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Mapping of Realism in Rendering onto Perception of Presence in Augmented Reality

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DIPLOMA THESIS

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Erklärung zur Verfassung der Arbeit

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Wien, 22. November 2017

David Schüller-Reichl

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Kurzfassung

Augmented Reality (AR) integriert virtuelle computergenerierte Objekte in die reale Umgebung. Im Idealfall fügen sich virtuelle Objekte in die reale Welt so ein, dass der Benutzer die virtuellen Objekte so wahrnimmt als wäre es Teil der realen Umgebung. Dass sich ein virtuelles Objekt in die reale Umgebung einfügt ist auch unter dem Konzept der Präsenz bekannt. Ein hohes Maß an Präsenz (oder auch Anwesenheit) ist besonders wichtig, wenn eine AR-Anwendung virtuelle Personen verwendet, um mit dem Benutzer zu interagieren. In dieser Arbeit wird untersucht ob eine visuelle realistische Darstellung (im weiteren Realismus) in AR-Anwendungen wichtig ist um ein hohes Maß an Präsenz zu erzielen. Zwei Hypothesen wurden erstellt um den Einfluss von Realismus auf die Wahrnehmung der Präsenz und auf den Benutzerkomfort bzw. Benutzererfahrung innerhalb von AR-Anwendungen zu untersuchen. H1: "Die Erhöhung des Realismus erhöht das Gefühl von Präsenz und Benutzerkomfort / Benutzererfahrung.". H2: "Der Uncanny Valley Effekt kann innerhalb des Experiments beobachtet werden.".

Um die aufgestellten Hypothesen zu untersuchen wurde eine Benutzerstudie durchgeführt, in der die Teilnehmer eine virtuelle Person mit unterschiedlichen Realitätsniveaus beobachteten. Jedes Realitätsniveau unterschied sich in Geometrie, Textur und Lichtquellen. Die entwickelte AR-Anwendung beinhaltete ein Rendering-System, mit dem das Realitätsniveau der virtuellen Personen eingestellt werden konnte. Die Ergebnisse unterstützten teilweise die erste Hypothese (H1) und zeigen, dass visueller Realismus ein wichtiger Faktor ist, um ein höheres Gefühl der Präsenz in einer AR-Anwendung zu erreichen. Die zweite Hypothese (H2) wurde nicht unterstützt. Wahrscheinlich aufgrund von technischen Einschränkungen, die eine realistische virtuelle Darstellung einer virtuellen Person nicht zuließen, so dass der Teilnehmer glauben würde, dass es tatsächlich eine reale Person sein könnte.

Das wichtigste Novum dieser Arbeit ist die Fokussierung auf das Präsenzgefühl gegenüber virtuellen Personen in AR-Anwendungen. Anders als Studien im Bereich VR weißen aktuelle Studien im Bereich AR darauf hin, dass der Einfluss von visuellen Realismus auf die Wahrnehmung der Präsenz unterschiedlich ist. Zukünftige Entwicklungen von AR-Anwendung mit dem Ziel hoher Präsenz zu erreichen können die Ergebnisse dieser Arbeit als Basis verwenden. Vor allem, wenn virtuelle Menschen verwendet werden, um mit Benutzern zu interagieren.

Abstract

Augmented Reality (AR) is about seamless integration of virtual computer-generated objects into the real-world view. Ideally, virtual objects should blend into the real world so that the user feels like the virtual objects are "here". The sense of something being ”here” is also known as the concept of presence. Presence is especially important if an AR application is using virtual humans to interact with the user. This thesis examines if the visual realism is essential to achieve the highest possible presence in an AR application. Two hypotheses were posed to examine the effect of realism on the perception of presence and the convenience of users within AR applications. H1: ”Increasing the level of realism increases the sense of presence and convenience of users.”. H2: ”The Uncanny Valley effect can be observed within the experiment.”.

The approach of this thesis to examine these hypotheses was to conduct a user study in which the participants experienced a virtual human with a specific visual realism levels. Each visual realism level differs in geometry, texture and lights. The developed AR application included a rendering system which allows the levels of realism of the virtual human to be set. The results partially supported the first hypothesis (H1) and indicated that visual realism is an important factor to achieve a higher sense of presence within an AR application. The second hypothesis (H2) was not supported, most probably due to technical limitations which did not allow such a realistic virtual representation of a human so that the participant would believe it could be a real person.

The main novelty of this thesis is its focus on the presence of virtual humans within AR. Recent studies showed that the influence of visual realism on the sense of presence if different in the field of AR than in VR. Future presence demanding AR application can take the results of this thesis of basis to achieve a higher sense of presence. Especially, if virtual humans are used to interact with users.

Contents

CHAPTER 1

Introduction

"*The main concept of Augmented Reality (AR) is to overlay spatially aligned virtual objects onto the real world. Ideally, the user perceives that the virtual and real objects coexist in the same space*" [Azu97] .

Seamless integration of virtual objects into the real world is often a goal of AR application. Ideally, virtual objects should integrate into the real world so that the user feels like the virtual objects are "here". The sense of something being "here" is also known as the concept of presence. To achieve the highest possible presence in an AR application, the level of realism could be an important factor. The effect of visual realism on the perception of presence in AR must be studied empirically.

1.1 Motivation

AR is a field that greatly depends on human perception. The usability of the final application, as well as the convenience for users, is based on how the virtual objects are interpreted and perceived by the users. Without knowing how users perceive virtual objects it is very difficult to develop AR application with the goal of a high level of presence. How can be a high level of presence in an AR application achieved if influencing factors are not known? Therefore, studying how AR affects human perception plays an important role in future AR application development.

The main goal of this thesis was to develop an AR rendering system with varying levels of realism and to use it to study the effect of increasing realism on the perception of presence and on the convenience of users in AR. The amount of realism was mapped to the presence score and user convenience to investigate the final dependence curve. During the study, different observations have been made. For example, the existence of an Uncanny Valle effect was studied.

Clarification how the level of realism affects the sense of presence can help future presence demanding AR applications to pay attention to the influencing factors. The observation of the Uncanny Valley effect can help developers to understand critical factors which could make the user disturbed of an AR application.

This is especially important if virtual humans are used to interact with an user. The user should concentrate on AR application and the content it tries to provide and should not be distracted from visual representation or laking sense of presence.

1.2 Approach

To study the effect of increasing realism in an AR application on the perception of presence and on the convenience of users, an experiment was designed. For the experiment, an AR application was implemented. During the experiment, the participant observes a virtual human (in this context, also known as a virtual agent). The AR application included a rendering system which allows the level of realism of the virtual agent to be set. The feeling of presence should be as high as possible by design. Therefore, and if allowed by technical possibilities, the implementation followed several findings in previous studies. The conducted experiment followed a ”within-group design”. Each participant experienced a virtual human with all different levels of realism in a random order. To measure the experiences, each participant filled out a questionnaire after each observation. The questionnaire followed and adapted questionnaires used in previous studies. It covers questions about collision, perception, presence, co-presence and social presence. They are also designed and adapted to measure a possible occurrence of the Uncanny Valley effect.

1.3 Expected Results

Recent publications in the research field of AR show tendencies that visual realism is important to achieve a higher sense of presence. It is expected that visual realism is an important factor for the sense of presence and convenience of an user. Also, the Uncanny Valley, which was not measured in a targeted manner in the past, is expected to be observed. Nevertheless, it is expected that technical limitations could rise problem to observe the Uncanny Valley and overall perception.

1.4 Structure

This thesis consists of six chapters. Chapter 1 ”Introduction” highlights the main idea, motivation and the approach of this thesis. Chapter 2 ”Background and Related Work” summarise the theoretical background of the field of research in AR, virtual humans, perception, presence and Uncanny Valley. Chapter 3 ”Methodology” describes the approach to study the effect of visual realism on the sense of presence and convenience of the user. Mainly, it contains the hypotheses, expected results, the experimental design of the conducted user study, the approach to create a virtual human with different visual realism levels and the approach to analyse the measured data set. Chapter 4 ”Results” contains the results of the made data analyzes following by its discussion in Chapter 5 ”Discussion”. Finally Chapter 6 ”Conclusion” summarises the overall findings and highlights important aspects for future work in this research field.

CHAPTER 2

Background and Related Work

2.1 Augmented Reality

"*AR is able to bridge the gap between real and virtual objects.*" [MS16]

Since the beginning of Augmented Reality (AR) in the 1960s [ABF+01], research in the field of AR has been growing [ABF+01]. In 1997 Azuma published a survey [Azu97] that *"defined the field, described many problems, and summarized the developments up to that point."* Azuma complimented the paper in 2001 [ABF+01] "denoting the rapid technological advancements" since 1997. Especially regarding display technology, interface, and interaction, visualization problems as well as new applications in AR. A complete chapter about the History of AR until 2015 can be found in the survey of Billinghurst et al. [BCL15]. This survey summarizes almost 50 years of research and development in the field of AR. It provides an overview of common definitions, recaps taxonomies of other related technologies, and shows how AR fits into them. The aforementioned papers together provide an extensive introduction to the research field of AR.

This section gives a short overview of the field of AR including definitions, classifications, technical requirements, types of AR systems, available software libraries as well as potential limitations and open problems.

"*... (AR) aims to create the illusion that virtual images are seamlessly blended with the real world*" [BCL15].

The quote above indicates that AR is about registering real world objects and combining them with virtual objects to the user's view. This must be done in real-time as a user looks at the real-world. These characteristics were stated by Azuma [Azu97] and were revisited in 2001 [ABF+01]. In summary, the main properties which define AR as a system are:

1. AR combines real and virtual objects in a real environment
2. AR runs interactively, and in real-time; and
3. AR registers (aligns) real and virtual objects with each other.

This definition "does not place any limitations on the type of technology used, nor is it specific to visual experience" [BCL15]. Virtual objects can also be an audio or haptic experience [BCL15].

Over time, different approaches to define and classify AR in relation of Virtual Reality (VR) have been published. Azuma et al. [ABF+01] summarized the differences between VR and AR as such: with VR "the surrounding environment is virtual, while in AR the surrounding environment is real," and also described AR as a variation of Virtual Environment (VE). Other than in AR, VR completely fades out the real world and puts the user inside an entirely simulated or virtual environment. Azuma [Azu97] described this as to "completely immerse a user inside a synthetic environment" [Azu97]. In AR, the real world can be seen as the basic layer for any other virtual layer. Therefore, the real environment is constantly scanned, analyzed, and interpreted to superimpose upon or composite virtual objects within it. Ideally, this can be done in such a realistic way that a user thinks that the real objects coexist in the same space.

Looking at the different definitions and classifications, Rekimoto and Nagao [RN95] define AR in the context of making the computer interface invisible, seeing AR as a complement to VR. Milgram and Kishino [MK94] define AR "in the context of other technologies" [BCL15], establishing a concept of "Mixed Reality" (Figure 2.1). Mann [ABRK13, Man02] extends the Milgram MR continuum by establishing a concept of Mediated Reality. The metaverse roadmap from Smart et al. [SCP07], which is based on Neal Stephenson's concept of the Metaverse [Ste94], established another approach to classify AR experiences by putting AR into context with the Mediality Continuum and Virtuality Continuum. Other classifications that "provide an alternative perspective to characterize AR experience" [BCL15] are, for example, Hugues concept based on functional purpose [HFN11], as well as Braz and Pereria's TARCAST taxonomy [BP08]. When it comes to specifying technological requirements of AR systems, Billinghurst et al. [BCL15] summarized that Azuma [Azu97, ABF+01] provided a useful definition. This thesis follows this summary. Table 2.1 shows a mapping of Azuma's properties to technical requirements described by Billinghurst et al. [BCL15].

Figure 2.1: Milgram's Mixed Reality continuum [MK94]

Various types of display technologies are available, as well as applications, to combine and composite representations of virtual objects with the real-world scenes. Azuma

Properties of AR as System	Technical requirements
Combines real and virtual objects in a real environment	A Display is needed that combines real objects with virtual objects
Runs interactively, and in real-time	A computer system that can generate interactive graphics and is able to react to users input in real-time
Registers (aligns) real and virtual objects with each other	A tracking system that tracks the users' viewpoints, registers real objects, and combines them with virtual objects.

Table 2.1: Mapping properties of AR to technical requirements [BCL15]

characterized AR system displays based on optical and video-based, see-through Head Mounted Display (HMD) technologies. See-through HMDs are devices that "let the user see the real world, with virtual objects superimposed by optical or video technologies" [Azu97]. In contrast, closed-view HMDs "do not allow any direct view of the real world" [Azu97]. Video see-through systems capture the real world via a camera and present the combined output to the user via a monitor. An Optical see-through system places the combiner (i.e., a monitor) in front of the user's eye. Figure 2.2 illustrates the concept of an optical and video see-through system. Azuma also described a monitor-based configuration with (i.e. Head-Up Displays) and without optical see-through (i.e., user sits in front of a monitor). In 1997, Azuma did not categorize the displays based on the location of the monitor or combiner. This was added in the complimentary paper from Azuma et al. in 2001 [ABF+01], in which the authors classify displays into the categories "head-worn", "handheld", and "projective". Head-worn displays (HMD) are placed in front of the user's eyes and are differentiated into optical see-through and video see-through systems. Handheld displays are flat-panel, video see-through AR systems. Projection display systems use projectors to overlay virtual information directly onto the real/physical world.

