A Study of the Application of Virtual Reality Technology as an Anthropometric Measurement Tool.

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Abstract. Fundamental factors such as constantly changing space usage habits, evolving technology, and various physical and demographic characteristics of space users today call the accuracy of anthropometric assumptions into question. This paper aims to reveal whether VR could be used as an anthropometric measurement tool based on VR's capacity to measure size perception. For this, the parameters that reveal the difference in size perception between VR and the real world were determined, and it was aimed to reveal their effect on the size perception process. Participants received instructions to estimate the sizes of various space components in experimental environments in both real and virtual reality. However, this approach was used to analyze the convergence and divergence between the assumptions rather than the accuracy of user-generated dimensional assumptions. The study's findings are presented as comparative graphical narratives of user estimates in physical and virtual environments.

Keywords: Anthropometry, Virtual reality, Size, Size perception, Interior architecture.

1 Introduction

In the interior architectural design process, each of the size features of the interior components must be correctly perceived by the designer and included in the process. At this point, the human being may be the most dimensionally important interior component. In this direction, the relationship between the discipline of anthropometry and architecture, which deals with the dimensional characteristics of human beings, is always current. Throughout the historical process, assumptions and generalizations have been made regarding the dimensional characteristics of the space and the space user. [1, 2, 3, 4, 5]. However, there is no end to producing a different anthropometric standard for each different case within the discipline of interior architecture. The inclusiveness of anthropometric acceptances within the interior architecture discipline is controversial for many reasons, such as changing space usage habits, developing technologies, and different demographic characteristics of each space user. Figure 1 supports this hypothesis and highlights the differences in the anthropometric studies referencing the interior design process. The main motivation of the study is to present a different perspective on this controversial situation.

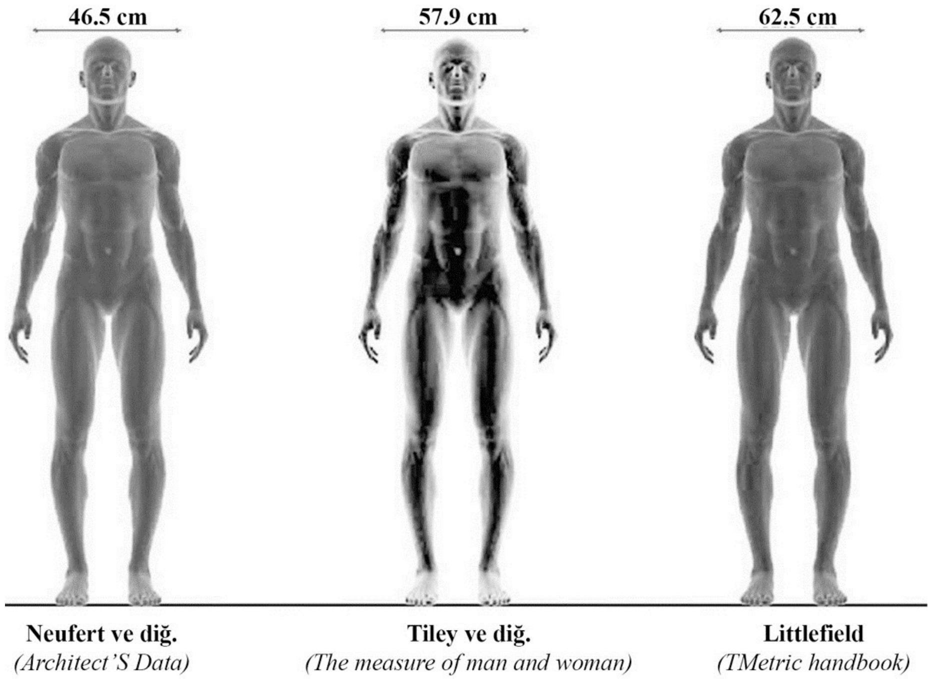


Fig. 1. Several measurements that corresponded to the measurement of the same human body limb emerged from different anthropometric researches [6]

This study, which deals with the comprehensiveness and currentness of anthropometric studies, is planned to include virtual reality (VR) technology, which offers a 1:1 scale experience, into the anthropometric measurement process. In other words, the hypothesis that VR might potentially perform as an "anthropometric measurement tool" is discussed. However, the study did not intend to measure human metrics by using VR. On the contrary, it is aimed to use VR as a tool to understand whether the space is suitable for the sizes of the user. As a result, instead of producing dimensional standardizations for each case and user, several inferences can be produced, and case-specific customized solutions can be created. The original value that this hypothesis can contribute to the research is that the anthropometric measurement process can be treated as egocentric rather than allocentric, and VR can provide this.

Besides being an up-to-date design tool, the main reason for choosing VR in the proposed anthropometric measurement idea is its possibilities in the context of design and user perception experience. Providing the user with a 1:1 scaled experience makes VR one of the most suitable tools for the content of the work. In addition, VR is a tool that can be used in measurement in the design process as it allows precise control of stimulus factors that may be difficult, complex, or impossible to manipulate in real situations [8]. On the other hand, concerns remain about whether VR offers sufficiently precise perception for research and real-world applications [8]. These concerns are also related to the lack of studies on the subject in the literature, and the presented paper aims to contribute to this deficiency.

