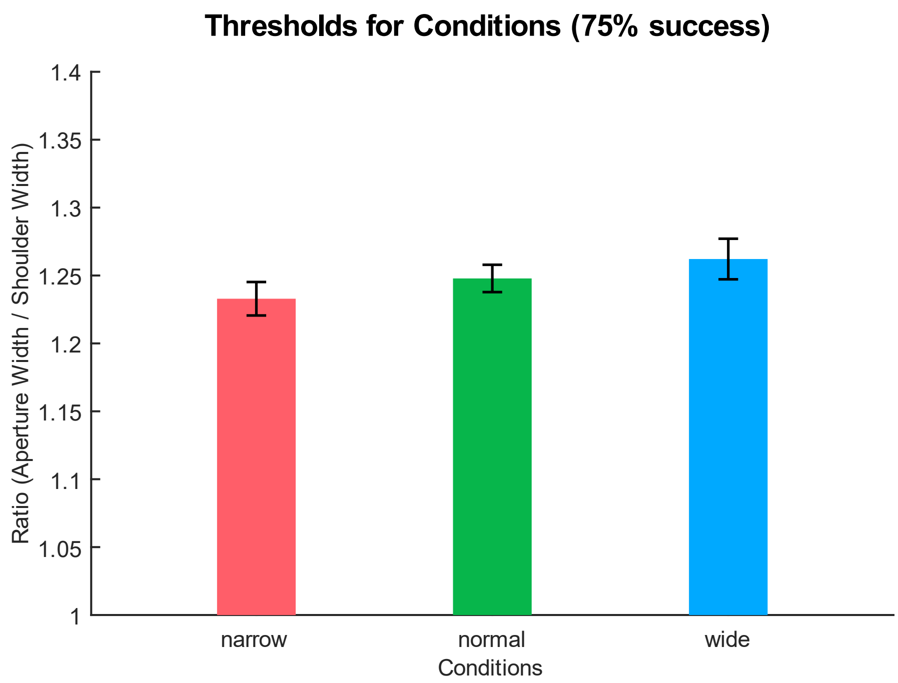


Figure 4 Psychometric thresholds with 75% success

The y axis of the figure shows the ratio between the aperture width and the virtual shoulder width. There isn't any difference between conditions in thresholds obtained from psychometric functions with a success of 75% when passing through an aperture.

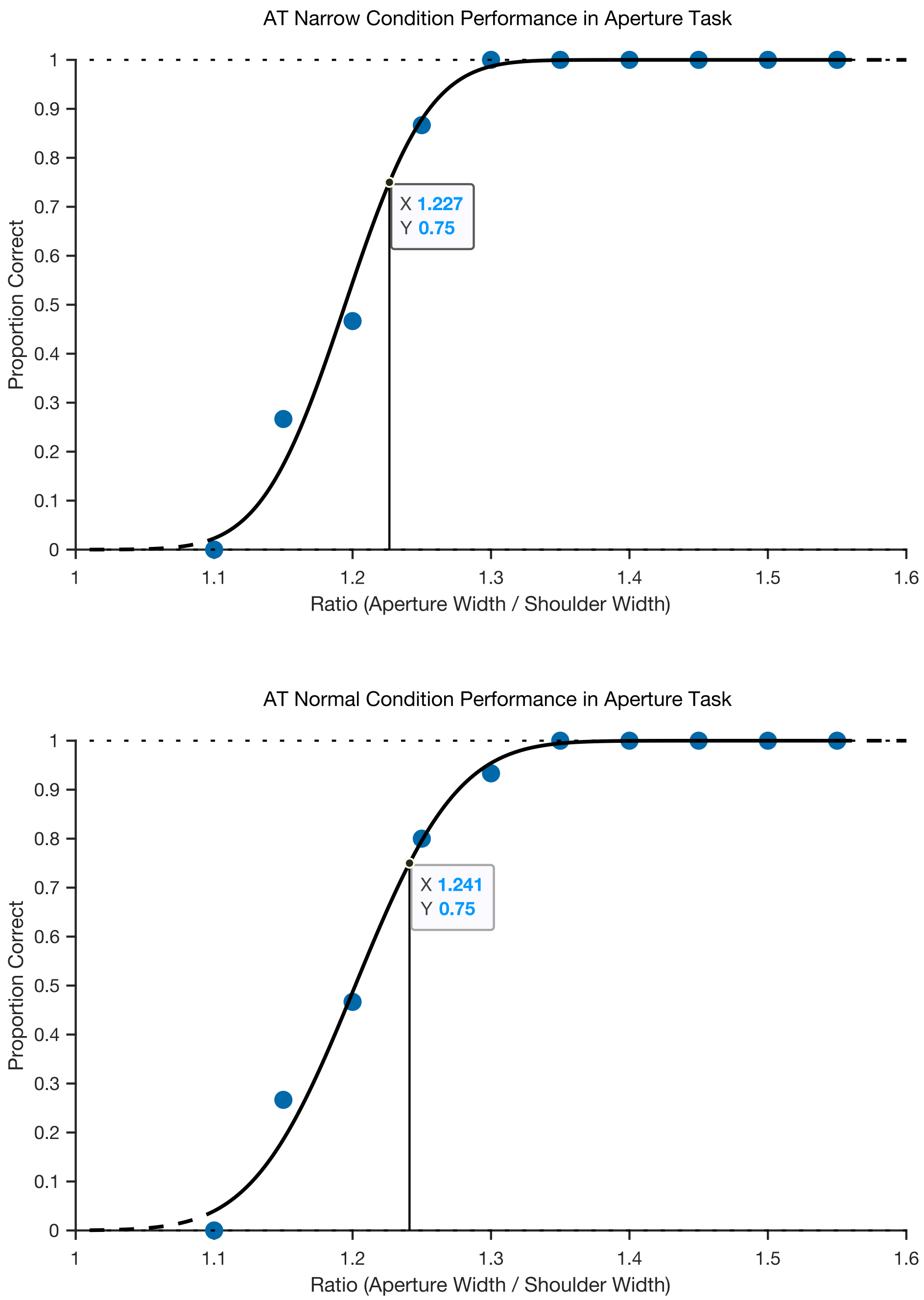


Figure 5 Psychometric functions of AT in aperture task

The y axis of the figure shows the success rate of a participant when passing through an aperture without colliding sidewalls. The x axis shows the ratio between aperture width and shoulder width. The blue dots represent the success ratio of a participant for 10 different ratios between apertures and shoulder.

2.4.3 Head data

Head data analysis was applied for whether there was an effect of scaling shoulder width on the reaching task on a table following the aperture task in the experiment. The head data referred to the 3D position at which a participant stood in order to reach a target on the table. In our analysis, we used x-axis of head data positions. The x-axis in the virtual environment represented the heading direction of the participants. The average of ten last head data points in the task was used as the dependent variable. LMM was applied to the head data with the equation (3),

$$\text{head} \sim \text{condition} * \text{target} + (\text{condition} * \text{target} \mid \text{participant}) \tag{3}$$

where “target” variable refers to the target positions on the table, which is a categorical type, consisting of 3 different categories (near, middle and, far).

Different LMM was applied to the head data for each group, considering the condition orders. “pre-narrow” group refers to the group in which participants first completed the narrow, and then the normal condition. “pre-wide” group means the group in which participants completed the wide condition before the normal condition. “post-narrow” and “post-wide” groups are also defined in the way that pre-narrow and pre-wide conditions are defined.

ANOVA applied on LMM showed that participants in the post-narrow group moved closer to the target when they were in the narrow condition ($F(1,1792) = 3.85$, $p = .049$). The main effect can also be seen in Figure 6 They also changed their standing position depending on the target position ($F(2, 1792) = 9.63$, $p < .01$). There was not an interaction effect found between the condition and the distance ($F(2, 1792) = 0.40$, $p = .67$).