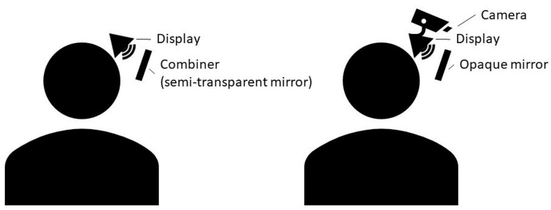

Figure 2.2: Concepts of optical see-through (left) and video see-through displays (right). Adapted from [ABF+01]

Billinghurst et al. [BCL15] took a detailed look into the approaches "Video-based AR Displays", "Optical See-through Displays," "Projection-based AR Displays," and "Eye Multiplexed AR Displays." AR displays are categorized based on where the display is placed between the user's eye and the real world to be consumed, including "Headattached Displays," "Handheld and Body-attached Displays," "Spatial Displays," and also "Other Sensory Displays." Discussing these approaches in detail would be beyond the scope of this thesis. The most important classification in the context of this thesis is the distinction between optical see-through and video see-through, as well as head-worn, handheld, and projective [BCL15].

Numerous libraries were developed in past that support the developer (or creator) with tools to design and develop AR applications. Billingshurst et al. [BCL15] discussed different development tools and arranged a couple of libraries and tools in "a hierarchy of decreasing programming skills required to use them." Table 2.2 illustrates the arranged hierarchy, including required skills and example tools or libraries.

Type of Tool	**Skill required**	**Example**
Low-level software library/framework	Strong programming/coding ability	ARToolkit, osgART, Studierstube, MXRToolKit
Rapid prototyping tools	Some programming ability, but design/prototyping skills	FLARManager, Processing, OpenFrameworks
Plug-in for existing developer tool	Skill with the developer tool that the plug-in works with	DART, AR-Media plug-ins, Vuforia and Metaio Unity plug-ins
Stand-alone AR authoring tools	No programming ability, but can learn stand-alone tool	BuildAR, Metaio Creator, Layar Creator, Wikitude Studio

Table 2.2: Hierarchy of AR development tools from most complex to least complex after Billinghurst et al. [BCL15]

A tracking system determines "the pose (position and orientation) of the viewer with respect to an 'anchor' in the real world" [BCL15]. This feature is crucial to registering real and virtual objects with each other. The most common real world "anchors" are paper image markers, a GPS position, or even automatically-created markers based on the registered environment. The term "tracking" follows the understanding of Billinghurst et al., that describes it as "the process of registering the system in 3D," [BCL15] which may include one or two phases, depending on the underlying technology.

1. Registration phase: Determining "the pose of the viewer with respect to the real world anchor" [BCL15]

2. Tracking phase: Updating "the pose of the viewer relative to a previously known pose" [BCL15]

Billingshurst et al. described some of the most common tracking techniques in their survey, like Visual Tracking, Inertial Tracking, GPS Tracking, Magnetic Tracking, and

Hybrid Tracking. The details of these tracking techniques can be found in the fourth chapter, “AR Tracking Technology,” of the Billingshurst et al. survey [BCL15].

All systems have strengths and weaknesses, which are often based on technological limitations. Besides technical limitations, other problem areas are user interface limitations and social acceptance [ABF+01]. Also, the lack of a standard language to describe AR content is a problem that limits the integration of AR content into existing tools. The Augmented Reality Markup Language (ARML) is still not widespread [MS16]. Comparing the problems noted in the papers from Azuma, from 1997 [Azu97] and 2001 [ABF+01], and Manuri et al. [MS16], from 2016, it is noticeable that the concern for privacy, misuse of data, and social acceptance increased over time. A detailed dive into current and future problems, as well as challenges, can be found in [Azu97, ABF+01, BCL15, MS16].

Some AR applications require high realism of virtual objects, which should look like the real objects themselves. The realism level of virtual objects greatly depends on rendering quality. Important settings to achieve high-quality renderings are discussed in the next sections.

2.2 Presence in Augmented Reality

Presence occurs when an individual overlooks or even forgets the use of technology during a mediated experience. In relation to the concept of presence, the terms experience and perception play an important role. This section explains the concept of presence as related to Augmented Reality (AR) and how the concept of presence is different in AR compared to Virtual Reality (VR).

The International Society for Presence Research provides an ”Explication Statement” [II00] of the concept of presence. In the statement, definitions of the term presence, as well as related terms, can be found. The following quote explains the term presence as a technologically-created experience in which an individual does not recognize technology to some degree; the term experience as an individual’s observation with objects; and the term perception as interpretations of experience.

”*Presence (a shortened version of the term ’telepresence’) is a psychological state or subjective perception in which even though part or all of an individual’s current experience is generated by and/or filtered through human-made technology, part or all of the individual’s perception fails to accurately acknowledge the role of the technology in the experience. Except in the most extreme cases, the individual can indicate correctly that s/he is using the technology, but at some level and to some degree, her/his perceptions overlook that knowledge and objects, events, entities, and environments are perceived as if the technology was not involved in the experience. Experience is defined as a person’s observation of and/or interaction with objects, entities, and/or events in her/his environment; perception, the result of perceiving, is defined as a meaningful interpretation of experience.*” [II00]

Lombard and Ditton, examine the key concept of presence in their research [LD97]. They argue that presence is a subjective property of a person, but also results from medium and user characteristics. The authors provide a unifying definition of presence, which can be applied to any medium and which also covers all six conceptualizations. The six conceptualizations of presence are "Presence as social richness," "Presence as realism," "Presence as transportation," "Presence as social actor within medium," and "Presence as medium as social actor." The full definition reads as follows:

"*A medium that becomes invisible and produces a perceptual illusion of nonmediation analogous to an open window can provide rich verbal and nonverbal information for social interaction (presence as social richness); objects and entities in such a medium should appear perceptually (if not socially) vivid and real (presence as realism); the illusion that there is no medium at work means there is no border between "this side" and "the other side" of the medium, so users can perceive that they have moved to the other side, that objects/entities from the other side have entered their immediate environment, or that they and other users are sharing a real or artificial environment (presence as transportation); the illusion of nonmediation will be more complete if the medium is perceptually and psychologically immersive (presence as immersion); and if we encounter people or entities within such a medium, even if there is no possibility of true social interaction with them, we are encouraged to respond to social cues they provide just as we would in nonmediated communication (presence as social actor within medium). Finally, when the medium itself presents us with social cues normally reserved for human-human interaction we are likely to perceive it not as a medium but as an independent social entity, a transformed medium (presence as medium as social actor).*" [LD97]

In conjunction with visual realism, it is important to look at the conceptualization of Presence as realism. It concerns the accurate representation of objects, events, and people that should sounds and/or feels like the real object or as it would be expected. It can be distinguished between social realism and perceptual realism. Perceptual realism is increasing if the representations look as expected. This is important to note because it gives a hint that visual realism is important for presence.

In conjunction with AR, it is important to look at the conceptualization of Presence as transportation, especially types such as "You are there" and "It is here." As Regenbrecht et al. [Reg02] argued, while in VR, presence is more about the type "You are there," in which the user is transported to another place; in AR, the type "It is here" is much more appropriate. The type "It is here" is about bringing a virtual object to the users' real environment.

Lombard et al. [LD97] also discuss cause and effect on presence. Therefore, they identified variables that influence presence within mediated systems or applications. Causes of presence are distinguished between "Causes of Presence as Invisible Medium" and "Causes of Presence as Transformed Medium." Each is divided into form variables, content variables, and media user variables. In conjunction with visual realism, the content variables of "Causes of Presence as Invisible Medium" are important. The content variables include the representation of "objects, human and nonhuman characters and personae, task and activities, messages, stories, etc." [LD97] that can influence presence positively or negatively.

However, the influence of visual realism on presence is still not clear as can be seen by different research results. This may be because of the different understanding of the term "presence" in VR and AR. Slater [Sla09] and Blascovich [Bla02] defined presence in the sense of 'being there.' As mentioned above, Regenbrecht et al. [Reg02] argued that presence in VR is about "You are there," while in AR, it is about "It is here." Sugano et al. [SKT03] also describe the contrast of Presence in AR and VR. Presence in AR "refers to how indistinguishable a virtual object seems from a similar real object played in the same environment," [SKT03] rather than in VR, where the term refers to "how immersed a user feels in a virtual space." They also point out presence as an important metric to evaluate AR systems. Therefore, previous findings regarding the influence of presence in VR should be reevaluated.

Vinayagamoorthy et al. [VB04] studied the consistency of visual realism between a virtual environment and characters by testing their hypothesis that less repetitive textures of the virtual environment and high fidelity of a virtual character lead to higher reported presence. However, the result showed a different behavior and only partly supported their hypothesis. The combination of the repetitive texture of the environment and high fidelity of the visual appearance of the character showed the lowest reported presence. One approach to explain that result was a discussion of possible occurrences of the Uncanny Valley. The Uncanny Valley effect is discussed in Section 2.6. Visual realism of characters is discussed in Section 2.5. Schuemie et al. [SvdSKvdM01] provide a useful overview of presence research in VR. Zimmons et al. [ZPP03] determined no significant influence of lighting and surface detail on presence in VR. Hendrix et al. [HB96], stated that research studying presence in VR found a positive influence of higher visual realism. Slater et al. "found greater behavioral and reported presence for static shadow compared to no shadows and for dynamic shadows compared to static shadows," [SUC95]. Mania et al. found "no difference in reported presence among the three conditions," [MR04]. In 2009, Slater et al. [SKMY09] concluded that there is "no clear message regarding the impact of the visual realism level on reported or behavioral presence" [SKMY09]. With the goal of clarification, Salter et al. [SKMY09] set up an experiment to determine the influence of recursive real-time ray tracing and ray casting and found presence to be significantly higher for ray tracing. However, because it was not clear if a higher illumination quality also influenced the reported presence, Slater et al. revisited this open question in 2012 [YMK+12] and found that illumination quality does not have an influence on presence, and so confirmed that only dynamic changes to shadows and reflections influence presence in VR.

In AR, the level of realism seems to have an important influence on presence. Sugano et al. [SKT03] found that shape and realistic shadow representations increase presence, even if the shadow is not photo-realistic. They also found that the position of the light source is not crucially important. Studying the effect of visual realism on search tasks in an MR simulation, Lee et al. [LRM+13] included a presence questionnaire within their experiment and could not find “any significant differences between the levels of realism” [LRM+13]. Kán et al. [KDB+14] studied the influence of illumination model on presence and found that presence is higher with global illumination than with direct illumination. They found “significant correlation between the perception of realism and presence” [KDB+14]. Kim and Welch [KW15] focused on finding characteristics of augmented reality humans (AH) to maintain, enhance, or even destroy (also known as “break in presence”) presence. In 2017, Kim et al. found that spatial and behavioral coherence with (real) physical objects is important for increasing presence [KMB+17]. A more detailed discussion about virtual humans in AR can be found in Section 2.3.

To study the effect of visual realism on presence, it is important to know the influencing factors on users’ perception of virtual object realism. Those factors are discussed in detail in Section 2.5. Effects of presence are distinguished between physiological and psychological effects [LD97].

To measure presence in AR, Regenbrecht et al. [Reg02] followed the psychological approach to developing a questionnaire. The goal of the questionnaire was to measure the impression of how well a virtual object is integrated into the real world, from a psychological point of view. The questionnaire, “Mixed Reality Experience Questionnaire,” from Regenbrecht et al. [Reg13, RBBS17], provides a list of items that can be used to measure Mixed Reality (MR) experiences. It provides a solid basis to measure presence in AR and can be adapted and extended. The questionnaire from Regenbrecht was used to measure presence in AR by Kán et al. [KDB+14], as well as Ling et al. [LNB+13].

Social presence and co-presence To measure the effectiveness of realistic virtual humans several measurements are available. The two most common are social presence and co-presence. Social presence describes the sense of being socially connected with other present humans (virtual or real persons). Copresence describes the sense of another person being present and being together [KW15, KMB+17, KBW17]. No universal agreement on definitions of term social presence and co-presence could be found. Harms and Biocca [HB04] categorized copresence as dimension of social presence.

“*Social presence is a mutual interaction with a perceived entity refers to the degree of initial awareness, allocated attention, the capacity for both content and affective comprehension, and the capacity for both affective and behavioral interdependence with said entity.*” [HB04]

“*Copresence is the degree to which the observer believes he/she is not alone and secluded, their level of peripheral of focal awareness of the other, and their sense of the degree to which the other, and their sense of the degree to which the other is peripherally or focally aware of them.*” [HB04]

Blascovich et al. [Bla02] highlighted the typology of presence dimensions (social presence, personal presence, environment presence) of Heeter [Hee92] and defined social presence as the “degree to which one believes that he or she is in the presence of, and interaction with, other veritable human beings.” [Hee92] Garau et al. [GSPR05] do not distinguish between copresence and social presence.

2.3 Virtual humans in Augmented Reality

"*Virtual humans are used as interfaces as well as real-time augmentations (three-dimensional computer-generated superimpositions) in real environments, as experienced by users through specialized equipment for enhanced mobility (e.g., ultra-mobile PCs and video see-through glasses).*" [MTPM08]

Virtual humans in AR have been used in different research fields. This section provides an overview of research which has been done with virtual humans.

Virtual humans can be distinguished between the virtual agent and the virtual avatar. A virtual agent is a computer controlled virtual human. A virtual avatar is a virtual human which is controlled by a real human [GSPR05].

Holz et al. [HDO09] surveyed different agent systems for social interaction along Milgram's Reality-Virtuality Continuum. In the survey, they discussed advantages and issues which came along with social interaction with virtual humans. Obaid et al. [ONP11] studied the perception of spatial relations and the perception of coexistence with virtual agents. They conducted an experiment in AR and VR that measured the participants voice compensation according to distances during interacting with a virtual agent. The authors compared measurements taken in AR and VR and found that the compensation effect was higher in AR. Kim et al. [KMB+17] combined these results with results from Loomis and Knapp [LK03] and assumed that this might be because participants perceive the distance between themselves and the AR agent with less perceptual errors. In another study, Obaid et al. [ODK+12] investigated physiological response of users from different cultural background during the interaction with a virtual agent. They found higher physiological arousal if the virtual agent has not the same cultural background. Specifically, they investigated interpersonal distance and eye-gaze and found that culturally appropriate eye gaze has a higher arousal impact than interpersonal distance.