Examining studies that deal with the concept and perception of size in VR reveals that size is generally handled within the scope of scale and depth [9, 10, 11, 12, 13]. Nevertheless, it is necessary to examine each component of the size concept separately for VR technology to perform as an anthropometric tool within interior architecture. The concepts of proportion and scale are among the fundamental principles of interior design; it is concerned with the dimensional relationship of objects, users, and space [5, 14, 15, 16]. The entire set of dimensional relations directly participates in the design process through the space's intended use and the desired effect. To put it more clearly, not only the depth but also the length, width, and the effects of the depth should be discussed separately. Consequently, an egocentric fiction can be created both in terms of the user and the size components of the space.

By all of this, the paper attempts to answer the question of "Is the perception of size in virtual reality different from the perception of size in the real world?" and "What is the potential use of virtual reality as an anthropometric measurement tool?". The paper aims to examine the relationship between interior architecture and size individually with all spatial components (object-space-human) belonging to the concept of size. In a more inclusive expression, the study's goal is to demonstrate the capacity of VR to simulate size perception, which offers the possibility of size experience on a 1/1 scale specific to each space and space user.

This article is structured into five sections. After this introduction, Section 2 presents the different perspectives on the size as a concept and the related literature on size concept and perceptual parameters in VR environments. The parameters used in the presented study and their definitions are given in Section 3. Then, Section 4 presents the implementation of the constructed VR experiment environments by detailing all exercises with their processes, outcomes, and evaluations. Section 5 discusses the experiment's achievements, limitations, repeatability, and future works.

2 Background

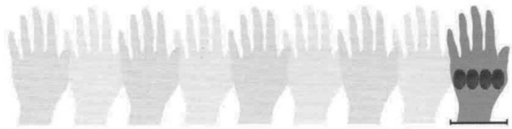
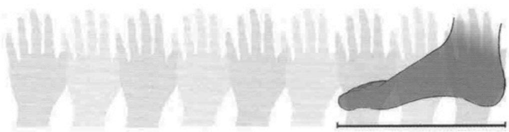
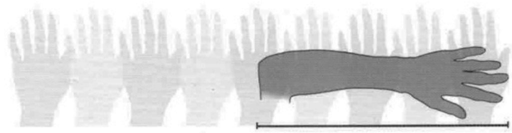
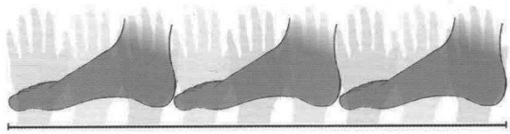
When we examine the historical development of the concepts of size and measurement, we see that the starting point is the human body. This situation is essential for understanding the origins of anthropometry. In addition, it is possible to find the origins of the standardization process of the human dimension here. In this context, in section 2.1, the development of the concept of size and different approaches to the concept of standardization are presented theoretically. In addition, in Section 2.2, the parameters affecting the concept and perception of size are presented in line with the differences and similarities in the physical and virtual environment.

2.1 Concept of Size

It is necessary to examine the representation of size to reveal the relationship between the space user and the concept of size. This examination is due to the fact that the concept of size is embodied in the historical process via the human body and parts. This concretization entails thinking one thing with another and organizing that thought through various relationships established between those two things [17]. Since ancient times, man has connected these two things by using his own body and parts. The fact that human parts were once the basis of units of measurement, as shown in Table 1, demonstrates this situation. However, the need for certain dimensional standardizations has emerged due to variables such as a person's physical characteristics and cultural differences.

Table 1. Some anthropometric units derived from the human body [18].

Anthropometric Units

Hand		**4 thumbs** *=1 hand (English)* *=1 palaiste (Ancient Greek)* *=1 drt (Ancient Egypt)*
Feet		**3 hands** *=1 feet (English)* *=1 pous (Ancient Greek)* *=1 pes (Ancient Rome)* *=1 bw (Ancient Egypt)* *=1 su-du -a (Ancient Sumerians)*
Cubit		**4.5 hands** *=1 cubit (English)* *=1 pechys (Greek)* *=1 coudee (French)* *=1 elle (German)*
Yard		**3 feet** *=1 yard (English)* *=1 guz (Persian)* *=1 vara (Spanish)*

This requirement, which manifests as the standardization of dimension representation within the scope of the unit of measurement, is a cross-section of the architectural and anthropometric study areas. However, considering the relationship between architecture and anthropometry solely as the physical relationship between the space user and the space is insufficient. It is also clear that people's previous aesthetic understanding is essential. In the past, the definition of absolute beauty was attempted to be defined through the human body, and it was acted on with the primitive notion that man is the measure of everything. For a long time, the study of proportional relationships between the dimensions of human body parts, their use as certain ratio constants, and their application in architecture was valid. The human body was symbolically emphasized in architecture with this mindset. This situation manifests itself as "comparing architectural fiction to the human body" or "geometrizing the human body." On the other hand, rationalist beliefs that the human body is not the foundation of absolute beauty have evolved over time. Geometrizing the human body and creating human figures with definite dimensional ratios did not help the architect support his ideas [19].

On the contrary, geometrized human figures are an unavoidable representation of the thought produced and go completely against human nature. Catching a relationship between geometric proportions and human figures created by daily life and actions is both impossible and unrealistic. By removing the impositions of this proportion, a wide variety of human forms can be seen, and man's place in the world can be based on more than a set of abstract ratios and numbers [18]. Figure 2 shows sketches that are important for understanding the relationship between different uses of space and anthropometric assumptions. These sketches, which critique the anthropometric standardizations advocated by many architects and designers, particularly Ernst Neufert, are valuable because they oppose the frozen expressions of anthropometric assumptions that assume the man is a machine. These sketches are vital as they clearly present the main motivation and hypothesis of the study.