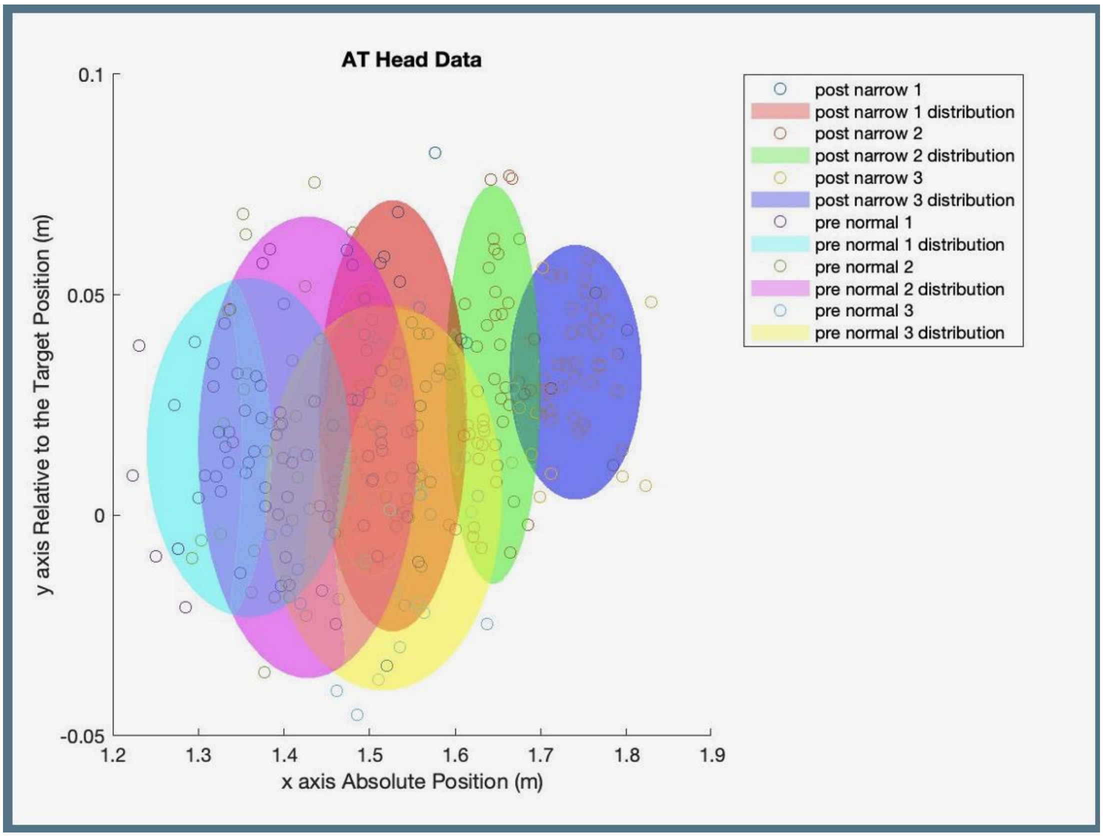


Figure 6 Head position data of one participant from post-narrow group

The x axis shows that the standing positions of the participants in their heading directions when they started to reach the target on the table. The y axis shows the relative y standing position with respect to the target. Ellipses with red, green, and blue colors represent the data in narrow condition and, ellipses with cyan, magenta, and yellow colors show data in normal condition. As can be seen from the figure, the participant moved closer to the target when in the narrow shoulder condition.

The main effect of target found in the post-narrow was not seen in the pre-narrow group ($F(1, 1492) = 0.01$, $p = .91$). Participants in this group also moved closer to reach the target at the far position ($F(2, 1492) = 4.63$, $p < .01$). The interaction of the two main factors was not found ($F(2, 1492) = 0.71$, $p = .49$).

When it comes to the post-wide group, they did not change their standing positions between conditions ($F(1, 1492) = 0.34$, $p = .56$), but they changed their behavior when the target was in different positions on the table ($F(2, 1492) = 25.2$, p

< .01). As in the post-narrow and pre-narrow groups, there was not any interaction effect between the condition and the distance variables ($F(2, 1492) = 2.83$, $p = .06$).

The last group, the pre-wide group had the same results with the post-wide group. There was not a main effect of condition ($F(1, 1192) = 0.16$, $p = .68$) but a main effect of target position ($F(2, 1192) = 19.17$, $p < .01$). As in the other groups, no interaction effect was found between the target positions and the condition ($F(2, 1192) = 0.91$, $p = .40$).

These results showed that the participants moved closer to the table when the target was at the farthest position, but this main effect of the condition on the head position was only observed for participants who completed the experiment in the post-narrow group. Finding the effect in the post-narrow group implied that for these participants, the effect of virtual narrow shoulder transferred to the arms and that they felt the need to adjust their standing position to reach the target.

2.4.4 Right hand data

Right hand data analysis was similar to the head data analysis. The preprocessing procedure was also same as in the head data analysis. So, the average of ten last right hand data positions were used in the analysis. Moreover, a similar LMM analysis was used using the same formula as in in the head data analysis:

$$\text{hand} \sim \text{condition} * \text{target} + (\text{condition} * \text{target} \mid \text{participant}) \tag{4}$$

Unlike in the head data analysis, ANOVA applied on the LMM showed that for participants in the post-narrow group, the main effect of shoulder width condition was non-significant ($F(1,1792) = .65$, $p = .42$), whereas the main effect of the target positions was ($F(2, 1792) = 110.09$, $p < .01$). The interaction effect between the condition and the distance was also found to be insignificant ($F(2, 1792) = 1.02$, p = 0.36).

The results for the pre-narrow group demonstrated similar patterns as in the the post-narrow group, such that conditions did not have a significant effect on the hand positions of the participants ($F(1, 1492) = .22$, $p = .63$), but target positions did ($F(2, 1492) = 4.95$, $p < 0.01$). The interaction of the two main factors was not found to be significant ($F(2, 1492) = .97$, $p = .37$).

For the post-wide group, we found that participants did not change their hand positions between conditions ($F(1, 1492) = 0.004$, $p = .94$), but they changed their behavior when the target was in different positions on the table ($F(2, 1492) = 34.4$, $p < 0.01$). As in the post-narrow and pre-narrow groups, there was not any interaction effect between condition and distance ($F(2, 1492) = .18$, $p = .83$).

The pattern of results in the pre-wide group was similar to the one in the post-wide group. There was not a main effect of condition ($F(1, 1192) = 0.76$, $p = .38$) but a main effect of target position ($F(2, 1192) = 27.04$, $p < .01$). As in the other groups, no interaction effect was found between target positions and condition ($F(2, 1192) = 0.68$, $p = 0.51$).

These results indicate that whereas right-hand positions did not change in different conditions, participants successfully discriminated the targets in different positions on the table.

2.4.5 Perceptual judgment

In order to analyze the perceptual judgment data, we conducted a LMM for each sequence of experimental conditions, separately. We applied the LMM with the following formula:

$$\text{threshold} \sim \text{condition} * \text{distance} + (\text{distance} + \text{condition} \mid \text{participant}) \qquad (5)$$

Here, the “threshold” variable represents the responses of the participants as a dependent variable, while the “distance” variable refers to the distances between the apertures and the avatar of a participant in the simulation. The variable “condition” indicates the condition in which a participant completed the experiment before the perceptual task. In the LMM, all independent variables were categorical. We applied ANOVA on LMM with a Satterthwaite approximation as in the other analyses.

In the post-narrow group, there was a main effect of condition ($F(1, 5.01) = 31.4$, $p < 0.01$), which demonstrated that participants responded with smaller apertures widths in the narrow condition than in the normal condition. There was also a main effect of distance ($F(2, 6.52) = 6.12$, $p = 0.03$), which we did not expect. When the distance between the aperture and the participants was 1.25, participants perceived that they could pass through the smaller apertures compared to when the distance between them was 2.25 m ($p = 0.04$). A similar effect was also seen between the comparison of the distances of 1.75 m and 2.25 m ($p = 0.01$). There was also an interaction effect between distance and condition ($F(2, 262.05) = 4.17$, $p = 0.01$). Perception of the pre-narrow group was also reshaped with condition ($F(1, 4.22) = 12.55$, $p = 0.02$) such that the minimum aperture length that the participants could successfully pass was found to be smaller in the narrow condition than in the normal condition. The main effect of the distance was significant ($F(2, 4.71) = 11.04$, $p = 0.01$). There was not an interaction effect found between condition and distance for this group ($F(2, 223.03) = 0.4$, $p = 0.66$).

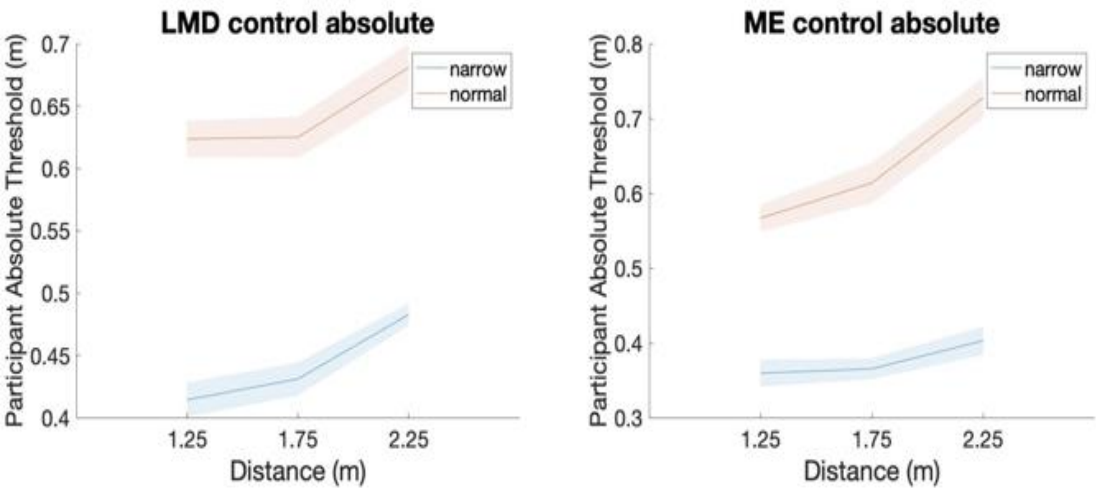


Figure 7 Absolute perceptual thresholds of two participants in post-narrow condition

The y axis of the figure shows responses of the participants for perceptual judgement. The x axis represents distances between the participant and the aperture. As can be seen from the figures, participants responded with lower values when they were in narrow condition.