Several applications which include virtual humans were developed. The survey of Magnenat-Thalmann et al. [MTPM08] summarized applications of interactive virtual humans in mobile AR. Moreover, they discussed how different fields could benefit from a virtual human interaction (i.e., in training scenarios). A check playing virtual human has been introduced by Torre et al. [TFB+00]. SpaceTime, an AR telepresence framework developed by Jo et al. [JKK15], significantly improved teleconference experience and communications performance by adapting the position and motion of a virtual human to the real environment in which it was placed. Room2Room, developed by Pejsa [PKB+16], is a life-size telepresence system using digital projectors. It projects the remote participants into the local participants' environment without the need of participant wearing special equipment.

2.4 Presence and virtual humans

The effect of virtual humans on real humans has been studied in VR and AR. Important issues in this research field are the influence on presence, copresence, social presence and how people react and respond to virtual humans. This section highlights important studies which have been made in this field.

Visual realism and interaction influence presence. Vinayagamoorthy et al. [VB04] studied presence responses across variations of visual realism in VR. They used virtual characters and measured the response of users within a VR application. Garau et al. [GSPR05] investigated the degree of virtual agents being treated as social entities rather than virtual objects within VR. They measured presence, copresence, heart rate and electrodermal activities (EDA) and found that users interact with virtual human more, even if only little interaction mechanisms were implemented. At no time users perceived the virtual human as real people. Yee et al. [YBR07] examined different studies to analyze if a virtual human improves users' performance. Despite the previous studies showing a positive effect of interface agents on task performance, they found that the actual effect is small. They stated that a visual representation of a virtual agent leads to more positive social interactions than no visual representation, but also that the realism of the virtual agent appears to matter very little.

Virtual humans socially influence the user in different ways. The degree of presence is different when the virtual human is perceived as agent or as an avatar. Guadagno et al. [GBBM07] studied social influence and persuasion in conjunction with virtual humans. Basically, they found that higher behavior realism of a virtual human leads to higher social presence. Also interesting is the finding that if participant believed that the virtual human is an avatar the behavioral realism and social presence were higher rated. Fox et al. [FAJ+15] examined the model of social influence in virtual environments of Blascovich [Bla02] and found that "avatars produced stronger responses than perceived agents." Kim and Welch [KW15] studied human-surrogate presence in AR and how perception of real human and associated social influence are connected. They understood the term human perception as how human users feel or interpret the human surrogate. Kim and Welch [KW15] also concluded that in the inability of augmented human to physically influence or control real objects in the real environment could be critical to establish or maintain the level of perceived realism and the sense of social presence. Therefore, they highlighted approaches to address this issue including a non-technical approach to the context dependent behavior of virtual humans [KW15].

Virtual humans should not conflict with the surrounding physical world. Kim et al. [KMB+17] used a virtual human to examine how the level of integration into the real-world impacts presence. They presented an experiment in which the virtual human did react to real physical objects. During the study the virtual human even asked the participant to move a chair to get around it, even if a virtual human could go through it. They concluded that "it is beneficial to have the virtual human's natural occlusion and proactive behavior (..) for higher social/copresence." [KMB+17] The findings show that to achieve a realistic virtual human in AR it is crucial to implement a virtual human such that it reacts to physical objects in the environment [KMB+17]. Also, Microsoft Developer guidelines for HoloLens Spatial Mapping [Mic17] highlights the need for conflict-free relationship and interactions between virtual objects and the real environment.

Studying the influence of visual realism on presence depends on technological possibilities. Guadagno et al. [GBBM07] pointed out that available technology is not capable of creating highly realistic virtual humans.

In conjunction with virtual realism of characters, visual realism and behavioral realism should be considered combined. Higher visual realism in character may lead to a higher expectation of behavioral realism [TBS+98], [VB04]. This is also how Nowak and Biocca [NB03] explained their VR experiment results that a higher anthropomorphism actually leads to a lower sense of presence, copresence and social presence.

2.5 Perception of visual realism in Augmented Reality

"*Perception, the recognition and interpretation of sensory stimuli, is a complex construct.*" [Cut03, KSF10].

AR mixes real-world objects with virtual objects. Therefore, it is often a goal to seamlessly integrate virtual objects into the real world. One approach to reach this goal is to achieve the highest possible visual realism of virtual objects. A virtual object's rating as realistic depends on the perception of the viewer. Which factors influence the perception of visual realism is an important research topic in the field of VR and AR. This section determines the influencing factors on users' perceptions of virtual objects' visual realism in AR.

2.5.1 Perception and perceptual Issues

"*Each sensory modality provides a different kind of information on which we base our interpretations and decisions.*" [KSF10]

Modalities interact with each other and strongly influence how humans perceive the world around them. Measuring these interactions is challenging. One approach is to match obtained environmental cues. Sometimes, cues override or conflict with each other. Conflicting cues often result in perceptually-incorrect augmentations [KSF10].

Perceptual issues are problems that arise while observing and interpreting information from virtual objects. These issues can arise from a combination of virtual and real object information, but also from the representations of real objects themselves. [KSF10]

Kruijff et al. [KSF10] classified perceptual issues in AR within the context of visual processing and interpretation pipeline (what they called perceptual pipeline). They organized issues into five classifications: environment, capturing, augmentation, display, and individual user differences. Moreover, they identified problems that affect perception of augmented content and stated that incorrect depth interpretation is the most common perceptual problem in AR applications. Kruijff et al. [KSF10] presented a variety of different approaches to address these issues. Among other things, they pointed out that it is not clear how much rendering quality or fidelity is needed to address perceptual issues.

This is based on a study of Thompson et al. [TWG+04], who found no direct relationship between the level of fidelity and the judgment of depth in digitally-reproduced graphics. Besides rendering quality, Kruijff et al. [KSF10] stated that illumination can affect fidelity of virtually augmented objects and their correct perception. Antialiasing can improve fidelity but may lead to perceptual distortions [KSF10]. Differences in rendering quality and antialiasing could lead to false stereoscopic disparity. Drascic and Milgram [DM96] also found this effect if differences between the resolutions of the captured video background and the rendered objects existed. Klein and Murray [KM08] found the influence of color schema on perception. Regarding illumination, Kruijff et al. [KSF10] pointed out that "correct illumination can also help to make the scenery more believable preventing augmented objects from looking like cardboard mock-ups."

2.5.2 Influencing factors

If a virtual object should look as realistic as possible (often referred to as photorealistic), usually the question arises what are the influencing factors. This section determines the influencing factors to create a realistic virtual object.

In computer graphics visual realism is defined as one of three levels of realism [Fer03]:

1. Physical realism: virtual objects provide the same visual simulation as the scene
2. Photo-realism: virtual objects provide the same visual response as the scene
3. Functional realism: virtual objects provide the same visual information as the scene

The questions of what does photo-realism mean in a perceptual context has not yet been fully answered [KDT+11]. An experiment of Hattenberg et al. [HFJS09] tried to find which algorithm creates the most realistic image. The results showed that indirect illumination and noisier images were rated as more realistic, but the authors also pointed out that these results cannot be generalized and there are other important influencing factors (on the perception of a scene). Elhelw et al. [ENC+08] tracked eye movement and found light reflections/specular highlights, 3D surface details, and depth visibilities to be important image features.

To achieve visual realism, various factors must be considered. In VE (Virtual Environment)-based application. Roussou et al. [DRÝ+03] found different factors to achieve an immersive impression:

- Consistent lighting
- Use of shadow
- The realness factor of the virtual experiences
- Virtual people

Haller [Hal04] stated that some other factors like shading, shadow integration and texture effects have to be considered in an AR based application. Moreover, following the three varieties of realism of Ferwerda [Fer03] we further focus on the visual perception. This does not mean that behavior realism is not important. Durand [Dur02] concluded that a virtual world should be more convincing and believable, rather than realistic.

Photogrammetric 3D reconstruction can be used to increase visual realism and with that human-likeliness. Latoschik et al. [LRG+17] studied the effect of avatar realism in VR on embodiment and social interactions and found that higher visual realism leads to higher human-like rating and a stronger feeling of body ownership. They created photogrammetry 3D scanned avatars and were able to show that "current 3D scan technology is capable of increasing the human-likeliness of avatars in immersive social Virtual Realities." [LRG+17]

Agusanto et al. [ALZN03] studied photorealistic rendering for AR using environment illumination, by using image-based lighting techniques and environment illumination maps. They were able to create a consistent and coherent virtual world reflecting the real world. To achieve a convincing AR application, Bimber et al. [BGWK03] created a consistent lighting situation between virtual and real objects. Key factors in their study were to illuminate captured reflection information of real objects under new lighting conditions and to approximately match direct and indirect lighting effects (such as shading, shadows, reflections, and color bleeding). Haller [Hal04] created an AR framework that uses photorealistic, as well as non-photorealistic, rendering techniques. Key factors of the framework were to consider shading, shadows, and bump mapping.

Shading is important if a realistic virtual representation is required. Flat shaded objects generally do not look realistic. Dynamic shading give a more realistic look than constant shading. Shades depend on the light source. The exactly correct placement of the light source does not have to be 100% accurate but it needs to approximately mimic the direction of the light in the real world. [Hal04, LRM+13]

"*Shadows are essential to improve the visual perception.*" [Hal04]

Shadows "can dramatically improve the realism" [Hal04], and are essential to create a 3D impression and make the 3D perception of virtual objects easier. [NNMH02] Sugano et al. [SKT03] highlighted the importance of shadows in an AR scenario. They studied the effect of a shadow representation of virtual objects in AR and focused on providing accurate shadows. They raised the question, "How different levels of optical consistency can affect a user's perception of virtual object realism?" [SKT03]. Regarding perception of visual realism, they found that shadows of virtual objects have a positive effect on spatial cues recognition, meaning that shadows are helpful "for recognizing position relationships in depth direction" [SKT03]. Haller [Hal04] also believes that shadows are equally important in a 3D stereo HMD (Head Mounted Display) because it helps to sense the distance between virtual objects more precisely. Shadows improve intractability of virtual objects [McC00]. Kruijff et al. [KSF10] also pointed out that "shadows can be helpful, providing an important depth cue." Similar to shading and shadowing geometry, time, and illumination should be consistent within AR applications [NNMH02]. Bump mapping simulates bumps or wrinkles on a surface and help to improve realism, without complex geometry [Hal04].

Knecht et al. [KDT+11] created "a framework for studying photorealistic rendering techniques in AR to investigate perceptual issues and visual cues." Their implementation included a rendering system in which different rendering modes and styles can be set up. They divided photorealistic image features into two main categories: Visual cues and augmentation style. Visual cues include inter-object spatial cues and depth cues. Augmentation style includes illumination, color and contrast, tone-mapping, and camera artifacts. They tested their framework by performing a user study testing three rendering conditions. The first one was without any cast shadow or indirect illumination. The second included shadows between real and virtual objects, but no indirect illumination. The third one had inter-object shadowing and indirect illumination. They found no significant effect from rendering conditions on task performance.

Lee et al. [LRM+13] studied the effects of visual realism on search tasks in a Mixed Reality (MR) simulation. In their experiment, they performed an AR search task experiment and repeated it within VR. For the VR application, the real-world location, where the AR experiment took place, was modeled three times. Each model had a different perceived level of visual realism. Regarding the goal of this section, it is interesting to look at their approach to varying visual realism. They used the same models and varied only a few factors of visual realism. They argued, "If we are careful not to inter-mix different data formats and rendering techniques or change their levels in opposite directions, there should be no interaction that could cause unanticipated responses in visual realism. If we only increase the factors, we argue that this produces progressively and objectively higher levels of visual realism." The chosen data format was a polygon-based model, and three factors of visual realism were varied: geometry, texture, and lighting. They increased geometry realism by increasing polygon counts. Texture realism was increased from no texture to simple textures, and up to high-resolution textures. Lighting realism was increased from simple flat shading to baked-in realistic lighting.

2.6 Uncanny Valley

To the best of our our knowledge, there has been no study that studied the Uncanny Valley effect specifically in AR. This is most likely due to technological boundaries and the still ongoing research about visual realism, perception, and presence in AR. This section explains the Uncanny Valley and presents related studies that mention the possible appearance or influence of the Uncanny Valley.

The theory of the Uncanny Valley was proposed in 1970 by Mori [MMK12], who studied the effect of human-like robot artifacts on humans. Ho et al. [HM10] describe the Uncanny Valley as "a hypothetical graph describing a nonlinear relation between a character's degree of human likeness and the emotional response of the human perceiver" [HM10]. Meaning that the sense of affinity increases with the human likeness of a non-human representation (i.e., an artificial hand), but falls rapidly into a valley if the representation hits around 80-100% of human likeness [MMK12]. In other words, if a human cannot be sure if it is real or not, the human can suddenly feel a strong refusal or even disgust. Figure 2.3 shows a graph which depicts the Uncanny Valley.