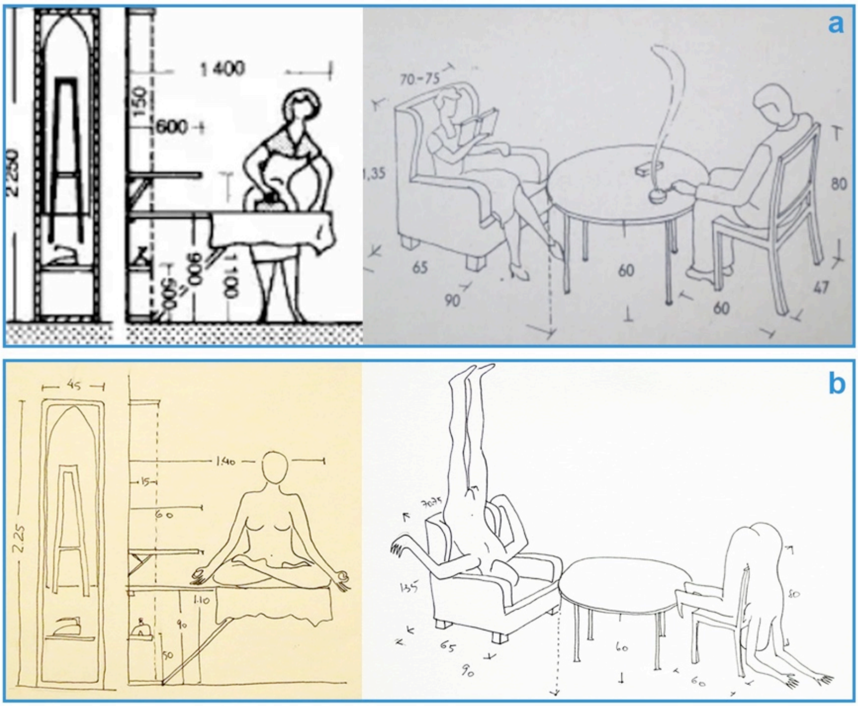


Fig. 2. The anthropometric assumptions made by Neufert (a) and the sketches produced in response to these assumptions are referred to as "Disturbing Neufert" (b).

2.2 Perception of Size and Parameters in a Virtual Reality Environment

Perception is a process that reflects the dialectic of cognition and behavior and provides response production as a result of the brain's evaluation of environmental stimuli as a sensory input. Perception, in other words, is the subjective description of the physical world. The perception process is divided into two stages [20]. The first is the sensory process, which is the physical part of the perception process in which environmental stimuli are received via the senses. The second process is the cognitive process, which is the process of comprehending and interpreting the stimuli that physically reach the brain with subjective parameters. Size perception emerges as a result of the dialectic of these two processes; it can change in response to changes in the sizes of the space, or it can change in response to changes in other parameters of the space while the sizes of the space remain constant. In this case, the study focuses on which parameters affect the perception of size and whether this situation is the same as the physical environment in virtual reality. The literature on the definition and components of virtual reality is presented in support of this idea.

Virtual reality is defined as a scientific and technological field that interacts in real-time by simulating the behavior of 3D entities in a virtual world through sensory-motor channels with one or more users and employing computer science and behavioral interfaces to do so [21]. This definition provides essential information - behavioral interfaces- about the perceptual differences between the physical and VR environments and how they can be controlled. Behavioral interfaces describe the hardware and software that transfer the user's movement or perceptions arising from real-world behavior to the virtual environment. These interfaces contribute to the perceptual process by bridging the gap between the VR user's movements and senses in the physical and computer environments. As a result, the VR user minimizes the difference in perception of space between the two environments by mimicking their physical environment behaviors. Behavioral interfaces are divided into two types: "sensory interfaces" and "motor interfaces." Sensory interfaces transport sensory stimuli from the computer environment to the user. Motor interfaces transfer the user's motor responses to the computer environment. These two interfaces are sub-components that feed off of one another to form behavioral interfaces. Figure 3 depicts the perceptual difference process between the VR and physical environments due to these interfaces.

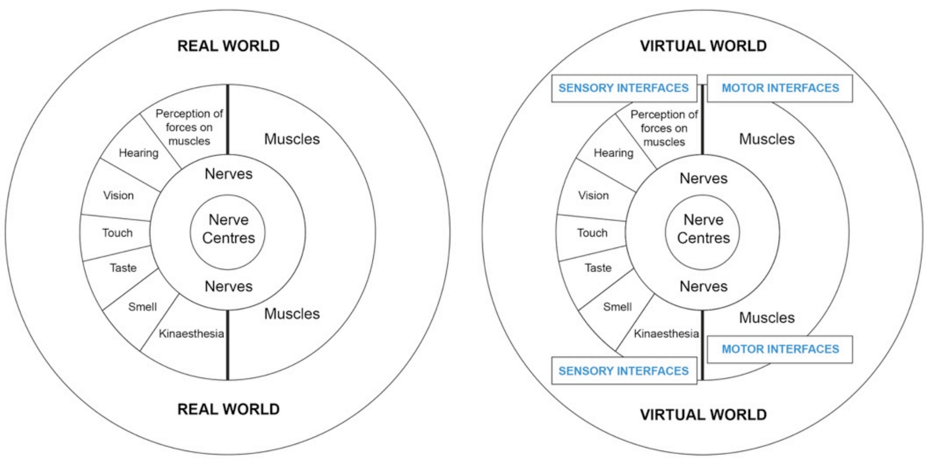


Fig. 3. Anthropocentric perception process diagram in physical (left) and virtual reality environments (right) [21].