For the post-wide condition, the main effect of the condition was preserved ($F(1, 3.00) = 36.3$, $p < 0.01$), although the effect of distances disappeared ($F(2, 3.94) = 2.72$, $p = 0.18$). The interaction between distance and condition was not found to be significant, either ($F(2, 173.04) = 2.66$, $p = 0.07$). The pre-wide group showed no main effect of condition ($F(1, 2.00) = 1.98$, $p = 0.29$) and of distance ($F(1, 2.03) = 1.98$, $p = 0.33$) and no interaction between condition and distance ($F(2, 131.01) = 0.68$, $p = 0.50$).

These results showed that except for the participants who first took the wide condition and then the normal condition, all participants were able to understand that the avatar they owned were different between conditions. Moreover, the distance perception was also affected in the narrow but not in the wide shoulder condition.

2.5 Discussion

According to the results we obtained from the analysis of the instantaneous velocity data at a distance of 5 cm from the aperture center, we observed that the participants could successfully adapt to different shoulder conditions. While we expected to see the adaptation progress in the experimental paradigm, our analyzes may have failed to show the adaptation process as the ratio between the door and the virtual shoulder-width differed continuously in consecutive trials. In other words, the speeds of the participants constantly changed due to the difficulty level of each trial, and the reason why the adaptation process was not observed may have been due to the discrepancies in these speed changes. One could expect that after a participant adapted to the narrow shoulder, they were expected to slowly pass through the aperture they had seen in the normal shoulder condition first, and then were expected to move faster on the feedback they received by hitting the walls. In the opposite case, it was expected that the participant would first pass quickly and then move slowly following the adaptation.

In addition to the instantaneous speed, the fact that the participants' perceptual threshold values were not different under different conditions may be taken as another indication that they showed adaptation to their novel shoulder widths.

Our main hypothesis is that if the virtual shoulder width of the participants in the first part of the experiment is narrower than the shoulder width in the second part of the experiment, the participants reach farther from the objects on the table because they would feel their arms longer in the second part of the experiment. In the opposite case, when the virtual shoulder width of the participants in the first part of the experiment is wider than the shoulder width in the second part of the experiment, participants reach out with their hands closer to the object when the adaptation occurs. To test the hypothesis, we first analyzed the right-hand data, but we couldn't find a main effect of shoulder-width condition on right hand positions.

There are several different explanations for not finding the main effect of shoulder-width in the right-hand positions. The fact that the participants started the experiment in different shoulder conditions instead of starting in their own normal shoulder width affected the adaptation process to the virtual environment, so the effect of the shoulder condition on the hand could not be observed. Another issue may be related to the time needed for them to adapt successfully to the self-avatar. Since participants did not discover the dimensions of the self-avatar together with its capabilities, they might not have been fully adapted to the virtual body (Day et al., 2019) but we may have observed an affordance-specific adaptation to the aperture task. Another possible explanation is that since we disrupt the distance perception of the participants, they could not adjust their hand positions properly.

Considering that the effect was not observed in participants who first completed the normal condition and then the wide condition and considering the adaptation of the participants for pass-through-ability, we can say that the adaptation on such a perception of pass-through-ability did not transfer to the perception of reachability. However, although there was no difference in the hand positions of the participants who first finished the normal condition and then the narrow condition, they stood further in the narrow condition to reach the target on the table. Standing closer to reach the target may lead to dismiss the effect of shoulder width on right hand positions. This suggests that there is an effect of changing shoulder width, but the effect has an asymmetrical feature that can be observed only when participants have narrow shoulders after their normal-size.

CHAPTER 3

SIMULATION EXPERIMENT

This experiment, which we carried out online due to COVID-19 pandemic, was conducted as a control to the findings obtained in the first experiment. The first hypothesis was that participants would pass through the apertures at similar speeds in different shoulder width conditions. The second hypothesis was that the effect of scaling shoulder width would also scale the arm length. Finally, the last hypothesis was that scaling shoulder width would affect the perceptual judgements of participants about the pass-through-ability affordance. In the first experiment, whereas the instantaneous speed and the pass-through-ability threshold ratio were similar across different shoulder groups, the effect of changing shoulder width on the reachability was only seen in participants who completed the experiment in the narrow shoulder condition following the normal shoulder trials.

The experiment was presented online using the heroku web service, thanks to a program prepared on the Unity game engine[1]. No audio or video recording was taken during the experiment. Informed consents were obtained from the participants who agreed on to participate in the study. Participants were asked to fill in the demographic information form after they completed the experiment.

3.1 Participants

Total number of participants was 20. Participants were mostly the ones who joined from snowball sampling. They were also recruited via convenient sampling on a voluntary basis. Students who took part in the research participation system from

[1] You can find the simulation from this site: https://webgl-experiment-2020.herokuapp.com/

Boğaziçi University received course credits in return for their participation; yet because they did not complete the experiment, their data was not included in the analyses. The simulation study was designed to be fully compliant with the online university research ethics requirements and approved by the Boğaziçi University Ethics Coordinating Committee (see Appendix B). Confidentiality and anonymity were ensured by saving data with randomly generated subject ID's.

3.2 Stimuli and apparatus

Experiment 2 was coded in the Unity 3D Game Engine version 2019.4.13f1. In order to present the experiment on an online platform, WebGL build of the project was compiled. All textures and materials in the simulations were as same as the ones in the VR experiment.

3.3 Procedure

In the simulation experiment, the task was similar to the one in the first experiment. There were four experimental groups, namely normal-narrow and normal-wide with grids, normal-narrow and normal-wide with no-grids. We also wanted to control the horizon with a grid condition in which there was a grid on the ground to simulate the horizon without changing textures in the environment. So, the groups were normal-narrow and normal-wide with grid. Moreover, there were some further adjustments in order to make the online experiment compatible with the VR version. The first adjustment was about the mouse movement and its corresponding movement on the computer screen. We included a calibration phase in order to match the movements in the simulation with the mouse movements of the participants. The second one was about the avatar, the speed of which was controlled using the mouse wheel. An assigned collider allowed the avatar to interact with the objects in the simulation. The third adjustment was about participants’ understanding of the nature of the task. After the calibration, participants took part in a training game to understand the requirements of the task. A hand model representing the real hand was only presented in the training game but not in the real experiment. Moreover, a red line signaled the allowed standing positions near the virtual table. After a right click of the mouse, participants could start reaching a target on the table in the simulation. To analyze the progress of a participant, we collected the mouse movements at each rendering frame. If participants were successful in the training game, after having collected minimum points for each task, they started doing the real experiment with the same instructions given in the VR experiment. During the experiment, we collected the virtual position of the avatar and mouse movement at each rendering frame of WebGL version of Unity Game Engine.

The experiment consisted of four stages. Since the interaction of the participants with the online system takes place through the mouse, the first step was the mouse calibration. In the second part, there was a training playground for participants to adapt to the experimental environment and the experiment interface and have some user experience in the experiment. In the third part, participants used the mouse to control an avatar with three different virtual shoulder size (narrow, normal and wide). In the final part, participants completed the perceptual judgment experiment for different conditions.

3.3.1 Calibration

There is a variability in the cursor movements of the computer mice we use in today's technology due to the differences in the operating system, the mouse features determined by the user and the hardware features of the mouse. A mouse calibration phase in this experiment allowed users with different mice to control the avatar comparably in the simulation environment. At this step, participants were asked to determine a physical, fixed distance (15 cm) in their real environment so that they could perform the same behavior in the simulation using the same movement in the real life (https://webgl-experiment-2020.herokuapp.com/StreamingAssets/olcum480.mp4). After the start and end points of this distance were marked, they brought their thumb to the starting point while using the mouse in a natural way. Having pressed the left button of the mouse with the index finger, participants moved the mouse to the end point and made another left button press with the index finger. They then returned to the starting point and the process was repeated for 25 times. Simultaneously with the distance calibration, changes in the object size during the forward and backward movements of the mouse were also calibrated using a display of a red cube scaled with respect to the behaviors controlling the mouse. The error margin between the displacement distance of the object and the distance of the mouse was brought to the measure of "mm" after repeating the process for 25 times (Figure 8). The mouse wheel was used to control the speed of the avatar. In a similar way we calibrated the movement of the mouse, we also introduced a wheel calibration phase, where participants pressed the left mouse button and turned the wheel forward for 5 times. The end of the calibration was marked by a second left button press[2].

[2] https://webgl-experiment-2020.herokuapp.com/StreamingAssets/tekerlek480.mp4

Figure 8 Mouse calibration scene in the simulation

In the mouse calibration scene, we displayed instructions, a cube and how much trials were left for the calibration. Summarized and simplified instructions were shown to the participants to calibrate the mouse correctly. The cube itself was scaled by moving the mouse. The text on the right side of the cube showed the size of one side of the cube. On the right bottom corner, how much trials were left was shown.

3.3.2 Playground

After the calibration phases, participants were taken into a training playground area for them to get used to the actual experimental environment. There were three different tasks in this training game environment. These tasks depended on the object that participants came across on the screen. There were two different objects that the participant encountered in this simulated environment. Those objects were the same objects that we used in the first experiment: (1) two building blocks, and (2) a table without legs. Participants had to accomplish one task for the former and two tasks for the latter. If participants saw two walls, their task was to pass through the aperture between the walls without colliding. If it was a table, they were instructed to bring the avatar they controlled close to the table so that they could reach the object on the table and press the left button. After bringing a model representing the hand to the target point on the table, they were asked to make a second left button press. For participants to move into the next step, they had to succeed in each of these three tasks separately. The score for each task was set to 10 points. The criteria for success were calculated on the points collected while performing the tasks. Participants had to collect 300 points separately for each task. We collected the task-oriented mouse movement data in the training game as well as in the real experiment.