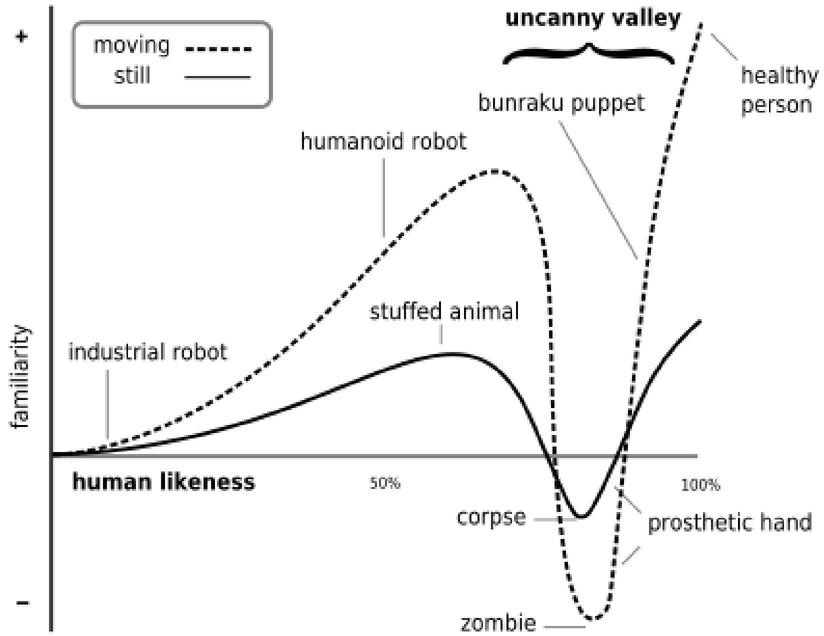

Figure 2.3: Uncanny Valley graph [MMK12]

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The Uncanny Valley effect could also occur in virtual environments and with virtual humans. Yee et al. [YBR07] raise the question of whether virtual agents are actually useful in improving user performance. The study confirmed this hypothesis but also pointed out that a realistic representation of a virtual agent has little influence on the performance. Nevertheless, the study also pointed out that the Uncanny Valley may have influenced these findings. The influence could not be proven and should be considered in future studies [YBR07]. Although Guadagno et al. [GBBM07] did not study the Uncanny Valley and could not investigate it empirically, they also pointed out that it may occur if a mismatch between the appearance and behavior of a virtual human appears. To measure the Uncanny Valley some studies used the Godspeed questionnaire. The Godspeed questionnaire originally describes a series of questions to measure the humans' perception of robots [BKCZ09]. The included concepts, anthropomorphism and likability, can serve as the x- and y-axes of Moris's graph (Figure 2.3) [BKIH09]. After empirical testing Ho et al. [HM10] rejected the Godspeed questionnaire as unsuitable to measure the Uncanny Valley effect and developed a new set of Uncanny Valley indices. The Uncanny Valley might affect presence. Vinayagamoorthy et al. [VB04] speculated while discussing results of their VR user study that ”characters being notably different in representation than the environment they inhabit, might lead the participant to think the world ”inconsistent and thus might lead the participant to feel less present” [VB04], and describes this speculation as an extension of the Uncanny Valley hypothesis. Kim and Welch [KW15] mentioned that it could be argued that the Uncanny Valley ”could be related to the failure of the sense of non-mediation or contextual inconsistencies” [KW15]. Lugrin et al. [LLL15] studied the impact of virtual realism on the illusion of body ownership (IVBO) in VR. The authors suspected the Uncanny Valley effect which could cause that the machine-like avatars generated lower IVBO than human-like avatars.

CHAPTER 3

Methodology

To study the effect of increasing realism on the perception of presence and the convenience of users in an AR application an experiment was conducted. The following chapter describes the experiment and the AR application which was implemented for this purpose in Subsection 3.3. Hypotheses (also see Subsection 3.1) were tested during the experiment. The discussion about the results and the comparison to the expected results (Subsection 3.2) can be found in Section 3.7.

3.1 Hypotheses

Two hypotheses are posed to examine the effect of realism on the perception of presence and the convenience of users within AR applications.

H1: Increasing the level of realism increases the sense of presence and convenience of users.

H2: The Uncanny Valley effect can be observed within the experiment.

3.2 Expected Results

Related work to the field of presence and AR lead to the expectation that the results will support the hypotheses (Subsection 3.1). Also, the Uncanny Valley, which was not measured in a targeted manner in the past, is expected to be observed. Studies in the field of AR often faced limitations due to technical possibilities of the used AR system. Especially the HoloLens, which is the AR system to be used in this study, often shows technical limitations. The limited field of view is expected to be the hardest challenge for presence study.

3.3 Experimental Design

The conducted experiment followed a within-group design. A within-group design was chosen because interpersonal differences can affect results in social presence studies as Kim et al. [KMB+17] argued. The virtual human was placed at a specific place in a room. An idle animation was used to give the virtual human a more human-like behaviour while standing. Additionally, the virtual human would also use a turn animation to align its body in the direction of the participant. The AR application included a rendering system which allows the levels of realism of the virtual human to be set. Each participant experienced a virtual human with all different levels of realism in a random order.

After each observation the participant filled in a questionnaire. The goal was to measure the perception of realism, presence, co-presence, social presence and the occurrence of the Uncanny Valley effect. Therefore, a questionnaire was constructed using specific questions designed for the particular purpose. Additionally, an open question was added which can be answered with own words. The rest of the questions were ordinal questions answered on 7-point Likert type items ranging from 1 (strongly disagree) to 7 (strongly agree). Besides these questions, the participants were asked about their gender and age.

3.3.1 Perception of realism

To measure the level of perceived realism one question, used in the presence study of Kán et al. [KDB+14] (based on [Reg02, Reg13, RBBS17]), was adapted. The question used to measure perception of realism can be found in Table 3.1

PR-1	Overall, how would you rate the degree of realness achieved by the virtual human; to what extent ”they seemed real to you.”

Table 3.1: Perception of realism questionnaire

3.3.2 Presence

To measure the overall sense of presence, the questionnaire followed the approach of a mixed reality (MR) presence questionnaire designed by Regenbrecht et al. [Reg02, Reg13, RBBS17]. To compare the virtual human with a real human, a question from [KDB+14] was adapted. The presence questions can be found in Table 3.2

P-1	Watching the virtual human (further ”guide”) was just as natural as watching the real world.
P-2	I felt I could have touched the guide.
P-3	The guide was part of the same space.
P-4	The guide and surrounding walls, furniture, doors, etc. were in the same environment.
P-5	Overall, how would you rate the sense of presence generated by the guide; to what extent “she/he was here”?

Table 3.2: Presence questionnaire

3.3.3 Co-presence

To measure co-presence, the questionnaire followed the approach of Kim et al. [KMB+17]. Their questions were based on questions used by Bailenson et al. [BBBL03, BHSS00]. They also added two own of their questions. The question used to measure co-presence can be found in Table 3.3.

CP-1	I perceived that I was in the presence of the guide in the room with me.

Table 3.3: Co-presence questionnaire

3.3.4 Social presence

To measure social presence, the questionnaire followed the approach of Kim et al. [KMB+17]. Their questions are based on the social presence questionnaire from Bailenson et al. [BBBL03]. The questions used to measure social presence can be found in Table 3.4. For the question number 3 "The thought that the guide is not a real person crosses my mind often." is a negative question. This question has to be inverted during result analysis.

SP-1	I felt the guide was watching me and was aware of my presence.
SP-2	The thought that the guide is not a real person crosses my mind often.
SP-3	I felt like I want to talk to the guide or asked him something

Table 3.4: Social presence questionnaire

3.3.5 Uncanny Valley

To identify the occurrence of the Uncanny Valley effect, scales, designed by Ho and MacDorman [HM10, HM17], were used. They created indices (further dimensions) to measure the appearance of the Uncanny Valley. These dimensions are *Humanness*, *Eeriness*, and *Attractiveness*. Each of these dimensions originally included multiple scales. The originally created scales can be found in Table 3.5. To prevent biased answers based on possible tiredness of the participant (after answering several questions before) we decided to limit the possible scales. Therefore, each participant was only asked about three dimensions. For each dimension a question about the dimension itself was created. Further, the participants were able to answer the question using the already used scale 1 (strongly disagree) and 7 (strongly agree). The questions used to measure Uncanny Valley can be found in Table 3.6. The questions number 2 "The guide seems eerie/creepy to me." and 3 "The guide created spine-tingling moments." are negative questions. These questions have to be inverted during result analysis.

#	**Dimension**	**Scale (-3 - +3)**
1	Humanness	Inanimate/Lifeless – Living/Alive
2	Humanness	Synthetic/Simulated – Real
3	Humanness	Mechanical movement – Biological movement
4	Humanness	Human-made – Humanlike
5	Humanness	Without definite lifespan/Immortal – Mortal
6	Eeriness(Eerie)	Dull/Boring – Freaky/Cool
7	Eeriness(Eerie)	Predictable – Eerie/Unpredictable
8	Eeriness(Eerie)	Plain/Simple – Weird
9	Eeriness(Eerie)	Ordinary – Supernatural
10	Eeriness(Spine-tingling)	Boring – Shocking
11	Eeriness(Spine-tingling)	Uninspiring – Spine-tingling/Fascinating
12	Eeriness(Spine-tingling)	Predictable – Thrilling
13	Eeriness(Spine-tingling)	Bland/Boring – Uncanny
14	Eeriness(Spine-tingling)	Unemotional – Hair-raising
15	Attractiveness	Ugly – Beautiful
16	Attractiveness	Repulsive/Disgusting – Agreeable/Enjoyable
17	Attractiveness	Crude/Raw/Uncut – Stylish
18	Attractiveness	Messy – Sleek/Decent

Table 3.5: Original Uncanny Valley scales adapted from Ho and MacDorman [HM10, HM17]

#	**Dimension**	**Question**
UV-1	Humanness	The guide seems to be human/alive/living.
UV-2	Eeriness(Eerie)	The guide seems eerie/creepy to me.
UV-3	Eeriness(Spine-tingling)	The guide created spine-tingling moments.
UV-4	Attractiveness	The guide was attractive/good looking/handsome.

Table 3.6: Uncanny Valley questions used in the experiment

3.3.6 Open Question

To collect possible other influencing factors of participants' perception of the experiment an optional open question was added. If preferred, the participants were allowed to answer in keywords. The used open question can be found in Table 3.7.

OQ-1	How would you describe the overall perception of the experiment? You can answer in keywords (of preferred).

Table 3.7: Open question of participants' perception

3.3.7 Questionnaire

All questions were put together and participants were asked to answer one questionnaire for each realism level. The complete questionnaire can be found in the Table 3.8. The questionnaire was put into an online form and the participants were asked to answer the questions electronically using a laptop.

	Perception of realism
PR-1	Overall, how would you rate the degree of realness achieved by the virtual human; to what extent ”they seemed real to you.”
	Presence
P-1	Watching the virtual human (further ”guide”) was just as natural as watching the real world.
P-2	I felt I could have touched the guide.
P-3	The guide was part of the same space.
P-4	The guide and surrounding walls, furniture, doors, etc. were in the same environment.
P-5	Overall, how would you rate the sense of presence generated by the guide; to what extent “she/he was here”?
	Co-Presence
CP-1	I perceived that I was in the presence of the guide in the room with me.
	Social Presence
SP-1	I felt the guide was watching me and was aware of my presence.
SP-2	The thought that the guide is not a real person crosses my mind often.
SP-3	I felt like I want to talk to the guide or asked him something
	Uncanny Valley
UV-1	The guide seems to be human/alive/living.
UV-2	The guide seems eerie/creepy to me.
UV-3	The guide created spine-tingling moments.
UV-4	The guide was attractive/good looking/handsome.
	Open question
OQ-1	How would you describe the overall perception of the experiment? You can answer in keywords (of preferred).

Table 3.8: Questionnaire used in the user study

3.3.8 Experimental Setup

The experiment was conducted in a room with about 6-meter width and 6-meter depth. The setup consists of a Microsoft HoloLens which is an optical see-through Head Mounted Display (HMD) system (also see Section 2.1) with a field of view of 30°x17.5°. The HoloLens is a fully closed-loop system which does not need external tracking systems. The HoloLens contains an inertial measurement unit (IMU) including an accelerometer, gyroscope, and a magnetometer, four sensors for environmental scanning, a depth camera with a 120°x120° angle of view, a 2.4-megapixel photographic video camera, four microphones, and a light sensor. Besides the Intel Cherry Trail SoC which contains the CPU and GPU the HoloLens also includes a custom Microsoft Holographic Processing Unit (HPU) which is a coprocessor. The Windows 10 operating system runs on the 64GB eMMC controlled by the SoC. SoC (1GB LPDDR3) and HPU (1GB LPDDR3) sahre a 8MB SRAM. The internal battery lasts about 2-3 hours (active using). Although the hardware is very potent for an HMD of its size, it is still a mobile device which suffers from potential technical limitations. These have to be kept in mind if an AR application is developed for the HoloLens. Unity[1] was used to develop the AR application for the experiment.

3.4 Virtual humans

3.4.1 Model

The goal was to provide a virtual human with different levels of realism. The sense of presence should be as high as possible by design. Therefore, the implementation followed several findings from previous studies. Sadly, due to the technical limitations (also see Subsection 6.1.1) of the used AR system HoloLens global illumination or shadows could not be used. To reduce the risk that different models could influence the results, the main structure of the particular virtual humans stayed the same for each virtual realism level except for the lowest realism level. Only a few factors were chosen (see Table 3.9) to be changed for each realism level. Changes of these factors were only made in one direction. In other words, increasing the level of visual realism would increase all factors. The geometries varied in different fidelity settings. The goal was to increase the visual realism only by increasing the chosen factors. This should minimize the risk of unanticipated responses in visual realism. This approach followed the approach of varying the level of realism of Lee et al. [LRM$^+$13]. Table 3.10 shows the different visual realism levels and the factor settings. Figure 3.1 shows examples of the virtual avatar for each realism level.

To create the virtual humans, the software Fuse from Adobe [2] was used. The Adobe general terms of use [3] allow the free use of every created character and animation in every embedded media. The generated character and animation were imported into Unity.