Virtual reality is also defined as "an immersive and interactive system based on calculable information" [22]. These are the three I's of VR: immersion, interactivity, and information density. These three terms are critical for controlling the perceptual process in the VR environment. Interaction refers to the user's ability to receive feedback in response to his movements in the VR environment. On the other hand, the informatic level of the interfaces used in the VR environment is defined by information density. The term immersion is used because the user in the VR environment feels as if they are in a different environment than their physical environment and are surrounded by it.

Fig. 4 depicts three different levels of immersion. There are three types of immersion: sensory-motor immersion, cognitive immersion, and functional immersion. The sensory-motor immersion is related to the user's physical immersion. Sensory- motor immersion process must first be overcome because users are physically connected to a computer through their senses and motor responses. The characteristics of the senses and motor responses are used to determine the level of immersion. Another level of immersion, cognitive immersion, refers to the ability to immerse the user in the VR environment mentally. The design of behavioral interfaces that transmit the user's sensory and motor movements in the physical environment to the virtual environment is an important factor at this point. The final level of immersion is functional immersion, which describes giving the user a purpose in the VR environment. In other words, the user must have a task to perform in the VR environment if he allows the VR environment to surround him physically and cognitively. Otherwise, the effect of the immersion levels in the first two levels will be diminished, and the transition from the VR environment to the physical environment will be accelerated.

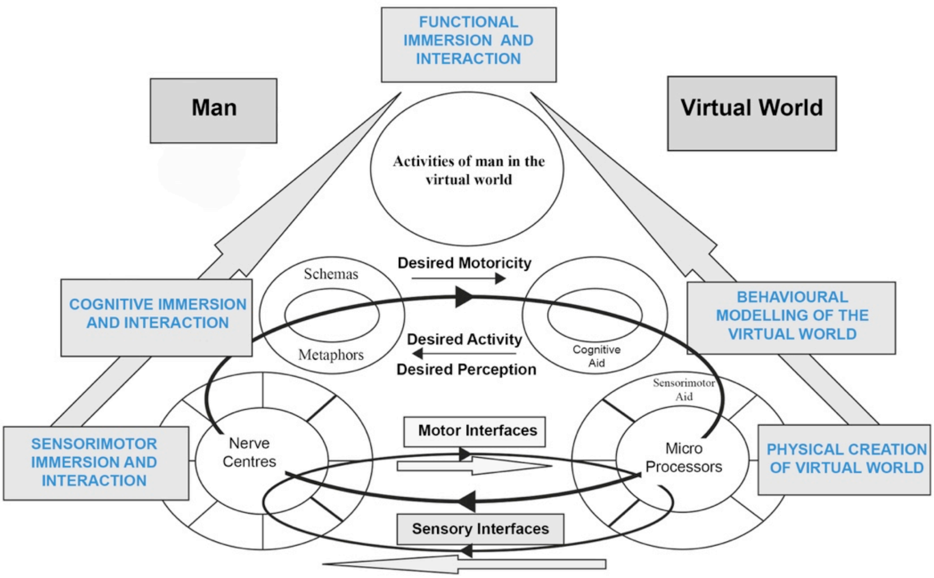


Fig. 4. Diagram of the perceptual process in a virtual reality environment [21].

In this context, the parameters presented as more inclusive titles affect the perceptual process in the virtual reality environment. However, some features of behavioral interfaces, interaction, information density, and immersion concepts are related to the technical features of the hardware. The present study does not concentrate on improving these technical characteristics. Instead, sub-headings that influence how sizes are perceived in a virtual reality environment and may impact these headlines during the modeling process have been identified. Section 3 provides a more comprehensive explanation of these sub-parameters used in the experimental study.

3 Definitions of Parameters

The parameters discussed in Section 2.2 that have an impact on how people perceive size mainly relate to the hardware specifications of virtual reality systems. However, it aims to identify the sub-parameters that can influence these head parameters to investigate the usage of VR as an anthropometric measurement tool. The beginning point for this has been the cues that individuals use in the process of visual perception.

The foundation of size perception is the ability to generate a visual sense of the third dimension for all components in a space. The signals arriving at the retina form the third dimension in the visual perception process. This process enables the perception of three-dimensional space by using various cues to parse and process visual information through various channels [21]. Of these cues, the subject of the study is the pictorial ones. Any visual information in two dimensions concerning relative distance that can be shown in a picture or image and from which three-dimensional inferences can be made is referred to as a pictorial cue. In essence, pictorial cues can be obtained from a static image [23]. Pictorial cues, on the other hand, are one of the object-centered (OC) parameters that will allow users to control size perception in an immersive VR environment. These parameters are as follows:

1. OC-P1: *The use of familiar sizes* (the use of reference objects) causes the user to estimate the size of objects or spaces for which the user does not know the size based on familiar sizes because the user knows the size of some objects in the space [24,25].
2. OC-P2: *Light, material, color, and texture* are parameters that ensure the correct production of information about the real forms and structures of objects, and their use in virtual reality influences size perception. [26].
3. OC-P3: Objects can be positioned relative to depth using sequential *positioning* (overlap) because it creates a size alignment.
4. OC-P4: *The field of view size* is a crucial factor in determining how much objects and space can be seen.