3.3.3 Experiment

At this part, participants were asked to cover their right arm with a cover so that they receive no visual feedback. They then moved onto the actual experimental part. In the main experimental environment, a trial was consisted of all tasks involving the two objects displayed independently on the playground. Participants were instructed to pass the avatar they directed through the aperture without colliding the building blocks, and then approach the table at a right distance and reach the target on the table. Unlike in the playground scene, participants were presented with no hand model in the last task and were given no visual feedback with respect to how close they were to the target.

The trial generation mechanism was the same as in the first experiment. There were 3 blocks with 50 trials for each condition. The distance between the building blocks was generated at ten different distances according to the shoulder width of the avatar. There were five trials for each different distance in each block. Therefore, there were 15 trials for each different distance in one condition. In each block, we avoided that the two consecutive trials did not have the same aperture width.

Unlike in the playground scene, there was also three different target points on the table. These were assigned randomly for each block. Since there were 50 trials in a block, the number of attempts for target locations was not equal within the block. Instead, target assignments were made with the total number equal using all three blocks.

In the experiment with three different independent conditions, a participant was randomly assigned to one of four different groups, based on our previous findings and method. One group completed the experiment first in the normal and then in the wide shoulder conditions, while the other group completed the experiment first in the normal and then in the narrow shoulder conditions. Those other two groups completed the experiment with a grid on the ground.

Data collection was also similar to the one in the first experiment. We collected data related to the participant's speed when passing through an aperture, the distance between the table and the avatar, and the distance between the target and the (invisible) model hand.

3.3.4 Perceptual judgment

Similar to the one in Experiment 1, the perceptual judgment task was performed for control purposes after an experimental condition was completed. In this part, participants were presented with two building blocks that were located at three different distances (5 m, 10 m, and 15 m). These building blocks were slowly approaching each other with 0.2 m/s. In any single trial, participants were asked to press the left mouse button at the minimum distance they thought the avatar they controlled could pass through the aperture. There were 12 trials for each distance, making a total of 36 trials in total. Following the perceptual judgment task, participants filled in a body perception questionnaire (Appendix C and Appendix D).

3.4 Results

We conducted five different analyses, each of which corresponded to the different parts of the experiment. The first analysis was about instantaneous speed, which checked the hypothesis that there was an adaptation to the novel body morphology for each different shoulder width condition. The second analysis was about deriving the psychometric threshold functions which demonstrated the performances of each participant in the aperture task for pass-through-ability affordance. The second and the third analyses were applied to check that whether there is an effect of novel shoulder width on the reachability affordance. For these analyses, the head data and right-hand data were selected as dependent variables, respectively. The last analysis was used to check the body adaptation perceptually. In all analyses, we used LLM, and the formulas were given in Wilkinson notation.

3.4.1 Instantaneous speed

Unlike calculating the instantaneous speed in the virtual reality experiment, it was not needed in the simulation experiment. The avatar speed in the simulation experiment was recorded in each rendering frame. The door task was completed when the avatar was in between the aperture walls. LMM was used with the formula (6).

$$\text{speed} \sim \text{ratio} * \text{condition} * \text{grid} + (\text{condition} + \text{ratio} \mid \text{participant}) \tag{6}$$

Where the “speed” dependent variable referred the instant speed at which the avatar was moving when it was 5 cm away from the center of an aperture. Avatar shoulder width condition (narrow, normal, or wide) was indicated with “condition” variable. “ratio” variable was the ratio between the aperture width and avatar shoulder width. Having a grid on the ground in the simulation environment was expressed as “grid” variable. Those three independent variables were assigned as categorical variables in the LMM and they had 3, 10, and 2 categories, respectively. “participant” variable was added to LMM as a random effect for condition, ratio, and intercept because it was assumed that the degree of adaptation and performance were different for all participants.

ANOVA for LMM with Satterthwaite approximation showed that having a grid on the ground did not affect the speed ($F(1, 15.74) = 3.14$, $p = 0.09$). There was a main effect of condition on speed ($F(2, 8.51) = 6.01$, $p = 0.02$), and participants were faster when in the wide condition than when they were in the normal and narrow conditions ($p = 0.013$ and $p < 0.01$ respectively), but there was not any difference between the narrow and normal conditions ($p = 0.37$). As expected, there was a main effect of ratio ($F(9, 39.129) = 2.75$, $p = 0.01$). Since there were ten different categories for the ratio, instead of reporting 45 different pair results, speeds in the trials when the ratio was 1.1 and 1.55 were compared and it was found that the latter is bigger than the former one ($p < 0.01$).

As in the VR experiment, we found that when controlling the avatar, participants did not change the speed of it in different conditions, but they made the avatar faster when passing through the wide apertures.

3.4.2 Aperture threshold ratio

Aperture threshold ratio is the ratio between a participant and an aperture such that the participant can pass through the aperture with a success of 75%. In order to calculate the threshold for each participant, psychometric functions were obtained with the help of psignifit library in MATLAB. LMM was used with the equation (7).

$$\text{threshold} \sim \text{condition} + \text{grid} + (1 \mid \text{participant}) \tag{7}$$

where ANOVA was applied to LMM. There was found to be no main effect of condition ($F(2, 27.748) = 0.71$, $p = 0.50$) and grid ($F(1, 17.791) = 0.48$, $p = 0.49$). So, the performances of participants were similar in different conditions and having a grid on the ground did not affect performances (see Figure 9 and Figure 10).

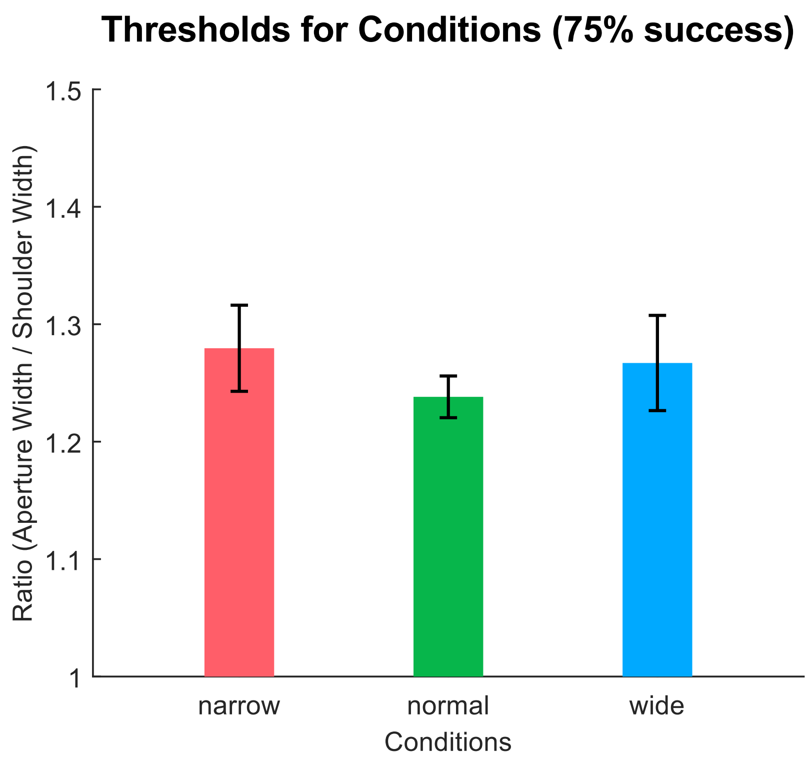
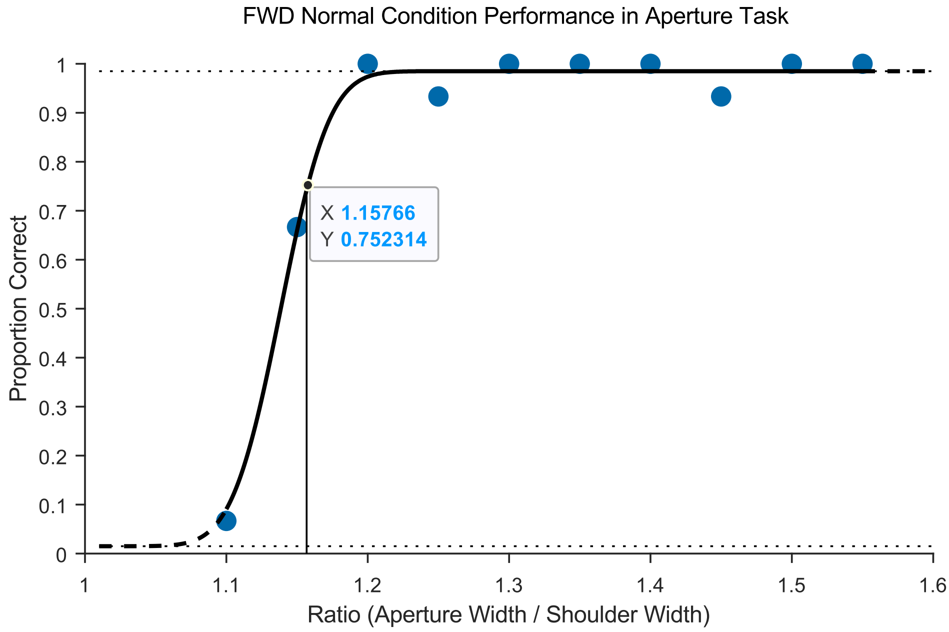


Figure 9 Psychometric thresholds with 75% success in simulation

The y axis of the figure shows the ratio between the aperture width and the virtual shoulder width. There is not any difference between conditions except for the normal condition in the thresholds obtained from psychometric functions with a success of 75% when passing through an aperture in the simulation.