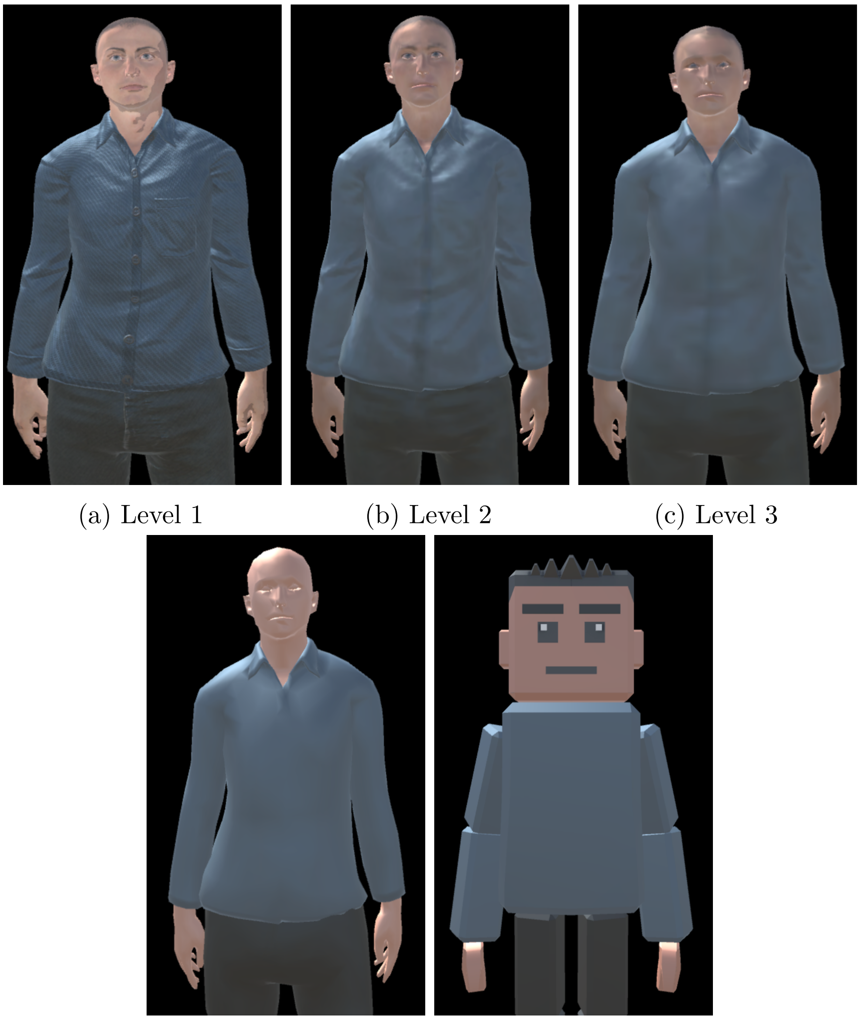
Geometry
Texture
Lighting
Shade and Shadow
Illumination

Table 3.9: Visual realism factors

[1] https://unity3d.com
[2] https://www.adobe.com/products/fuse.html
[3] https://www.adobe.com/legal/terms.html

	Geometry	**Texture**	**Lights, Illumination and Shadows**
Level 1	100%	1024x1024	5 light sources; direct illumination; no shadows due to technical limitations
Level 2	60%	128x128	4 light sources; direct illumination; no shadows due to technical limitations
Level 3	40%	64x64	3 light sources; direct illumination; no shadows due to technical limitations
Level 4	20%	To texture; only plain color	2 light sources; direct illumination; no shadows due to technical limitations
Level 5	Block avatar	To texture; only plain color	1 light sources; direct illumination; no shadows due to technical limitations

Table 3.10: Visual realism levels and factors



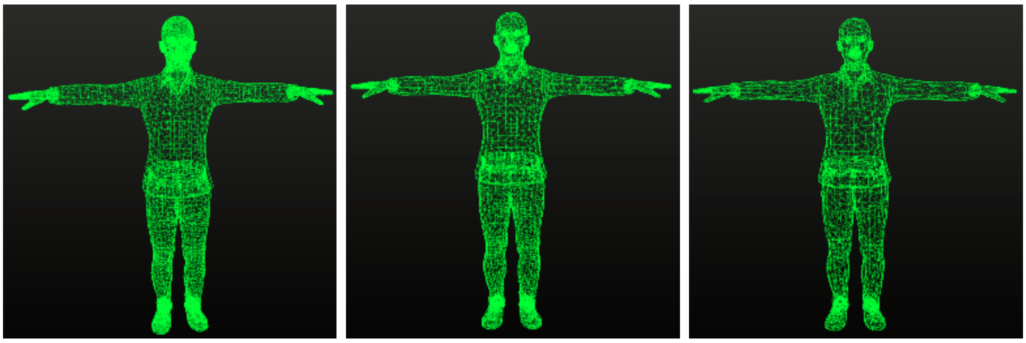
(a) Level 1 (b) Level 2 (c) Level 3

(d) Level 4 (e) Level 5

Figure 3.1: Used virtual human at different visual realism levels

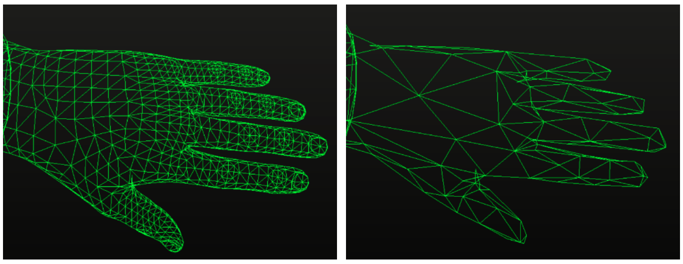
3.4.2 Geometry

Geometry was varied by polygon counts. Starting with the highest possible polygon settings, they were reduced accordingly. Figure 3.2 and Figure 3.3 shows examples of a virtual human with different counts of polygons at the different levels.



(a) 32323 Polygons (b) 12928 Polygons (c) 6464 Polygons

Figure 3.2: Examples of polygons of a virtual human at different levels



(a) Polygons of a virtual humans hand (b) Polygons of a virtual humans hand after 80% polygon reduction

Figure 3.3: Example of polygons of a virtual humans hand

3.4.3 Texture

The texture was varied by resolution. We started with the highest possible resolution setting and reduced it accordingly. Figure 3.4 shows examples of a virtual human with varying resolutions of texture at the different realism levels.

(a) Texture resolution 1024x1024 (b) Texture resolution 128x128 (c) Texture resolution 64x64 (d) No texture

Figure 3.4: Examples of a virtual humans with different texture resolutions

3.4.4 Lights

Light sources are necessary to make the virtual humans visible. Light sources at the highest realism level were placed based on real light conditions in the actual room where the experiment took place. Therefore, five light sources were placed with different colors and angles. Table 3.11 shows the different lights with their color, angle setting as well as in which level they were visible. Light number 3,4 and 5 were light spots in the area of the virtual human, which is why the all have the same color and angle settings. Figure 3.5 shows an example view of the light sources color and angle.

Light number	Light color [HEX]	Light angle (Euler rotation)	Level visibility
1	DDCACAFF	(100,-125,0)	Level 1
2	C7C179FF	(30,-80,0)	Level 1-2
3	FFFFFFFF	(25,-160,0)	Level 1-3
4	FFFFFFFF	(25,-160,0)	Level 1-4
5	FFFFFFFF	(25,-160,0)	Level 1-5

Table 3.11: Light sources

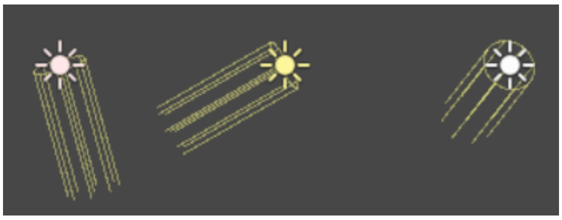


Figure 3.5: Light sources

.

3.4.5 Illumination

Only direct illumination was taken into account. While Kán et al. [KDB+14] found a significant positive impact of global illumination on the sense of presence in AR environments, unfortunately, due to the limited technical capabilities (also see Subsection 6.1.1) of the used AR system global illumination could not be used.

3.4.6 Shadow

Due to technical limitations (also see Subsection 6.1.1) and the resulting risk to negatively influence the perception of the participant it was decided not to use shadows. Nevertheless, it should be mentioned here that the occurrence of shadows significantly influence the realistic appearance of a visual object and it is important for the perception of AR scenes. [KDB+14] It helps users to better understand the placement of a virtual object in the real world. The visual realism of the shadows depends strongly on its resolution.

Unfortunately, the HoloLens uses light-based displays. These displays add virtual objects into the field of view of the user by adding light to the real-world, but it cannot reduce light. This means that a traditional dark shadow would be transparent to the user's eye. If the virtual object would be a static object, there are some workarounds which can be used. The first possibility is to place a plane right under the virtual object and the shadows would be shown on the plane. The second possibility is to implement a so-called 'negative shadow'. The goal of a negative shadow is to add a glow to the floor around the virtual object. The negative shadow would appear darker than its surrounding. Microsoft describes the possibility of using a negative shadow in their documentation as well:

"Many designers have found that they can even more believably integrate holograms by creating a "negative shadow" on the surface that the hologram is sitting on. They do this by creating a soft glow on the ground around the hologram and then subtracting the "shadow" from the glow. The soft glow integrates with the light from the real world and the shadow grounds the hologram in the environment." [4].

Another problem which occurs if using shadows with the HoloLens is the limited performance which results in a bad resolution of the shadow. The virtual human uses idle animation and also turns to the user's direction. In the context of shadows, this would mean that a shadow should dynamically change accordantly to the idle animations and further has to be calculated in real-time. These real-time calculations are performance expensive. This results in a limited resolution of the shadows. It was decided not to use shadow since it appeared that the resolutions of dynamic shadows was to low and would most likely influence the perception of the user.

3.4.7 Animations

Since users expect a realistic behavior of photorealistic rendered virtual objects [Hal04], all used animations are animations which have been recorded with a real human using motion capture systems. Table 3.12 shows the used animations during the user study. The animations were obtained from the online service Mixamo Adobe[5]. The Adobe general terms of use [6] allow the free use of every created character and animation in every embedded media. The generated character and animation were imported into Unity.

[4]https://docs.microsoft.com/en-us/windows/mixed-reality/hologram
[5]https://www.mixamo.com/
[6]https://www.adobe.com/legal/terms.html

Name	Description
Idle	Used while virtual human does not do any action.
Turn right 1	Character turns 45° towards user
Turn right 2	Character turns 90° towards user
Turn right 3	Character turns 135° towards user
Turn right 4	Character turns 180° towards user
Turn left 1	Character turns -135° towards user
Turn left 2	Character turns -90° towards user
Turn left 3	Character turns -45° towards user

Table 3.12: Animations used in user study

3.4.8 Occlusion

Due to the experimental design, it was decided that it is not necessary to implement occlusion features. Nevertheless, it is important to know that Kim et al. [KMB+17] showed that virtual humans should be implemented concerning the physical objects in the environment to achieve a higher sense of presence.

3.5 Prestudy of virtual humans

The approach to create different realism levels of a virtual human and order was desinged by author of this thesis. To avoid a possible biased view on the realism level a prestudy was conducted. To goal of the prestudy was to confirm the designed order.

3.5.1 Method

The main aim of the prestudy was to confirm the used approach to create different realistic levels of a virtual human. A web application was implemented in which the user initially see pictures of the different avatars in random order. The task was to order the avatars according to the users' perception of realism from the most realistic to the least realistic one.

3.5.2 Hypothesis

The prestudy hypothesized that the different visual realism levels created in Subsection 3.4 and further the desinged order (from lowest to highest realism level) listed in Table 3.10 agrees with the perception of real persons (i.e. participants perceive the realism levels increasing in the same order as designed by the author).

3.5.3 Expected result

It was expected that the submitted order of realism levels indicated by the participants matches with the visual realism levels created in Subsection 3.4 and further listed in

Table 3.10. Figure 3.6 shows the expected order.

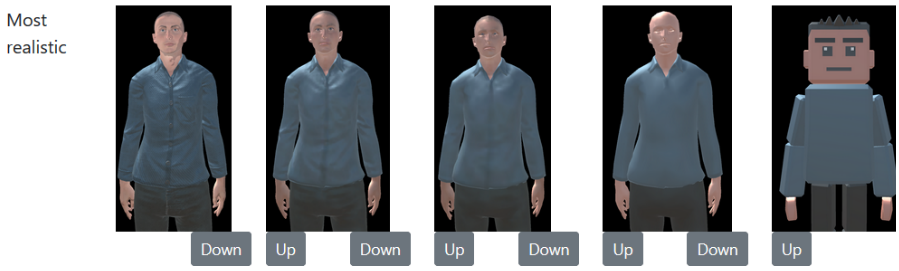


Figure 3.6: Expected order of visual realism levels

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3.5.4 Experimental Design

Participants were asked to order the pictures of the virtual humans according to the realistic levels from the most realistic to the least realistic. Using buttons the user was asked to move the pictures up or down / left to right (depending on the layout). Finally, the user could submit his answers. The design of the web application can be seen on Figure 3.7.