On the other hand, the user-centered (UC) parameters are those that the user may alter regarding how they perceive size in a VR environment. Because humans have established measurement units using their body parts and use their bodies as measuring tools, human body parts are an effective parameter in the size perception process. In the VR environment, size perception is influenced by the following user-centered factors:

1. UC-P1: *The user's virtual hand size* is an essential parameter for users who have grasped the space in a size sense with their body and limbs throughout the historical process. The size of their virtual hands affects the overall size perception of the space for users who can only see their hands in relation to their bodies in immersive VR environments (except in immersive VR environments produced for advanced use). The parameter "the size of the virtual hand in the VR environment" is related to the origin of the concept of size [27,28,29,30].
2. UC-P2: One of the most physically important parameters is the *users' eye level* and the gap between their eyes. The height of the users' eyes and the adjustment of the distance between their eyes are effective in the size perception process in the model prepared for the VR environment. Eye level

is an essential and usable variable in allowing the space used to perceive his height and the space sizes differently [9,12,13].

3. UC-P3: *Familiarity* implies that users physically experience the space in the same way that they do in a VR environment. This familiarity is essential for users physically experiencing the space and forming an opinion about its size and character.

As a result, identifying the parameters that influence size perception is critical for transforming size perception in the VR environment into a more controllable one. In this context, these parameters were used as a foundation in different environments explicitly designed for the experimental study, and their effects on the perception of size were revealed.

4 Experimental Study

This section presents the experimental study with its outcomes. Ten undergraduate students from Istanbul Technical University's Department of Interior Architecture participated in these studies. We considered the criteria of continuing undergraduate study in the field of interior architecture and not having any prior experience in VR when choosing the participants. In order to test the OC-P1 and OC-P2 parameters, we set up the criteria for continuing undergraduate education in the field of interior architecture. To test the UC-P1, UC-P2, and UC-P3 parameters, we set the requirement that participants had no prior VR experience.

4.1 Aims of Experimental Study

In the paper, we implemented an experimental study as a methodology. We created experimental environments in the real world and virtual reality as part of the experimental study process. The participants were asked to answer size assumption questions about the space's elements inside these environments. The process of dimensional assumption was done in both the real world and VR. We did not use this method to evaluate the accuracy of user-generated dimensional assumptions. Instead, we have preferred using dimensional assumptions made in physical and virtual environments to examine their relationship.

The methodology aims to determine whether the perception of size in the VR and physical environments is the same. If it is the same, we aimed to answer the question of whether VR can be used as an anthropometric measurement tool that can be used as a tool that can accurately simulate size perception. During the experiment, the authors noted the size assumptions made by the students in both physical and virtual reality environments. Graphical representations of the size assumptions were produced by analyzing the data obtained from the experiment. Thus, it is aimed to make a comparative evaluation of the representations produced together with the research questions of the study and the theoretical framework presented.

4.2 Experiment Environments

We created six different environments as part of the methodology of the experimental study. Experiment participants were asked to make predictions about the size properties of the space. The experimental study's methodology is based on comparing the differences in predictions made by the same person for six different experimental environments designed to accommodate different size perception parameters. Figure 5 depicts six different experimental environments coded as A, B1, B2, B3, C1, and C2.

A, is the actual physical space. The physical location for this research was one of our university's classrooms.

For use in a VR, B describes a completely modeled representation of A. B1, one of B's subspaces, is a virtual space that contains all of A's quantitative and qualitative features. In other words, B1 is a photo-realistic representation of A. B2 is a raw model virtual space containing only A's quantitative parameters. In other words, B2 is a non-photorealistic representation of A. B3 is a virtual space in which users who experience the B1 through VR have their eye level raised by 40 cm.

C, virtual spaces in which participants' interaction with the space is increased, and the sizes of the space and reference objects are produced again by participants. In this context, the C1 is an enlarged variation of the B2 with constant space ratios. Users were asked to return the size of the C1 to B2 in this environment. C2 is a virtual space in which the participants in C1 are increased to 1.5 times the size of their virtual hands. Thus, it was intended to reveal the effect of this situation on size perception by manipulating the sizes of the experiment participants' human body parts.

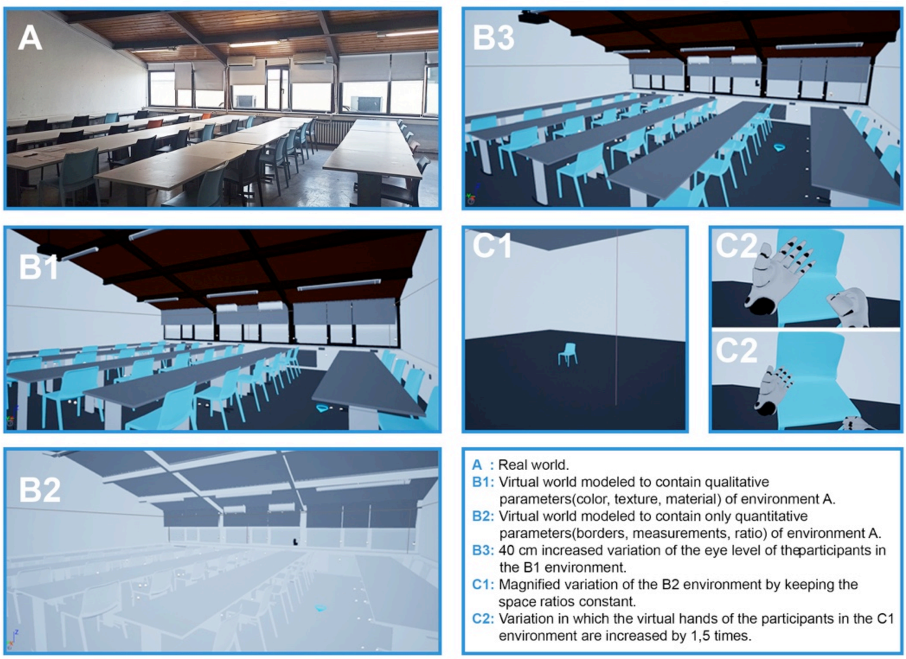


Fig. 5. Coding and visual representations of experimental environments.