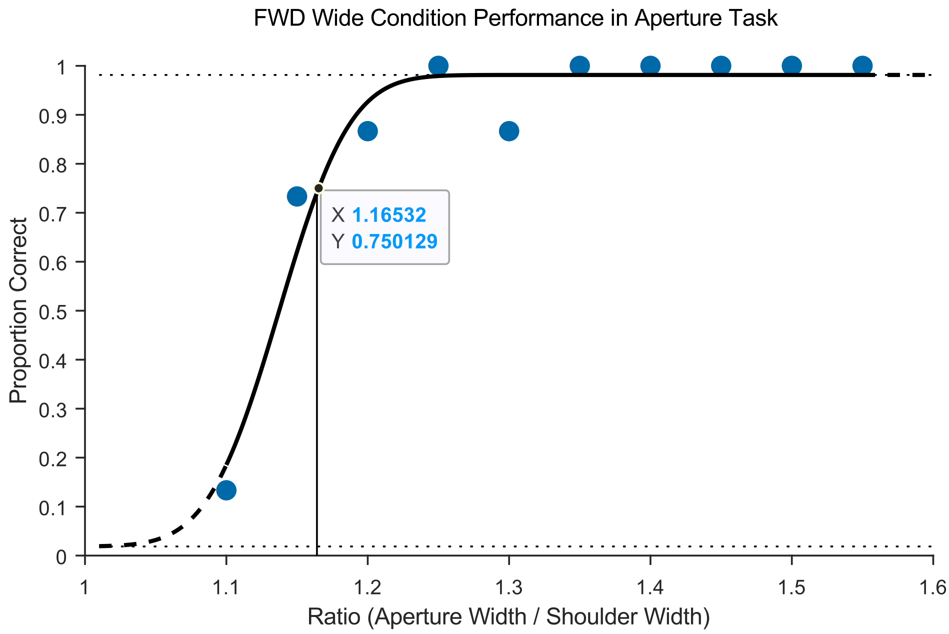


Figure 10 Psychometric functions of FWD in aperture task

The y axis of the figure shows the success rate of a participant when passing through an aperture without colliding sidewalls. The x axis shows the ratio between aperture width and shoulder width. The blue dots represent the success ratio of a participant for 10 different ratios between apertures and shoulder.

3.4.3 Head data

Head data analysis is related to the reaching task on a table which came after an aperture. The head data refers to the position at which avatar stands in order to reach a target on the table. LMM was applied to the head data with the formula (8).

$$\text{head} \sim \text{condition} * \text{target} * \text{grid} + (\text{condition} * \text{target} \mid \text{participant}) \quad (8)$$

The target position on the table is indicated with "target" variable and it is a categorical variable which has 3 different categories (near, middle and, far). ANOVA applied on LMM with Satterthwaite approximation showed that people did not change the position of the controlled avatar when a target was shown in different positions ($F(2, 22.347) = 2.72$, $p = 0.08$) but when participants controlled the avatar in different conditions, people adjusted the position of the avatar ($F(2, 15.245) = 9.4$, $p < 0.01$). Post-hoc analysis showed that participants made avatar move closer to the target when they were in the narrow condition than when they were in the normal condition ($p < 0.01$), but there was no difference between the avatar positions when they were in the normal and wide conditions ($p = 0.14$). There was a not statistical difference between the positions of the avatar controlled by participants who saw grid on the ground and the positions of the avatar controlled by those who did not see grid on the ground ($F(1, 17.712) = 0.76$, $p = 0.39$). All the interaction effects between target position, condition and grid were statistically insignificant ($p > 0.05$).

As in the analysis of head data positions in VR experiment, we found that the main effect of shoulder width condition on the avatar standing positions is significant, but the effect was only seen when participants took part in the narrow after the normal condition. Unlike in the VR experiment, we did not find any effect of target position in the simulation experiment.

3.4.4 Right hand data

When it comes to the right hand data analysis, the last position of the avatar hand, at which participant gave the final response with the click of a left mouse button, was used as a dependent variable. The same formula in the head data analysis was used in LMM. ANOVA was also applied to LMM as in the head data analysis case.

When participants saw a target in a different position on a table, they adjusted their hand movements ($F(2, 16.08) = 12.06$, $p < 0.01$). Post-hoc analysis showed that there was a difference between the hand positions of the participants when the target was at the near and middle positions ($p < 0.01$). The same difference was also found between the target at the middle and the target at the far position ($p = 0.02$). Moreover, people also changed their behavior when in different conditions ($F(2, 13.08) = 5.63$, $p = 0.02$). When applying post-hoc analysis, we found that while participants were in narrow condition, they moved closer to the target than the normal condition ($p = 0.01$). However, as in the head data, there was not a difference between normal and wide conditions ($p = 0.18$). Having a grid on the ground in the simulation environment did not change the behavior as in the head data analysis ($F(1, 17.438) = 0.58$, $p = 0.45$). There was no interaction found between condition, target position and grid ($p > 0.05$).

The results were aligned with the results in VR experiment for the right-hand data but there is only one difference that there was an effect of shoulder width condition on reachability task.

3.4.5 Perceptual threshold

The last part of the analysis is about perceptual threshold experiment, which was conducted after each condition. LMM was applied with the formula (9).

threshold ~ distance * condition * grid + (condition + distance | participant)   (9)

Here, “threshold” variable refers to responses of the participants, and it is the dependent variable. “distance” variable corresponds to distances between apertures and the avatar of a participant in the simulation while “condition” indicates the condition in which a participant completed the experiment before the perceptual task. “grid’ variable indicates whether the simulation environment has grid on the ground or not. In the LMM, all independent variables were categorical. ANOVA on LMM was applied as in the other analyses.

There was a main effect of condition ($F(2, 16.378) = 3.9$, $p = 0.04$), which showed that participants who were in the normal condition responded with larger aperture widths when they were in the normal condition than when they were in the narrow condition ($p = 0.02$). However, there wasn’t any difference between the wide and normal conditions ($p = 0.78$). There was neither a main effect of grid ($F(1, 17.841) = 0.11$, $p = 0.74$) nor a main effect of distance ($F(2, 20.175) = 3.39$, $p = 0.053$). Moreover, there was not a significant interaction effect between condition, grid, and distance either ($p > 0.05$).

3.4.6 Body ownership questionnaire

Body ownership questions were evaluated with the following procedure: The first and the fourth questions were related to bodily alienations, so the answers for these questions were substracted from 10. After substracting, the mean of the all answers were calculated for all groups. Two-way ANOVA was applied to the mean scores with conditions and grids as main effects. There was not any main effect of condition ($F(1, 16) = 2.55$, $p = 0.13$), and of grid ($F(1, 16) = 0.03$, $p = 0.84$). There was not any interaction between condition and grid either ($F(1, 16) = 0.13$, $p = 0.72$). These results showed that participants in different groups did not show any difference in body ownership.

3.5 Discussion

According to the results we obtained from the analysis of the instantaneous velocity data at a distance of 5 cm from the door center, we found that the participants adapted to different shoulder conditions. Since we did not change the paradigm to find the process, as in the VR experiment, the adaptation process of the novel shoulder width was lost in the speed changes between trials.

In addition to the instantaneous speed, the fact that the participants' threshold values were not different under all conditions is another finding that showed their adaptations. It also supports our results from the VR experiment. It is also worth to mention that even if the experiment was a simulation, it gave us meaningful results about the adaptation for the novel shoulder widths.

Results from the head and right-hand data analyses showed that adaptation of the participants to the novel shoulder width changes the way they interact with the environment only when they adapt to the narrow shoulder condition. In our case, participants who took the narrow condition after the normal condition changed their reaching behaviors to reach the target on the table.

Perceptual threshold results also supported our results from the analyses of the head and right-hand data in the simulation. Whereas participants in the narrow condition understood boundaries of the avatar controlled in the simulation, those who controlled the avatar in the wide condition didn’t seem to have the same effect. Although the psychometric thresholds were similar in all conditions, it may not be enough for participants in the wide condition to understand the boundaries of the avatar.

From the simulation experiment, we reached to a conclusion that participants could understand the abilities and the boundaries of an avatar when they were in the narrow after the normal condition. Not finding such results for participants who took the wide condition after the normal condition supports the idea that the effect of changing shoulder width is asymmetrical.

CHAPTER 4

GENERAL DISCUSSION AND CONCLUSION

Our results showed that when participants controlled avatars with different shoulder width, their speed and psychometric thresholds were similar to each other. Moreover, we found similar results for perceptual judgement task in both VR and simulation experiments except the fact that participants who completed the wide shoulder condition after the normal in the VR had a perceptual awareness of their virtual body dimensions whereas this effect was absent in the simulation experiment. Our reachability task analysis showed that there was an effect of scaling shoulder width when participants completed the narrow condition after the normal (see Appendix E for summary).