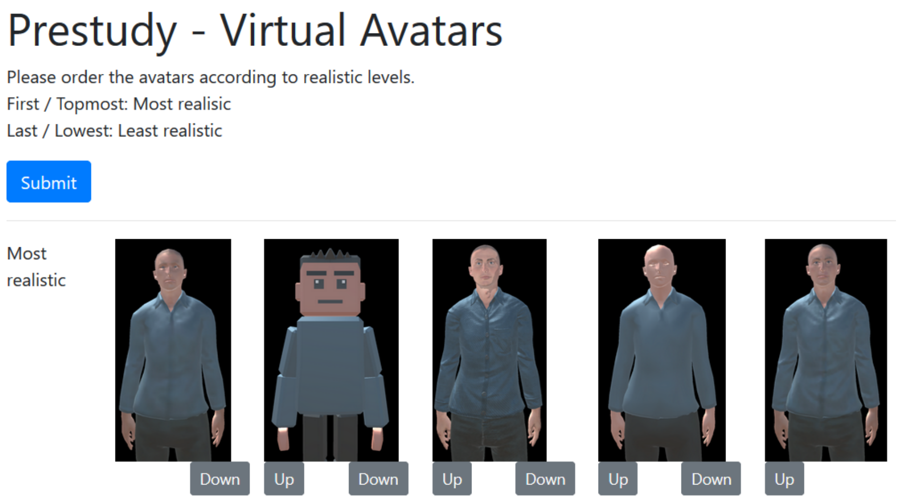

Figure 3.7: Prestudy web application

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3.5.5 Results

20 individual persons participated in our prestudy. 19 ordered the pictures in the expected order. One person submitted precisely the other way round as expected. We assumed that the person misunderstood the task.

3.5.6 Conclusion

The result confirmed the expected order and so the different realism levels of virtual humans created by us. The expected order of realism can further be used during the experiment.

3.6 Participants and Procedure

Thirty-one people aged between 19 to 71 participated in our main presence study, with an average mean of M = 33.29, SD = 11.61. The group of participants consisted out of 12 women and 19 men. All participants were informed about the study and signed a consent to participate in the research study. After fitting the HMD on the head of the participant, she was asked to stand at an initial position in the room. Right next to the starting point virtual button could be found. The participants could start the experiment by interacting with the button. The virtual human was placed at a certain place in the room. The participant could walk around to observe the avatar from different distances and angles. She was asked to observe the virtual human for at least two minutes. After the participant felt ready, she could walk to a table to fill out the questionnaire. After filling out the questionnaire, the was asked to go back to the initial starting point and push/click the virtual button. These steps were repeated five times (once for each realism level). Each participant experienced all five different realism levels in a random order (within-group design).

3.7 Data Analysis

All in all 15 questions were recorded. These can be broken down into four categories: Collision, Perception of realism, Presence and Uncanny Valley. Each category is statistically analyzed depending on the underlying data. In each category, the realism levels (1-5) can be understood as sample groups or conditions. The within-group design of the experiment, in which participants are the same in each sample group, is decisive to choose the correct statistical test. [Fie17]

3.7.1 Collision

The first question the participants could answer by a single choice. They could choose one of three options. These options are further transformed into nominal data 1, 2 and 3. Table 3.13 shows the mapping of the single choice answer and the transformed number.

On the way to the table...	**Transformed number**
... you crossed/went through the virtual human	1
... you went around the avatar to avoid a collision	2
... you did not use the direct path and went around the corner to avoid a collision	3

Table 3.13: Collision answer mapping into nominal data

To analyze the behavior of the participants the frequencies of the answers for each realism level were calculated. The mode was used to calculate the central tendency. Due to the within-group design of the experiment, it can be assumed that the answers may be biased after a participant answered the question about the collision in the first condition. To analyze this circumstance the first conditions where evaluated separately by analyzing the answers after the first observation of each participant.

3.7.2 Perception of realism

One question measured the level of perceived realism. It was a question answered on a 7-point Liker type item ranging from 1 (strongly disagree) to 7 (strongly agree). Ordinal data limits the possibilities of statistical tests. To analyze this question the frequency of answers were investigated. To analyze if differences across the realism levels are significantly different the Friedman test was used. The ANOVA tests only provide information about the differences between the different conditions but does not provide any information which specific differences are in fact significant. [Fie17] Wilcoxon signed-rank tests were used to examine the specific differences between the conditions. [Fie17] The decision of using non-parametric tests was made because the data violated the assumption of normal distribution.

3.7.3 Presence

The presence questionnaire consists out of nine questions to measure presence. Cronbach's alpha was utilized to analyze the internal consistency of the questions. All questions were answered on a 7-point Liker scale ranging from 1 (strongly disagree) to 7 (strongly agree). The presence questionnaire can be broken down into three categories: General presence, Co-Presence and Social-Presence. Each category consits out of one or more questions. Five questions about general presence, one about co-presence and three about social presence. Question number two of the category Social presence "The thought that the guide is not a real person crosses my mind often." was inverted from 1-7 to 7-1 because of the negative nature of this question (also see Subsection 3.3)

The questions were merged using the mean for analyzing the overall representation of presence. The repeated-measures ANOVA test was used to analyze if the means are significantly different across the realism levels. In case a repeated-measures ANOVA showed significant differences the parametric paired-sample t-test was used to verify this trend. The parametric tests could be used because the means between the conditions were normally distributed.

3.7.4 Uncanny Valley

Four questions measured the effect of the Uncanny Valley. Cronbach's alpha was used to analyze internal consistency of the questions for each realism level. These were ordinal questions answered on a 7-point Liker type item ranging from 1 (strongly disagree) to 7 (strongly agree). The questions used to measure Uncanny Valley can be found in Table 3.6. The questions number 2 "The guide seems eerie / creepy to me." and 3 "The guide created spine-tingling moments." were inverted by recoding from 1-7 it to 7-1 because of the negative nature of this question. Further the median of these question were calculated, because it is a subgroup one group Eerieness (also see Section 3.3).

The questions were merged using the mean for analyzing the overall representation of presence. The repeated-measures ANOVA test was used to analyze if the means are significantly different across the realism levels. In case a repeated-measures ANOVA showed significant differences the parametric paired-sample t-test was used to verify this trend. The parametric tests could be used because the means between the conditions were normally distributed.

3.7.5 Open question

The last question was an open question. The participants were allowed to answer in keywords or not at all (optional). To analyze the answers the quantity how many actually answered were measured. Further, for each level the keywords were analyzed and categorized based on the notion.

CHAPTER 4

Results

The following chapter shows the specific results of the statistical examination of the experiment.

4.1 Collision

For each realism condition participants were asked if they avoided a collision with the avatar. This section evaluates this collision question and shows the results for each realism level from 1 (highest realism) to 5 (lowest realism). The results of a frequency analysis can be found in Table 4.1. Additionally, Figure 4.1 shows the histograms for each realism levels.
Level 1
15 participants out of 31 went through the virtual human. 14 participants went straight to the table but tried to avoid a collision. 2 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 1 (collision).
Level 2
11 participants out of 31 went through the virtual human. 15 participants went straight to the table but tried to avoid a collision. 5 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 2 (no collision).
Level 3
17 participants out of 31 went through the virtual human. 11 participants went straight to the table but tried to avoid a collision. 3 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 1 (collision).
Level 4
15 participants out of 31 went through the virtual human. 10 participants went straight

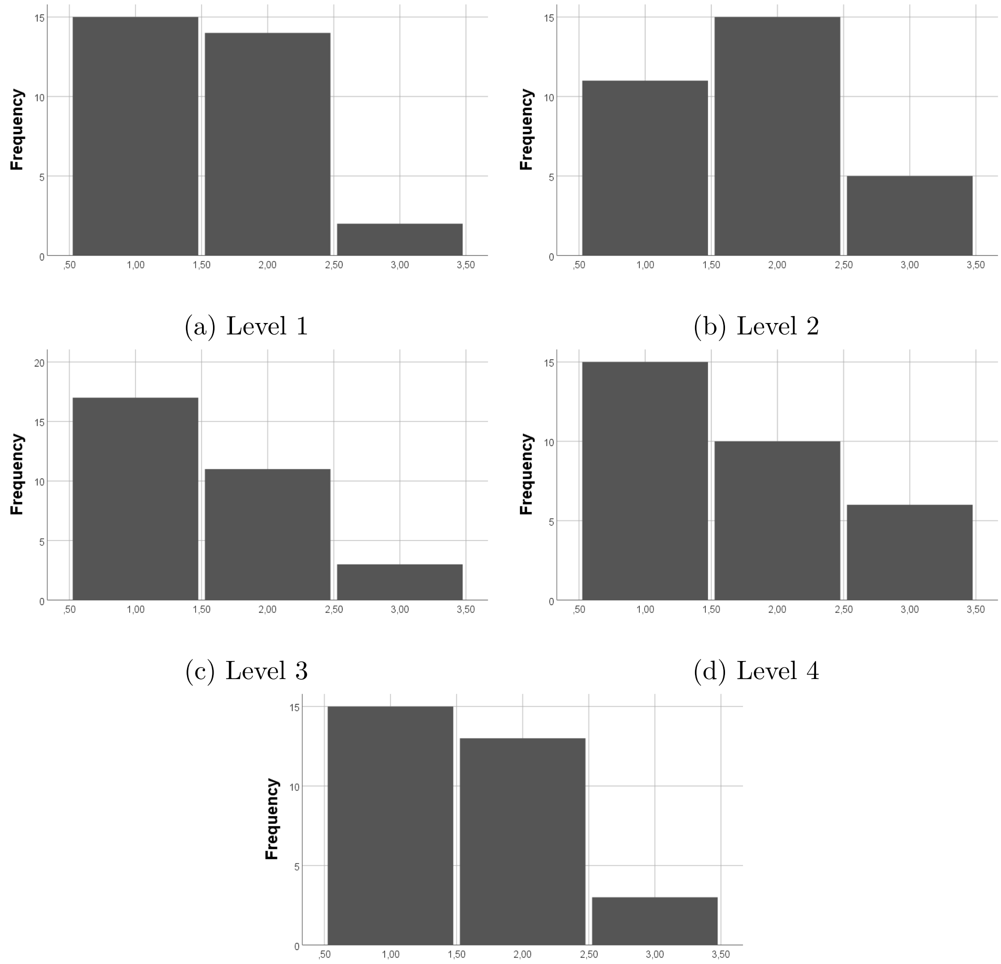
to the table but tried to avoid a collision. 6 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 1 (collision).

Level 5

15 participants out of 31 went through the virtual human. 13 participants went straight to the table but tried to avoid a collision. 3 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 1 (collision).

	1 (Collision)	**2 (No collision)**	**3 (Detour)**	**Mode**
Level 1	15	14	2	1
Level 2	11	15	5	2
Level 3	17	11	3	1
Level 4	15	10	6	1
Level 5	15	13	3	1

Table 4.1: Collision - Contingency table



(a) Level 1 (b) Level 2

(c) Level 3 (d) Level 4

(e) Level 5

Figure 4.1: Collision histograms

The answers of the first rounds condition can be found in the Table 4.2. Additionally, Figure 4.2 shows the histograms for each realism levels.

Level 1
6 persons experienced level 1 during the first condition. 4 participants went through the avatar. 2 participants went straight to the table but tried to avoid a collision. 0 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 1 (collision).

Level 2
8 persons experienced level 2 during the first condition. 4 participants went through the avatar. 2 participants went straight to the table but tried to avoid a collision. 2 participants did not go the shortest way to the questionnaire and went around a corner

to avoid a collision. The calculated mode value was 1 (collision).

Level 3

5 persons experienced level 3 during the first condition. 4 participants went through the avatar. 1 participants went straight to the table but tried to avoid a collision. 0 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 1 (collision).

Level 4

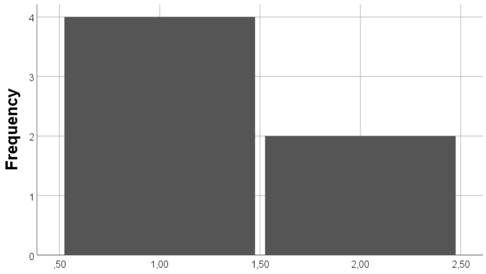
2 persons experienced level 4 during the first condition. 0 participants went through the avatar. 1 participants went straight to the table but tried to avoid a collision. 1 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculation of the mode results in two possible values: 2 (no collision) and 3 (detour).

Level 5

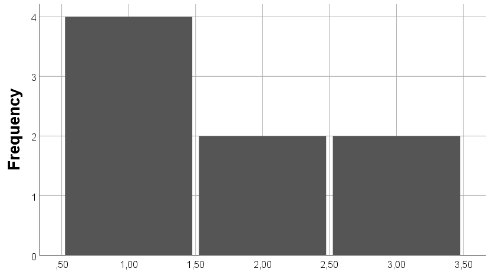
10 persons experienced level 5 during the first condition. 6 participants went through the avatar. 3 participants went straight to the table but tried to avoid a collision. 1 participants did not go the shortest way to the questionnaire and went around a corner to avoid a collision. The calculated mode value was 1 (collision).