The followings are the goals of comparing six different experimental environments:

- Demonstrating the OC-P1, OC-P3, and OC-P4 parameters between the photo-realistic modeled VR environment and the physical environment between the A-B1 environments,

- To investigate the effect of OC-P2 parameters on the perception difference between the VR and physical environments between A-B2 environments.
- To investigate the effect of OC-P2 parameters on the size perception difference between B1 and B2 VR environments,
- To investigate the effect of the UC-P2 parameter on their perception of the size of the space between the B1-B3 environments and the photo-realistic modeled VR environments,
- Participants in the experiment are asked to reconstruct the space's proportions in the VR environment in the C1 environment. Hence, the objective was to demonstrate the impact of UC-P3 parameters.
- In the C2 environment, it is aimed to reveal the effect of the UC-P1 parameter of the users between VR environments on the size perception of the space.

4.3 Procedure

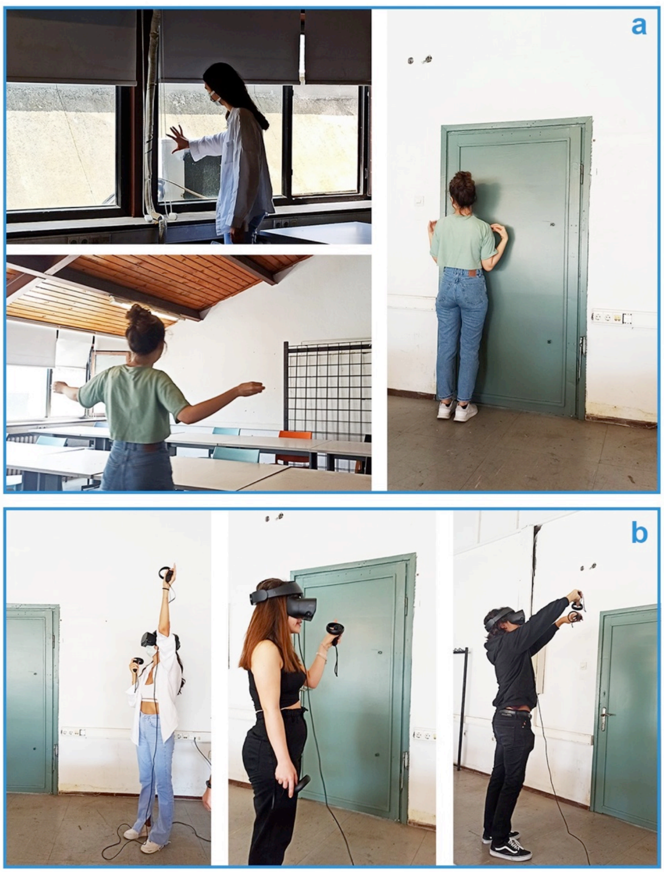


Fig. 6. The participants' dimensional estimation processes in the physical environment (a) and the virtual reality environment (b).

The primary goal of the experimental environment procedure was to ensure the safety of the experiment participants. Before the experimental studies, the floor area where the participants will experience Head Mounted Displays (HMDs) was defined for this purpose (2.5x5 meters). Furthermore, "Oculus Guardian," which creates protective virtual borders in the third dimension, was used to keep the experiment participant from colliding with physical objects. Following this, the equipment was placed in the experimental space. Figure 6 depicts the size assumption process of experiment participants in both physical and virtual environments.

The study was conducted in 5 steps, followed uniformly by each participant.

1. Participants experienced the A environment, and the following questions were used to make size assumptions for the A environment:

- "What is the width, depth, highest point's height, and lowest point's height of the space?"
- "What is the window's height and width?"
- "What is the door's height and width?"