Warren and Whang (1987) demonstrated that there is a constant ratio between shoulder width and aperture width when passing through an aperture. Another study conducted by Warren (1984) also showed that the relationship between leg length and stair width is body-scaled. Our results were aligned with the body-scaled relationship as opposed to extrinsic or absolute metric. The relationship between the sizes assigned in different body proportions and the aperture width remains constant. On the other hand, Higuchi et al. (2006) conducted an aperture task in which there were external tools to extend the shoulder width to pass through an aperture and, they did not find a body-scaled relationship when passing through an aperture. Instead, the relationship was explained in terms of absolute metrics. These results led us to say that when participants own a body, they have a body-scaled relationship with the environment but the relationship changes when using external tools.

When comparing the simulation study to the VR experiment, the results are similar for the pass-through-ability. The psychometric thresholds of participants to pass through an aperture are also similar. Since results from both studies support each other, we can suggest that people can embody a novel shoulder and show similar performances.

Fath and Fajen (2011) found in a virtual reality study that the locomotion and perceptual judgement did not differ in an environment with horizon and an environment without horizon. However, not finding hand effect in virtual reality led us to add a grid condition in the simulation experiment because we thought that the presence of grids might influence the reaching behavior of the participants. The results in the simulation experiment showed that this was not the case. Moreover, grid condition did not affect the perceptual judgment and performance of participants in the pass-through-ability task, either. So, our results rather supported the findings of the study of Fath and Fajen (2011) for grid condition.

Considering the analyzes we made on hand and head data, participants who completed the narrow condition moved closer to the table. The absence of this result for the participants who first took the narrow condition in the VR experiment is a sign that the conditions are affected by each other. The fact that this effect does not appear in the wide shoulder condition indicates that there is an asymmetry in the effect of changing shoulder width.

When we compared the results we obtained in the hand data, the effect of the shoulder width condition, which was seen in the simulation, but not found in the VR experiment, was an unexpected result, but we think that the results may be explained through the proprioceptive and visual feedbacks. On the simulation, there was a fine-tuning part as the participants reached the target. After making this adjustment, since the avatar on the simulation remained in a fixed position, the stimulus on the screen did not change, while reaching the target with their hands. Thus, participants moved their hands further in the narrow condition. Another explanation is that the proprioceptive feedback during the simulation was also in a fixed position, which further boosted the effect. In the VR experiment, on the other hand, there was an update on the visual system and change in the proprioceptive feedback caused by the active movement of the participants, due to the head movement. Because of the update, there was no difference between the shoulder conditions while the participants reached the targets.

According to the hypotheses we had established, we expected that the participants would reach the targets from a farther distance in the wide shoulder condition, but we did not find such results. We thought that when we performed the perceptual threshold experiment, the participants would realize that they had broad shoulders, but when we evaluated the same result together with the simulation experiment, we observed that the participants could not fully understand the limits of their bodies in the broad shoulder condition. These results are aligned with the results in the study by Day et al. (2019), which indicated that it takes time for people to understand the boundaries and capabilities of a novel body.

When considering the asymmetry we found in the study, we can evaluate the asymmetry from the point of view in the RHI. In one study (Pavani & Zampini, 2007), it was observed that the participants could not internalize the largest of the five different sized plastic hands, and therefore the effect of the illusion was weakened. In our study, we can say that even when no visual stimulus related to the hand or body is given, RHI and our study may affect the same area which is related to the mechanism of embodiment. Another explanation is that the participants might not have understood the dimensions of their bodies because they could not fully understand the collision feedback they received while passing through the aperture in the wide condition as the participants decided whether they could pass through a wide gap from a certain distance while performing the pass-through-ability task. If they could not see the walls in the visually incoming information during the decision, the body limits may not have been fully understood because the collision occurred in the absence of awareness.

The fact that we found an effect on the reaching task of the participants while only changing the shoulder width showed that there is a common feature between these two affordances. The common feature may be due to two different reasons. Due to the adaptation of the novel shoulder widths, there may be a change in the body schema of the participants and this change may also affect reaching out with the hand. According to this inference, we can say that body images are reshaped after passing through a common area in the brain. The effect can also be explained through the affordance hierarchy (Wagman, Caputo, & Stoffregen, 2016). There are lower-level affordance types for the pass-through-ability and the reachability in the affordance hierarchy. The pass-through-ability and reachability of these affordances are evaluated. In our study, we may have affected a perceived common lower-level affordance which is shared by those two affordances. In other words, the change in the shoulder, which affects the pass-through-ability, may have changed the lower-level affordance type, and the effect may have occurred in the reaching action due to the change of the lower-level affordance.

Overall, performances of the participants were similar for the pass-through-ability task. However, without using any visual feedback about the body, we showed that participants moved closer to the target for the reachability task after having narrowed down the shoulder width even in the simulation. For a future work, the relationship between the pass-through-ability and the reachability may be investigated by manipulating the arm-span length to see whether those two affordances do in fact affect one another.

APPENDIX A

ETHICS COMMITTEE APPROVAL FOR VR EXPERIMENT

ÖZYEĞİN ÜNİVERSİTESİ

Nişantepe Mh.
Çekmeköy, Istanbul
T:0216 564 5000
info@ozyegin.edu.tr
www.ozyegin.edu.tr

İNSAN ARAŞTIRMALARI ETİK KURULU
TOPLANTI TUTANAĞI

TOPLANTI SAYISI	:	**2019/12**
TOPLANTI TARİHİ	:	11.11.2019
TOPLANTI YERİ	:	Özyeğin Üniversitesi
KATILANLAR	:	Prof. Dr. Canan Ergin Dr. Sibel Oktar Dr. Ceren Hayran Şanlı

ARAŞTIRMA ETİK KURULU
PROJE BAŞVURU FORMU (FORM A)

Projenin Adı	Sanal Gerçeklik Ortamında Beden Algısı
Proje Yürütücüsü	Öğr. Gör. Can Bora Sezer
Proje Yürütücüsünün İletişim Bilgileri	bora.sezer@ozyegin.edu.tr 0532 211 1097 0216 564 98 70
Projeye katılan diğer araştırmacılar	Doç. Dr. Erhan Öztop - Özyeğin Üniversitesi, Bilgisayar Mühendisliği Doç. Dr. Emre Uğur Boğaziçi Üniversitesi, Bilgisayar Mühendisliği Doç. Dr. İnci Ayhan Boğaziçi Üniversitesi, Psikoloji Safa Andaç Boğaziçi Üniversitesi, Bilişsel Bilim
Projenin süresi (Başlangıç ve bitiş tarihi)	Proje süresi 5 aydır. Başlangıcı 20 Kasım 2019, Bitişi 20 Nisan 2020
Araştırmanın Amacı ve Özeti	Araştırma sanal gerçeklik (Virtual Reality) ortamlarında kullanıcılara atanan sanal bedenlerin (avatarların) benimsenme sürecine odaklanmaktadır. Araştırmanın amacı, katılımcılara farklı omuz genişliklerinde avatarların atanması durumunda çeşitli ebatlardaki geçitlerden geçerken gösterdikleri davranışları gözlemlemektir. OZU Sanal Gerçeklik Laboratuvarı'nda yürütülecek deneyde, katılımcılardan sanal gerçeklik başlıklarını takmaları ve ellerine verilen kumandalarla sanal iki duvar arasından geçerek ileride görünen bir düğmeye basmaları istenecektir. Çözülmeye çalışılan temel sorular, avatar sahiplenme sürecinin evrelerinin belirlenmesi ve kullanıcıların kişisel beden imajlarının, avatarları vasıtası ile ne derece manipüle edilebilir olduğunun anlaşılmasıdır.
Araştırmanın Yöntemi	Deneyler Özyeğin üniversitesinin sanal gerçeklik laboratuvarında (OZU VR Lab) gerçekleştirilecektir.

CHS.