	No of participants	**1 (Collision)**	**2 (No collision)**	**3 (Detour)**	**Mode**
Level 1	6	4	2	0	1
Level 2	8	4	2	2	1
Level 3	5	4	1	0	1
Level 4	2	0	1	1	2 and 3
Level 5	10	6	3	1	1

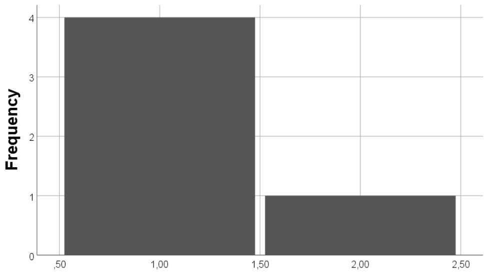
Table 4.2: Collision in the first round - Contingency table



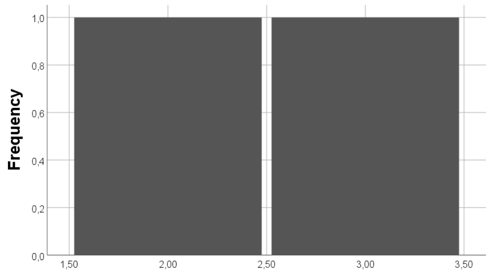
(a) Level 1



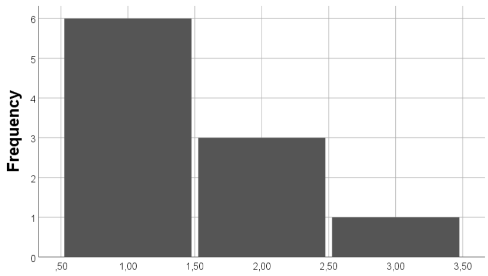
(b) Level 2



(c) Level 3



(d) Level 4

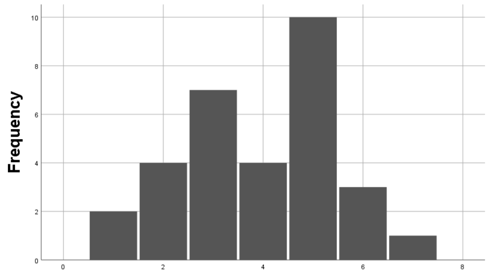


(e) Level 5

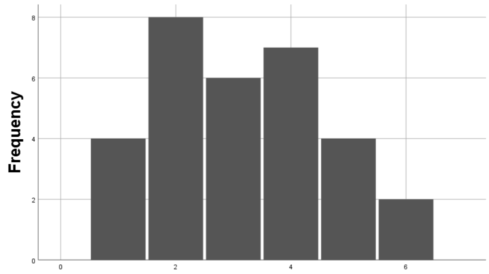
Figure 4.2: First round collision histograms

4.2 Perception of realism

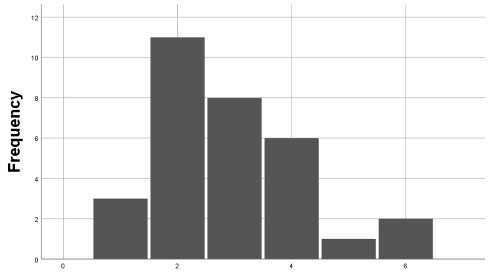
To measure perception of realism the question "Overall, how would you rate the degree of realness achieved by the virtual human; to what extent ”they seemed real to you." was used. Frequency analysis shows that the list of top one frequent answers for each realism level mostly equals the expected order, but the frequencies and their plots showed that the differences between level 2 and 3 are most likely not significant. Figure 4.3 shows a histogram of the answers for each realism level. The contingency table (Table 4.3) shows the frequency of the answers for each level. The top one frequency of each realism level is highlighted as bold. The median values from 1 to 5 are M1 = 4, M2 = 3, M3 = 3, M4 = 2, M5 = 1. Figure 4.4 shows a plot of the median of the perceived realism over all realism levels.



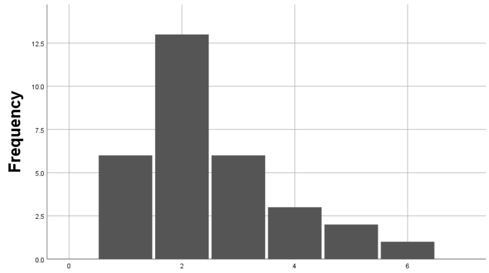
(a) Level 1



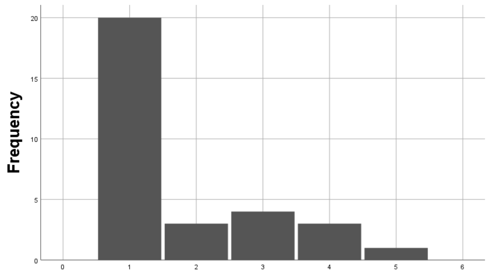
(b) Level 2



(c) Level 3



(d) Level 4



(e) Level 5

Figure 4.3: Histograms of perceived realism

	1	**2**	**3**	**4**	**5**	**6**	**7**
Level 1	2(6%)	4(12%)	7(22%)	4(12%)	**10(32%)**	3(9%)	1(3%)
Level 2	4(12%)	**8(25%)**	6(19%)	7(22%)	4(12%)	2(6%)	0(0%)
Level 3	3(9%)	**11(35%)**	8(25%)	6(19%)	1(3%)	2(6%)	0(0%)
Level 4	6(19%)	**13(41%)**	6(19%)	3(9%)	2(6%)	1(3%)	0(0%)
Level 5	**20(64%)**	3(9%)	4(12%)	3(9%)	1(3%)	0(0%)	0(0%)

Table 4.3: Contingency table - Perceived realism scores from 1-7 (horizontal) for each realism level (vertical)

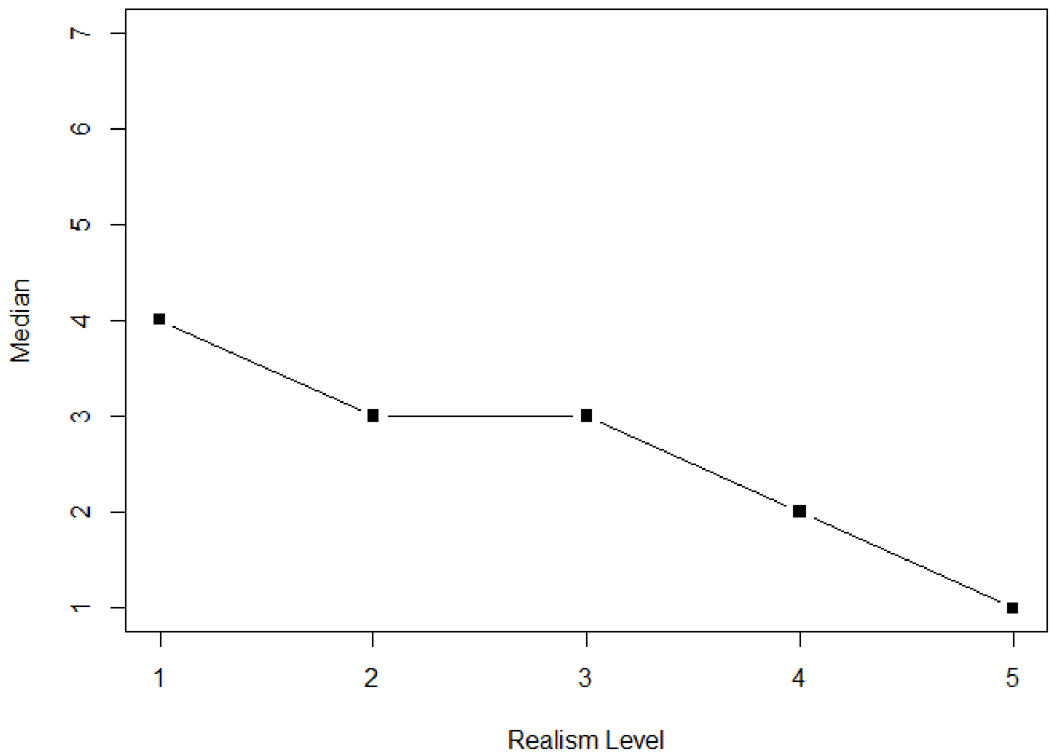


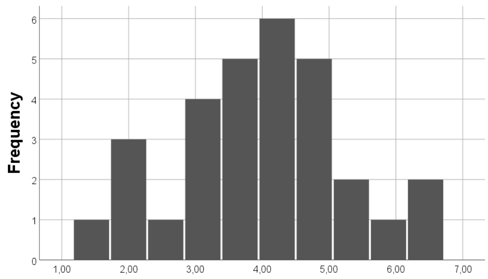
Figure 4.4: Median of perceived realism scores from 1-7 (vertical) for each realism level 1-5 (horizontal)

Friedman's ANOVA showed that perception of realism of each level did significantly change, $\chi^2{}_F(4) = 47.259$, $p < 0.001$. Wilcoxon tests were used to follow up this finding. It appears that the perception of realism from level 2 to level 3 has not significantly changed, T = 92.5, Z = -1.158, p = 0.247. All other differences were significant. The perception of realism from level 1 to level 2 has significantly changed, T = 66, Z = -2.224 p = 0.026. From level 3 to level 4 it did significantly changed, T = 26, Z = -2.025, p = 0.043. From Level 4 to 5 perception of realism has significantly changed,T = 76, Z = -2.374, p = 0.018.

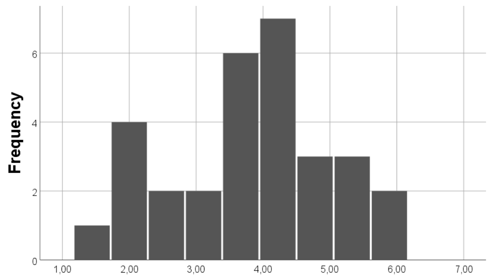
4.3 Presence

As mentioned in Subsection 3.7.3 the presence questionnaire can be broken down into three categories: General presence, Co-Presence and Social-Presence. The following section first analyzes the overall representation of presence by using the calculated mean value. The Subsections 4.3.1, 4.3.2, and 4.3.3 further analyze the categories.

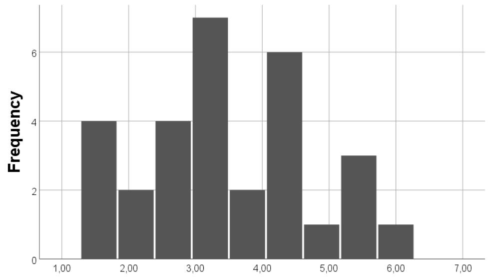
The questionnaire about presence consists out of nine questions. Cronbach's alpha showed a high internal consistency of the presence questionnaire. Level 1 $\alpha = 0.906$, Level 2 $\alpha = 0.873$, Level 3 $\alpha = 0.886$, Level 4 $\alpha = 0.886$, Level 5 $\alpha = 0.848$. The means of the answers of each participant were calculated to analyze the data. The histograms in Figure 4.5 shows a wide range of answers in each level. Especially level 4 in Figure 4.5d and level 5 in Figure 4.5e.



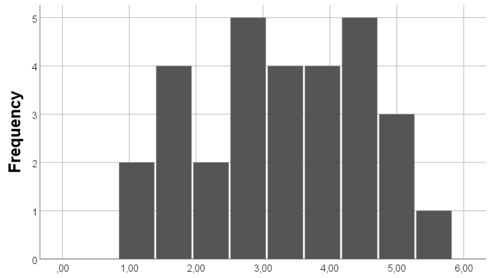
(a) Level 1



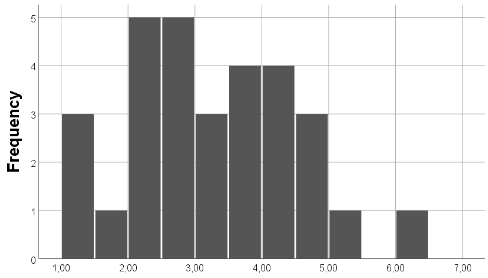
(b) Level 2



(c) Level 3



(d) Level 4



(e) Level 5

Figure 4.5: Presence histogram

The overall mean of each level, plotted in Figure 4.6, shows that presence decreases with a lower realism level. Table 4.4 shows the median, mean, confidence interval and standard deviation of each level.

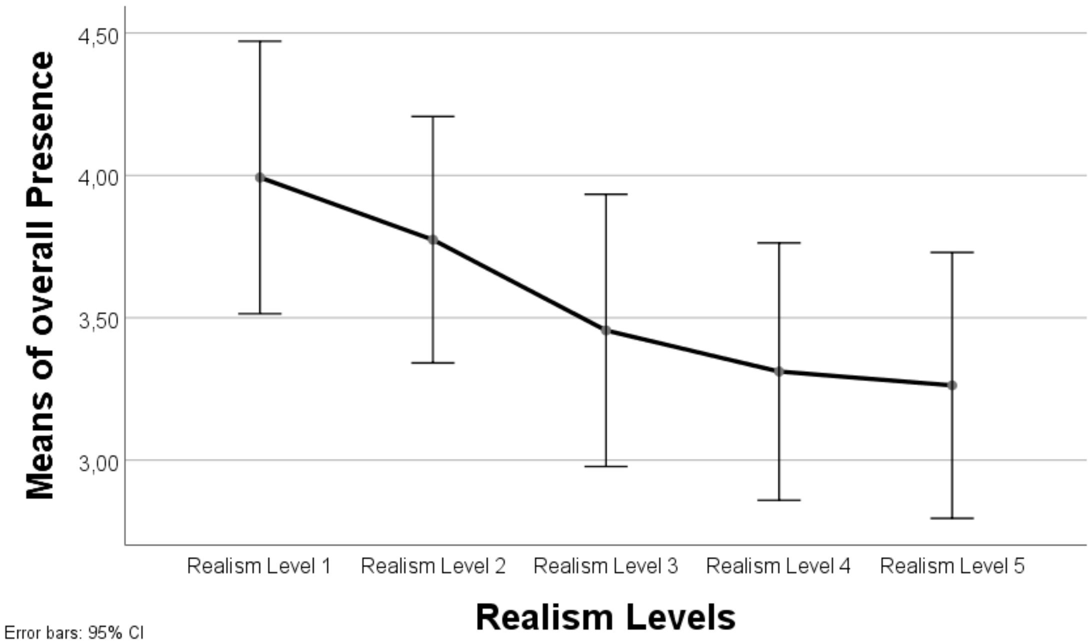


Figure 4.6: Mean of presence across realism levels

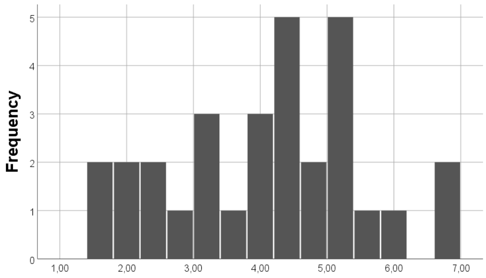
	Median	**Mean**	**95% confidence interval**	**Standard deviation**
Level 1	4.2222	3.9926	[3.514, 4.471]	0.234
Level 2	3.9444	3.7741	[3.341, 4.207]	0.212
Level 3	3.1667	3.4556	[2.978, 3.934]	0.234
Level 4	3.3889	3.3111	[2.859, 3.763]	0.221
Level 5	3.1667	3.2625	[2.796, 3.729]	0.228