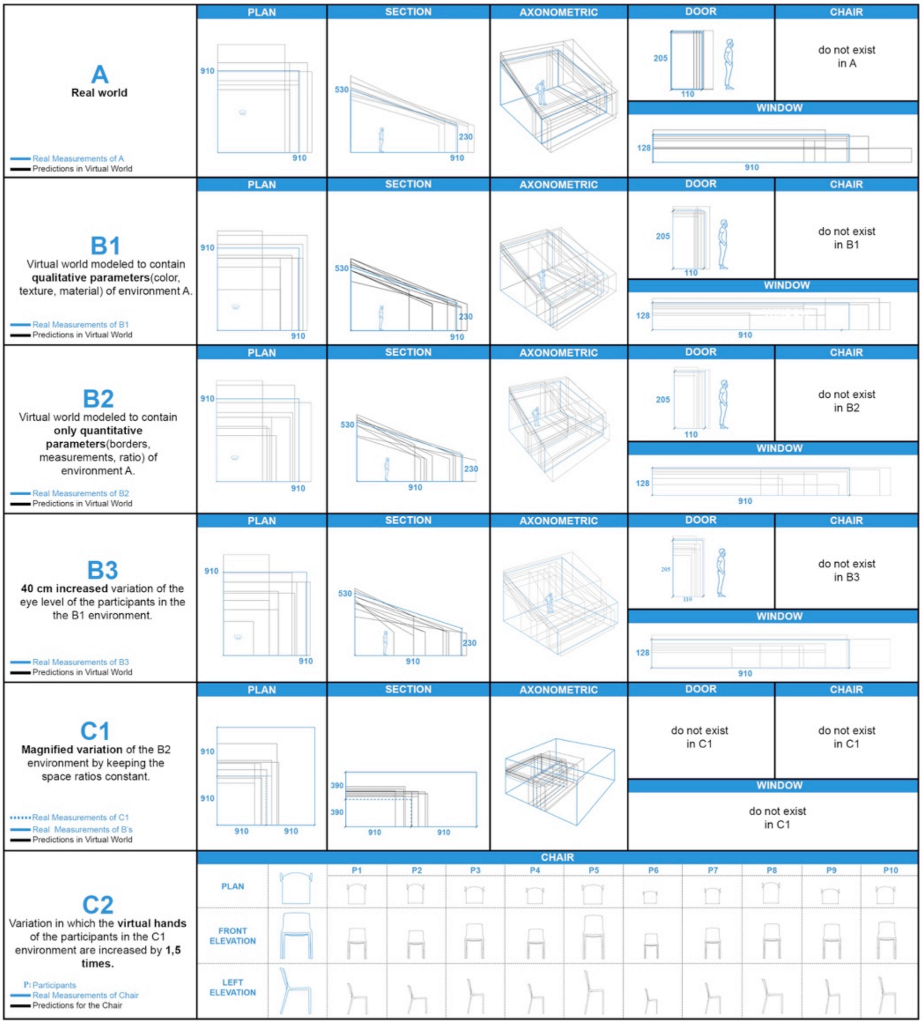
2. The participant receives their first experience with HMDs. Interface experiments were done to learn fundamental VR abilities like teleporting and interacting with objects (grabbing, throwing, stacking, etc.). As a result, the switch to the VR environment was completed.
3. Participants experienced the B1, B2, and B3 environments, and the same questions from Step-1 were repeated in each of these environments.
4. Participants experienced the C1 environment and compared the C1 environment with the B2 environment in terms of dimensions.
5. Participants experienced the C2 environment, and the following questions were used to make virtual hand-size assumptions and analyze the C2 environment:

- "Has your virtual hand size changed since the last experimental environment?"
- "If it has changed, how much has your virtual hand size increased?"
- "How do you figure out the chair size?"

4.4 Data Collection and Findings

As the experimenters, we verbally obtained the data set containing the size assumptions. The purpose of this situation is to keep experiment participants from removing their HMDs and losing their perception of the environment. After a verbal data collection process, the obtained data were visualized for analysis. A graphic narrative was created to depict the quantitative difference between the visualizations and the actual size of the spaces experienced and the predictions made by the participants. Data visualizations were created for all A, B1, B2, B3, C1, and C2 environments, and a layout was used to compare the data. This layout includes the plan, section, and axonometric graphs, as shown in Table 2.

Table 2. Architectural representations of experimental data.



The followings were observed *environments A&B1:*

- Individual assumptions about the width and length of the environment do not reflect the actual dimensions of the space. Nevertheless, the assumptions about the space's form (square, rectangular, etc.) produce more accurate results.
- Assumptions about the space's height are more accurate than assumptions about its width and height.
- Assumptions of the space's slope are closer than assumptions of the space's two different heights.
- Door size assumptions are more accurate than window size assumptions.

The followings were observed in the *B2 environment:*

- When OC-P2 parameters are removed, size assumptions gradually deviate from real-world dimensions.
- Participants' assumptions about the overall geometric shape of the space started to weaken.
- In addition to the width and length assumptions, the space's height and slope assumptions deviate from the actual space dimensions.
- The assumptions of the dimensions of the door and window deviate from the accurate dimensions due to a misunderstanding of the borders and level of detail of the door and window.

The followings were observed in the *B3 environment:*

- The change in UC-P2 parameter caused the space to appear much smaller than it is.
- The change in space height assumptions is greater than 40cm (UC-P2 parameter).
- The space's window and door are perceived to be much smaller than they are. Experiment participants' assumptions of the door height are smaller than their own dimensions. This shows that participants completely lost their perception of size in the B3 environment.

The followings were observed in the *C1 environment:*

- In the VR environment, space constraints affect size perception positively.
- Although no volume is created near the desired volume, close volumetric relationships can be established.
- The heights of the spaces created reveal closer values than width and height, and users have an egocentric size perception between their own height and the height of the space.