ÖZYEĞİN ÜNİVERSİTESİ

Nişantepe Mh.
Çekmeköy, Istanbul
T:0216 564 5000
info@ozyegin.edu.tr
www.ozyegin.edu.tr

	Katılımcılara VR gözlükleri giydirilerek ellerine görev takiplerinde kullanılmak üzere birer adet kumanda verilecektir. Deneyin gerçekleştireceği alan 3 x 5 m^2 boyutlarındadır. Deneyin başlangıcında, katılımcının orijinal boy yüksekliği ve omuz genişliği vücut ölçülerinin kaydedilmesi amaçlı olarak, Sanal gözlük uzamsal yüksekliği ve kolların yatay olarak açılım pozisyonunda VR kumanda cihazlarını içeren bir ölçüm protokolü takip edilecektir. Bunu takiben katılımcılara sanal gerçeklik ortamında farklı ebatlarda geçitlerden geçme görevi verilecektir. A noktasından B noktasına yürüme mesafesi 4m uzunlukta ayarlanmıştır. Katılımcılardan bu noktalar arasında ileri geri yürümeleri ve alanın sonundaki sanal düğmelere basmaları istenecektir. Bu esnada katılımcılara atanan avatarların omuz genişlikleri farklı ölçüler atanarak manipüle edilecektir. Katılımcıların geçitlerden geçerken kumandalardan ve sanal gerçeklik başlığından gelen konum verileri, hızlanma ve yavaşlama gibi davranışların analizi için kaydedilecek, bu davranışlar sanal omuzların ne derece içselleştirildiğinin parametrik ve nesnel endeksleri olarak değerlendirilecektir. Deney sonunda, sanal omuzlarla ilişkili yapılan manipülasyonun katılımcı üzerindeki etkilerini ölçmek üzere bir beden aidiyet ölçeği verilecek, katılımcılardan bu ölçekteki sorulara yanıt vermeleri istenecektir. Beden aidiyet ölçeği, sanal bedene olan adaptasyonu ve sanal omuzların ne derece içselleştirildiğini ölçen sorular içermektedir.
Etik ve Veri Yönetim Planı	Bu çalışmadan elde edilecek bilgiler tamamen araştırma amacı ile kullanılacak olup kişisel bilgiler gizli tutulacaktır. Çalışmaya katılanların isimleri ya da kurumları hiçbir yerde yazılmayacak bunların yerine kod isimler kullanılacaktır. Bu araştırmaya ait bütün kayıtlar ve dosyalar yalnızca araştırmacıların erişimindeki şifreli bilgisayarlarda korunacak, başka bir ortama aktarılması durumunda ise sadece kilitli dolaplarda saklanacaktır. Katılımcıların verileri anonimize edilerek akademik yayın amacı ile kullanılabilir. Veriler çalışma tamamlandıktan sonra ve bilimsel yayınlar yayımlandıktan 5 yıl sonra silinecektir.
Katılımcı Özellikleri	Çalışma için hedeflenen katılımcı sayısı 30 dur. Katılımın gönüllülük esasına dayalı olması planlanmaktadır. Hedeflenen katılımcı profili daha önce Sanal gerçeklik deneyimi olan ve olmayan gruplardan seçilecektir. Katılımcılar ÖzÜ Deney Katılımcı Sistemi (SONA) üzerinden seçilecektir. Yapmak istediğimiz araştırmanın fiziksel ya da duygusal herhangi bir risk getirmesi beklenmemektedir. Kimi

CHS

Nişantepe Mh.
Çekmeköy, Istanbul
T:0216 564 5000
info@ozyegin.edu.tr
www.ozyegin.edu.tr

	katılımcılarda sanal gerçeklik çalışmalarında zaman zaman rastlanan mide bulantısı, baş dönmesi gibi hafif seyirli rahatsızlık göstergeleri belirebilir. Bu durumlarda çalışma hemen kesilecek ve çalışmaya devam edilmeyecektir. Katılımcının rahatsızlığı sona erene kadar kendisine eşlik edilecektir. Deneye giren katılımcının SONA sistemi üzerinden kendisine COD 312 ya da COD 202 derslerinden birini alması durumunda 1,5 kredi verilecektir.
Araştırma Bütçesi ve Kaynakları	Deneyler Özyeğin üniversitesinin sanal gerçeklik laboratuvarında (OZU VR Lab) gerçekleştirilecektir. Deney için gerekli olan sanal gerçeklik başlığı ve kumandalar halihazırda laboratuvarda mevcuttur. Katılımcılara para gibi herhangi maddi bir teşvik verilmeyecektir.
Ek Belgeler	Aşağıda sıralanmış olan belgeler ekte sunulmuştur: EK 1. Bilgilendirme ve gönüllü katılım formu (Form B) EK 2. Kontrol Listesi (Form C: işaretler ve imzalar tamamlanmış olarak) EK 3. Katılımcı Onam Formu EK 4. Katılımcı Bilgi Formu EK 5. Beden Aidiyeti Anketi EK 6. Katılımcı Çağrı Yazısı

Özyeğin Üniversitesi İletişim Tasarımı Öğr. Gör. Can Bora Sezer'in yürütücülüğünü üstleneceği *"Sanal Gerçeklik Ortamında Beden Algısı"* başlıklı proje değerlendirilmiştir.

Proje etik açısından uygun bulunmuştur. ☒
Projenin etik açısından geliştirilmesi gerekmektedir. ☐
Proje etik açısından uygun bulunmamıştır. ☐

İmzalar:

Prof. Dr. Canan Ergin Etik Kurulu Başkanı	Dr. Sibel Oktar Etik Kurulu Üyesi	Dr. Ceren Hayran Şanlı Etik Kurulu Üyesi

APPENDIX B

ETHICS COMMITTEE APPROVAL FOR ONLINE SIMULATION

Evrak Tarih ve Sayısı: 29.03.2021-9900

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ
SOSYAL VE BEŞERİ BİLİMLER YÜKSEK LİSANS VE DOKTORA TEZLERİ ETİK İNCELEME KOMİSYONU
TOPLANTI TUTANAĞI

Toplantı Sayısı	:	14
Toplantı Tarihi	:	25.03.2021
Toplantı Saati	:	13:00
Toplantı Yeri	:	Zoom Sanal Toplantı
Bulunanlar	:	Dr. Öğr. Üyesi Yasemin Sohtorik İlkmen, Prof. Dr. Ebru Kaya, Prof. Dr. Fatma Nevra Seggie
Bulunmayanlar	:	

Safa Andaç

Bilişsel Bilim

Sayın Araştırmacı,

"Sanal Gerçeklikte Omuz Genişliğini Ölçeklendirmenin Erişilebilirlik ve Geçilebilirlik Sağlarlıkları Üzerine Etkisi " başlıklı projeniz ile ilgili olarak yaptığınız SBB-EAK 2021/10 sayılı başvuru komisyonumuz tarafından 25 Mart 2021 tarihli toplantıda incelenmiş ve uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya çevrimiçi olarak katılımı ve oybirliği ile alınmıştır. COVID-19 önlemleri kapsamında kurul üyelerinden ıslak imza alınamadığı için bu onam mektubu üye ve raportör olarak Ebru Kaya tarafından bütün üyeler adına e-imzalanmıştır.

Saygılarımızla, bilgilerinizi rica ederiz.

Prof. Dr. Ebru KAYA
ÜYE

e-imzalıdır
Prof. Dr.Ebru KAYA
Raportör

SOBETİK 14 25.03.2021

APPENDIX C

BODY OWNERSHIP QUESTIONNAIRE

(ORIGINAL TURKISH VERSION)

1. Deney sırasında sahip olduğum bedenin kendi bedenimden farklı olduğunu hissettim.

Kesinlikle katılmıyorum 0 1 2 3 4 5 6 7 8 9 10 Kesinlikle katılıyorum

2. Kendi bedenimle sanal ortamın içindeymişim gibi hissettim.

Kesinlikle katılmıyorum 0 1 2 3 4 5 6 7 8 9 10 Kesinlikle katılıyorum

3. Sanal bedeni kendimin kontrol ettiğini hissettim.

Kesinlikle katılmıyorum 0 1 2 3 4 5 6 7 8 9 10 Kesinlikle katılıyorum

4. Deney sırasında kendimi dışarıdan izliyormuşum gibi hissettim.

Kesinlikle katılmıyorum 0 1 2 3 4 5 6 7 8 9 10 Kesinlikle katılıyorum

5. Gerçekleştirdiğim eylemlerin benden kaynaklı olduğunu hissettim.

Kesinlikle katılmıyorum 0 1 2 3 4 5 6 7 8 9 10 Kesinlikle katılıyorum

APPENDIX D

BODY OWNERSHIP QUESTIONNAIRE

1. I felt as if the virtual body that I owned during the experiment was different from my real body.

Strongly Disagree 0 1 2 3 4 5 6 7 8 9 10 Strongly Agree

2. I felt as if my body was immersed in the virtual environment.

Strongly Disagree 0 1 2 3 4 5 6 7 8 9 10 Strongly Agree

3. I felt as if I controlled virtual body.

Strongly Disagree 0 1 2 3 4 5 6 7 8 9 10 Strongly Agree

4. I felt as if I was watching myself from third person view during the experiment.

Strongly Disagree 0 1 2 3 4 5 6 7 8 9 10 Strongly Agree

5. I felt as if the actions were manifested by myself.

Strongly Disagree 0 1 2 3 4 5 6 7 8 9 10 Strongly Agree

APPENDIX E

COMPARISON OF VR AND SIMULATION EXPERIMENTS

Analyses	**VR Experiment**	**Simulation**
Instantaneous Speed	Similar across all conditions	Faster in wide shoulder condition
Psychometric Thresholds	Similar	Similar
Head Data Analysis	Participants with narrow shoulders moved closer	Avatars with narrow shoulders were moved closer
Right-Hand Data Analysis	No change in hand position	Invisible hand was moved closer to the target in narrow
Perceptual Threshold	Pre-wide group did not understand the boundaries of the body	Wide group did not understand the boundaries of the avatar body

REFERENCES

Ackroyd, K., Riddoch, M. J., Humphreys, G. W., Nightingale, S., & Townsend, S. (2002). Widening the sphere of influence: using a tool to extend extrapersonal visual space in a patient with severe neglect. *Neurocase, 8*(1–2), 1–12. doi: 10.1093/neucas/8.1.1

Aldhous, J., Hetherington, R., & Turner, P. (2017, July). *The digital rubber hand illusion*. doi: 10.14236/ewic/HCI2017.59

Banakou, D., Groten, R., & Slater, M. (2013). Illusory ownership of a virtual child body causes overestimation of object sizes and implicit attitude changes. *Proceedings of the National Academy of Sciences*, *110*(31), 12846–12851. doi: 10.1073/pnas.1306779110

Berti, A., & Frassinetti, F. (2000). When far becomes near: remapping of space by tool use. *Journal of Cognitive Neuroscience*, *12*(3), 415–420. doi: 10.1162/089892900562237

Botvinick, M., & Cohen, J. (1998). Rubber hands ‘feel’ touch that eyes see. *Nature*, *391*(6669), 756. doi: 10.1038/35784

Bourgeois, J., Farnè, A., & Coello, Y. (2014). Costs and benefits of tool-use on the perception of reachable space. *Acta Psychologica*, *148*, 91–95. doi: 10.1016/j.actpsy.2014.01.008

Canzoneri, E., Ubaldi, S., Rastelli, V., Finisguerra, A., Bassolino, M., & Serino, A. (2013). Tool-use reshapes the boundaries of body and peripersonal space representations. *Experimental Brain Research*, *228*(1), 25–42. doi: 10.1007/s00221-013-3532-2

Chang, C., Wade, M. G., & Stoffregen, T. A. (2009). Perceiving affordances for aperture passage in an environment–person–person system. *Journal of Motor*

Behavior, *41*(6), 495–500. doi: 10.3200/35-08-095

Edge.org. (n.d.). Retrieved October 5, 2021, from https://www.edge.org/response-detail/11182

Eves, F. F. (2014). Is there any {Proffitt} in stair climbing? {A} headcount of studies testing for demographic differences in choice of stairs. *Psychonomic Bulletin \& Review*, *21*(1), 71–77. doi: 10.3758/s13423-013-0463-7

Fath, A. J., & Fajen, B. R. (2011). Static and Dynamic Visual Information about the Size and Passability of an Aperture. *Perception*, *40*(8), 887–904. doi: 10.1068/p6917

Geuss, M., Stefanucci, J., Creem-Regehr, S., & Thompson, W. B. (2010). Can {I} pass?: using affordances to measure perceived size in virtual environments. *Proceedings of the 7th {Symposium} on {Applied} {Perception} in {Graphics} and {Visualization} - {APGV} '10*, 61. Los Angeles, California: ACM Press. doi: 10.1145/1836248.1836259

Gibson, James J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin.

Gibson, James Jerome, & Carmichael, L. (1966). *The senses considered as perceptual systems* (Vol. 2). Houghton Mifflin Boston.

Higuchi, T., Cinelli, M. E., Greig, M. A., & Patla, A. E. (2006). Locomotion through apertures when wider space for locomotion is necessary: adaptation to artificially altered bodily states. *Experimental Brain Research*, *175*(1), 50–59. doi: 10.1007/s00221-006-0525-4

Higuchi, T., Cinelli, M. E., & Patla, A. E. (2009). Gaze behavior during locomotion through apertures: {The} effect of locomotion forms. *Human Movement Science*, *28*(6), 760–771. doi: 10.1016/j.humov.2009.07.012

Higuchi, T., Takada, H., Matsuura, Y., & Imanaka, K. (2004). Visual estimation of spatial requirements for locomotion in novice wheelchair users. *Journal of Experimental Psychology: Applied*, *10*(1), 55–66. doi: 10.1037/1076-898X.10.1.55

Joy, T., Ugur, E., & Ayhan, I. (2021). Trick the body trick the mind: avatar representation affects the perception of available action possibilities in virtual reality. *Virtual Reality*. doi: 10.1007/s10055-021-00511-8

Knapp, J. M., & Loomis, J. M. (2004). Limited field of view of head-mounted displays is not the cause of distance underestimation in virtual environments. *Presence: Teleoperators and Virtual Environments*, *13*(5), 572–577. doi: 10.1162/1054746042545238

Lessard, D. A., Linkenauger, S. A., & Proffitt, D. R. (2009). Look before you leap: jumping ability affects distance perception. *Perception*, *38*(12), 1863–1866. doi: 10.1068/p6509

lriki, A., Tanaka, M., & Iwamura, Y. (1996). Coding of modified body schema during tool use by macaque postcentral neurones: *NeuroReport*, *7*(14), 2325–2330. doi: 10.1097/00001756-199610020-00010

Pegna, A. J., Petit, L., Caldara-Schnetzer, A.-S., Khateb, A., Annoni, J.-M., Sztajzel, R., & Landis, T. (2001). So near yet so far: {Neglect} in far or near space depends on tool use. *Annals of Neurology*, *50*(6), 820–822. doi: 10.1002/ana.10058

Penfield, W., & Boldrey, E. (1937). Somatic Motor and Sensory Representation in the Cerebral Cortex of Man as Studied by Electrical Stimulation. *Brain*, *60*(4), 389–443. doi: 10.1093/BRAIN/60.4.389

Quanjer, P. H., Capderou, A., Mazicioglu, M. M., Aggarwal, A. N., Banik, S. D., Popovic, S., … Zelter, M. (2014). All-age relationship between arm span and height in different ethnic groups. *European Respiratory Journal*, *44*(4), 905–912. doi: 10.1183/09031936.00054014

Ramachandran, V S, & Hirstein, W. (1998). The perception of phantom limbs. The D. O. Hebb lecture. *Brain*, *121*(9), 1603–1630. doi: 10.1093/BRAIN/121.9.1603

Ramachandran, Vilayanur S, & Blakeslee, S. (1999). *Phantoms in the brain: probing the mysteries of the human mind* (1st Quill). New York: Quill.

Roth, D., Lugrin, J.-L., Galakhov, D., Hofmann, A., Bente, G., Latoschik, M. E., & Fuhrmann, A. (2016). Avatar realism and social interaction quality in virtual reality. *2016 IEEE Virtual Reality (VR)*, *2016-July*, 277–278. doi: 10.1109/VR.2016.7504761

Salmanowitz, N. (2018). The impact of virtual reality on implicit racial bias and mock legal decisions. *Journal of Law and the Biosciences*, *5*(1), 174–203. doi: 10.1093/jlb/lsy005

Schütt, H. H., Harmeling, S., Macke, J. H., & Wichmann, F. A. (2016). Painfree and accurate {Bayesian} estimation of psychometric functions for ({Potentially}) overdispersed data. *Vision Research*, *122*, 105–123. doi: 10.1016/j.visres.2016.02.002

Sirigu, A., Grafman, J., Bressler, K., & Sunderland, T. (1991). Multiple representations contribute to body knowledge processing: {Evidence} from a case of autotopoagnosia. *Brain*, *114*(1), 629–642. doi: 10.1093/brain/114.1.629

Slater, M. (2008). Towards a digital body: {The} virtual arm illusion. *Frontiers in Human Neuroscience*, *2*. doi: 10.3389/neuro.09.006.2008

Slater, M., Spanlang, B., Sanchez-Vives, M. V., & Blanke, O. (2010). First Person Experience of Body Transfer in Virtual Reality. *PLOS ONE*, *5*(5), e10564. doi:

10.1371/JOURNAL.PONE.0010564

Sposito, A., Bolognini, N., Vallar, G., & Maravita, A. (2012). Extension of perceived arm length following tool-use: {Clues} to plasticity of body metrics. *Neuropsychologia*, *50*(9), 2187–2194. doi: 10.1016/j.neuropsychologia.2012.05.022

Thompson, W. B., Willemsen, P., Gooch, A. A., Creem-Regehr, S. H., Loomis, J. M., & Beall, A. C. (2004). Does the quality of the computer graphics matter when judging distances in visually immersive environments? *Presence: Teleoperators and Virtual Environments*, *13*(5), 560–571. doi: 10.1162/1054746042545292

Wagman, J. B., Caputo, S. E., & Stoffregen, T. A. (2016). Sensitivity to hierarchical relations among affordances in the assembly of asymmetric tools. *Experimental Brain Research*, *234*(10), 2923–2933. doi: 10.1007/s00221-016-4695-4

Wagman, J. B., & Malek, E. A. (2007). Perception of whether an object can be carried through an aperture depends on anticipated speed. *Experimental Psychology*, *54*(1), 54–61. doi: 10.1027/1618-3169.54.1.54

Wagman, J. B., & Taylor, K. R. (2005). Perceiving affordances for aperture crossing for the person-plus-object system. *Ecological Psychology*, *17*(2), 105–130. doi: 10.1207/s15326969eco1702_3

Warren, W. H. (1984). Perceiving affordances: {Visual} guidance of stair climbing. *Journal of Experimental Psychology: Human Perception and Performance*, *10*(5), 683–703. doi: 10.1037/0096-1523.10.5.683

Warren, W. H., & Whang, S. (1987). Visual guidance of walking through apertures: Body-scaled information for affordances. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(3), 371–383. doi: 10.1037/0096-

1523.13.3.371

Witt, J. K., Proffitt, D. R., & Epstein, W. (2005). Tool use affects perceived distance, but only when you intend to use it. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(5), 880–888. doi: 10.1037/0096-1523.31.5.880

Won, A. S., Bailenson, J., Lee, J., & Lanier, J. (2015). Homuncular Flexibility in Virtual Reality. *Journal of Computer-Mediated Communication*, *20*(3), 241–259. doi: 10.1111/JCC4.12107