The followings were observed in the *C2 environment:*

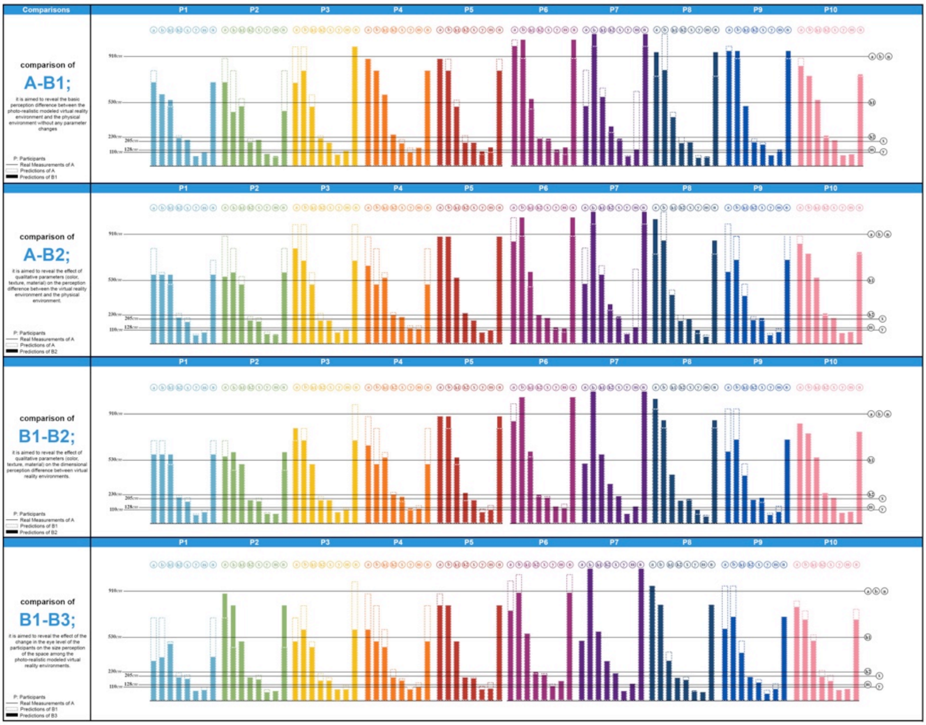
- In the VR, all participants perceive the objects to be smaller than they are because the size of their virtual hands has increased.
- The size of virtual body parts that users can control or see in the VR influences the overall size perception in the VR.

Making comparative analyses is essential in terms of the variety and accuracy of the results obtained from the study and observing the data obtained from the experimental environments created individually. Table 3 details the comparisons between A-B1, A-B2, B1-B2, and B1-B3 environments.

It aims to demonstrate the OC-P1, OC-P3, and OC-P4 parameters between the photo-realistic modeled VR environment and the physical environment between the A-B1 environments. The followings were observed between A-B1:

- The size assumptions made in the A environment are more accurate than those in the B1 environment.
- Assumptions of the space's height between environments A and B1 are closer than assumptions of the space's width and length. Vertical surfaces affect size perception more than horizontal ones.
- Size assumptions for objects familiar to participants are very close to actual sizes.
- Assumptions made in VR are similar to those made in the physical world and produce more positive results for some participants.

Table 3. Data from experimental environments are compared using graphics.



It aims to investigate the effect of OC-P2 parameters on the perception difference between the VR and physical environments between A-B2. The followings were observed between A-B2:

- The size assumptions made in the A environment are more accurate than those in the B2 environment.
- Assumptions about the height of the space are more accurate than assumptions about the width and length of the space.
- OC-P2 parameters are important for the perception of space height.
- It is difficult to perceive the general geometric features of the space due to the decrease in the level of detail related to the space.

It aims to investigate the effect of OC-P2 parameters on the size perception difference between B1 and B2 VR environments. The followings were observed between B1-B2:

- Compared to the B1 environment, the assumptions about the space's width and length of the space in the B2 environment differ from reality.
- Assumptions of space height in B1 and B2 environments are close or the same.
- OC-P2 parameters are important factors influencing size perception in VR, and processing them in the model improves the size perception process.

It aims to investigate the effect of UC-P2 parameters on their perception of the space size between the B1-B3 environments and the photo-realistic modeled VR environments. The followings were observed between B1-B3:

- In the B3 environment, the assumptions about the width, length, and height of the space deviate more from reality than in the B1 environment.
- Participants could relate to their own sizes. Participants' size perceptions of objects like doors and windows differed significantly between B1 and B3.
- Because of the change in parameter UC-P2, the space appears much smaller than it is.
- The change in space height assumptions is greater than the increase in eye level.

5 Conclusion

This paper examined whether VR could be used as an anthropometric measurement tool based on VR's capacity to measure size perception. With the method used, an egocentric perspective regarding anthropometry and size perception was created instead of the allocentric perspective used by anthropometric generalizations. For this, the parameters that reveal the difference in size perception between VR and the real world were determined, and it was aimed to reveal their effect on the size perception process. The main findings of the paper are:

- The perceptual differences between the virtual and physical environments can be minimized, and VR can simulate size perception in the physical environment to the greatest extent possible.
- Instead of making anthropometric dimension generalizations, making personalized anthropometric measurements with VR is a more up-to-date method. Since VR can simulate size perception close to the real world, it has significant potential.
- It seems that the perceptual difference between the real world and VR can be reduced by elaborating on the parameters described in Section 3 during the pre-VR modeling process.
- We think many parameters affect the perception of dimension in the VR environment, just like in the real world. However, considering them holistic rather than individual parameters can create more positive outcomes.

The main limitations of this paper are:

- We did not measure the effect of the demographic information of the participant group; we conducted the study on the process. The effect of these characteristics of the participants on the perceptual process could have added a different perspective to the study by increasing the number of participants.
- The constraints on the technological features of VR described in Section 2 affected the perceptual process. Technical features such as the use of non-tactile controllers and the use of a wired HMD device negatively affected the immersion levels of the participants.
- It was observed that while the participants were performing the dimensional estimation process with their body parts in the real world, doing this with hardware in a VR environment negatively affected the process.

As a result of these findings, it is clear that more research on the perceptual process in the VR environment is needed. The vision for future studies are as follows:

- Model ideas for the design process to be completed entirely over the virtual environment can be created by creating interactive design environments within the VR environment. Thus, increasing immersion allows studies on the VR perceptual process to be conducted more successfully.

- In the context of size perception being a process related to the participant's own body, the potential of using augmented reality (AR) or mixed reality (MR) can be repeated with the method used in this paper.
- VR can be used to detail design processes specific to user profiles with different dimensions, such as children, in the context of enabling customization of the dimension process in design.

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