Table 4.4: Mean and standard deviation of presence

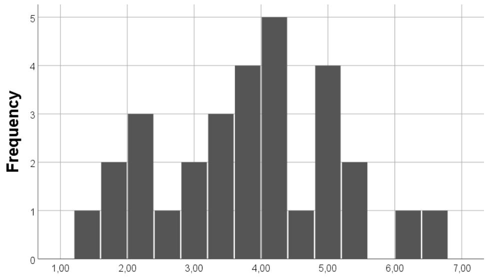
The repeated-measures ANOVA showed that there were significant changes across the means, F = 10.055, p = <0.01. The assumption of normal distribution of the differences between the levels was fulfilled. The Shapiro-Wilk test for the differences from level 1 to level 2 returned a statistic value SW = 0.963, p = 0.345. Shapiro-Wilk of differences between level 2 and 3, SW = 0.95, p = 0.16. Shapiro-Wilk of differences between level 3 and 4, SW = 0.974, p = 0.664. Shapiro-Wilk of differences between level 4 and 5, SW = 0.9465, p = 0.119. The assumption of sphericity has not been violated. The Mauchly test shows no significant variance changes, p = 0.095. The estimators of sphericity, Greenhouse-Geisser, $\epsilon = 0.825$, and the Huynh-Feidt, $\epsilon = 0.944$, showed a good fit. A value of 1 of a sphericity estimator would be perfectly spherical. Paired-sample t-test was used to follow up findings of the repeated-measures ANOVA test, which does not provide information which levels are actually significantly different. The difference of mean of level 1 and 2 was not significant, t = 1.481, p = 0.149, BCa 95% CI[-0.08333, 0.52037], with a difference of 0.21852. The difference of mean of level 2 and level 3 was significant, t = 2.707 , p = 0.011, BCa 95% CI[0.007789, 0.555915], with a difference of 0.31825. The difference of mean between level 3 and level 4 was not significant t = 1.485, p = 0.148, BCa 95% CI[-0.05443, 0.34332], with a differences of 0.1444. The difference of mean between level 4 and 5 was not significant, t = 0.371, p = 0.714, BCa95% CI[-0.21956, 0.31679], with a difference of 0.04861.

4.3.1 General Presence

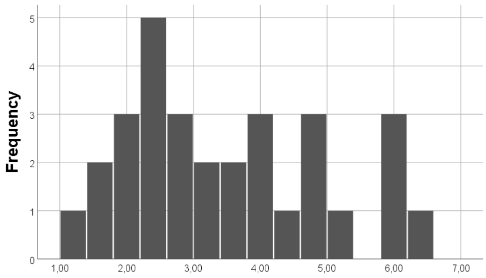
The questionnaire about the general presence consists out of five questions. Cronbach's alpha showed a high internal consistency of the presence questionnaire. Level 1 $\alpha = 0.913$, Level 2 $\alpha = 0.890$, Level 3 $\alpha = 0.913$, Level 4 $\alpha = 0.923$, Level 5 $\alpha = 0.876$. The means of the answers of each participant were calculated to analyze the data. The histograms in Figure 4.7 shows a wide range of answers in each level.



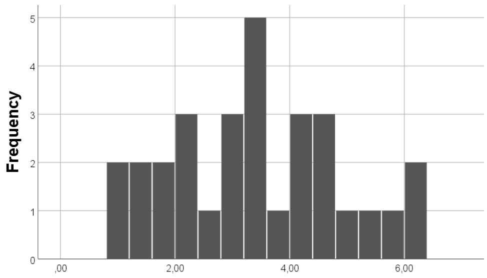
(a) Level 1



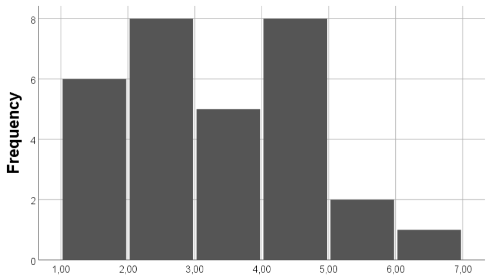
(b) Level 2



(c) Level 3



(d) Level 4



(e) Level 5

Figure 4.7: General presence histogram

The overall mean of each level, plotted in Figure 4.8, shows that presence decreases with a lower realism level. Table 4.5 shows the median, mean, confidence interval and standard deviation of each level.

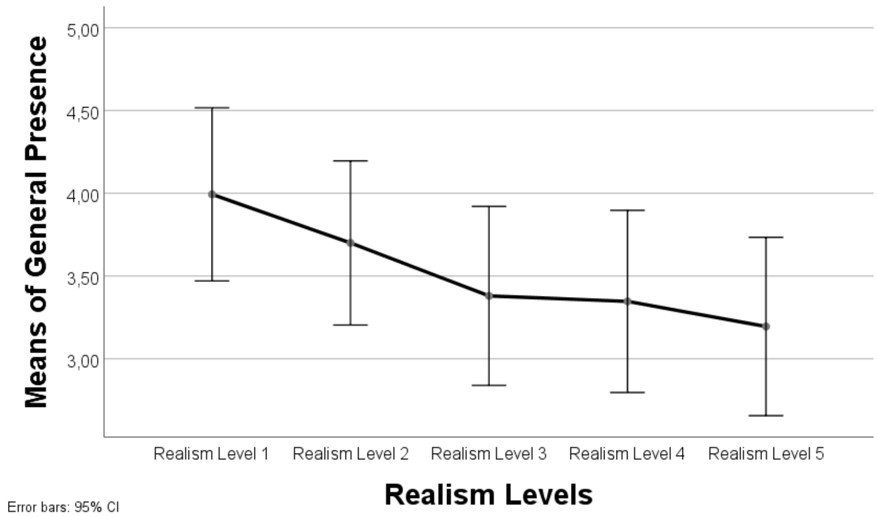


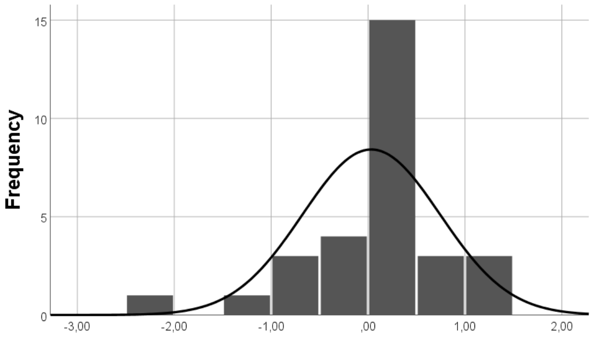
Figure 4.8: Mean of general presence across realism levels

	Median	**Mean**	**95% confidence interval**	**Standard deviation**
Level 1	4.2	3.9933	[3.47, 4.516]	1.40097
Level 2	3.6	3.7	[3.204, 4.196]	1.32847
Level 3	3.1	3.38	[2.839, 3.921]	1.44828
Level 4	3.2	3.3467	[2.796, 3.897]	1.47432
Level 5	3.4	3.1950	[2.656, 3.734]	1.4432

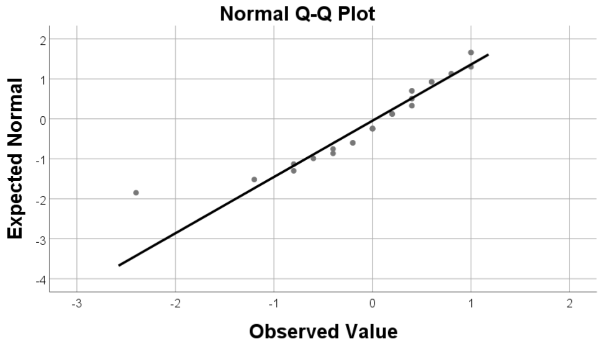
Table 4.5: Mean and standard deviation of general presence

The repeated-measures ANOVA showed that there were significant changes across the means, F = 7.938, p = <0.01. The assumption of normal distribution of the differences between the levels was fulfilled. The Shapiro-Wilk test for the differences from level 1 to level 2 returned a statistic value SW = 0.959, p = 0.276. Shapiro-Wilk of differences between level 2 and 3, SW = 0.964, p = 0.383. Shapiro-Wilk of differences between level 3 and 4, SW = 0.892, p = 0.005. Because of the low p-value, a graphical analysis was made. The graphical analysis showed that the statistical Shapiro-Wilk test is disturbed by outliers and a high quantity of a specific difference. Figure 4.9 shows the histogram of the differences including a normal distribution curve, a normal Q-Q Plot, and a Box-Plot. Shapiro-Wilk of differences between level 4 and 5, SW = 0.931, p = 0.051. The assumption of sphericity has not been violated. The Mauchly test shows significant variance changes, p = 0.380. The estimators of sphericity, Greenhouse-Geisser, $\epsilon = 0.847$, and the Huynh-Feidt, $\epsilon = 0.972$, showed a good fit. A value of 1 of a sphericity estimator would be perfectly spherical. Paired-sample t-test was used to follow up findings of the repeated-measures ANOVA test, which does not provide information which levels are significantly different. The difference of mean of level 1 and 2 was not significant, t =

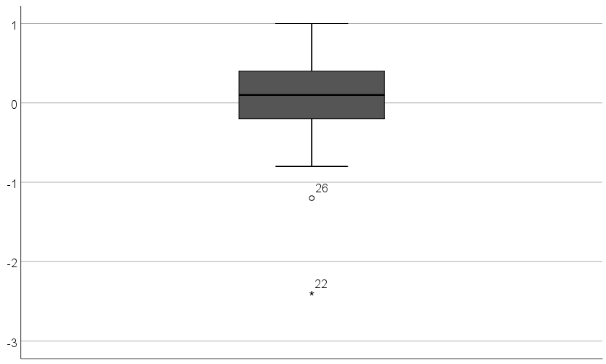
1.735, p = 0.093, BCa 95% CI[-0.05238, 0.63905], with a difference of 0.29333. The difference of mean of level 2 and level 3 was significant, t = 2.183 , p = 0.037, BCa 95% CI[0.02025, 0.61975], with a difference of 0.32. The difference of mean between level 3 and level 4 was not significant t = 0.257, p = 0.799, BCa 95% CI[-0.23204, 0.29870], with a differences of 0.0333. The difference of mean between level 4 and 5 was not significant, t = 0.99, p = 0.33, BCa95% CI[-0.16161, 0.46494], with a difference of 0.33.



(a) Histogramm with normal distribution curve



(b) Normal Q-Q Plot

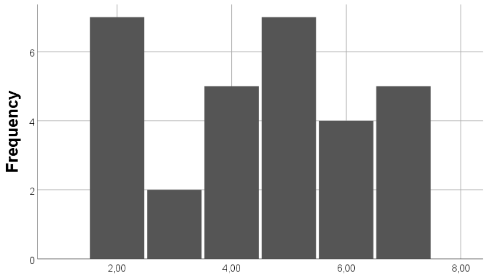


(c) Box-Plot

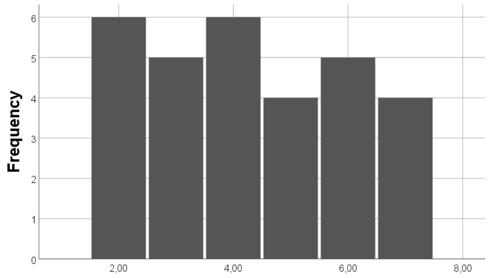
Figure 4.9: Graphical normal distribution analysis between differences between general presence mean values of realism level 3 and 4

4.3.2 Co-Presence

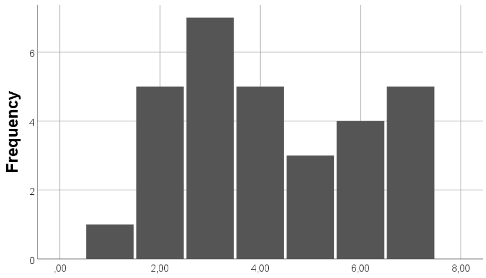
One question was used to measure Co-Presence. The means of the answers of each participant were calculated to analyze the data. The histograms in Figure 4.7 shows a wide range of answers in each level.



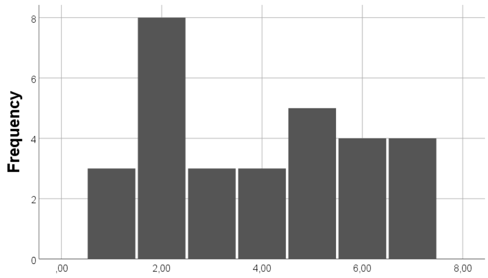
(a) Level 1



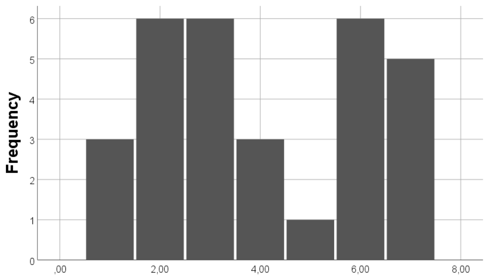
(b) Level 2



(c) Level 3



(d) Level 4



(e) Level 5

Figure 4.10: Co-Presence histogram

The overall mean of each realism level plotted in Figure 4.11 shows that presence decreases with a lower realism level, except for level 4 to 5. Table 4.6 shows the median, mean, confidence interval and standard deviation of each level.

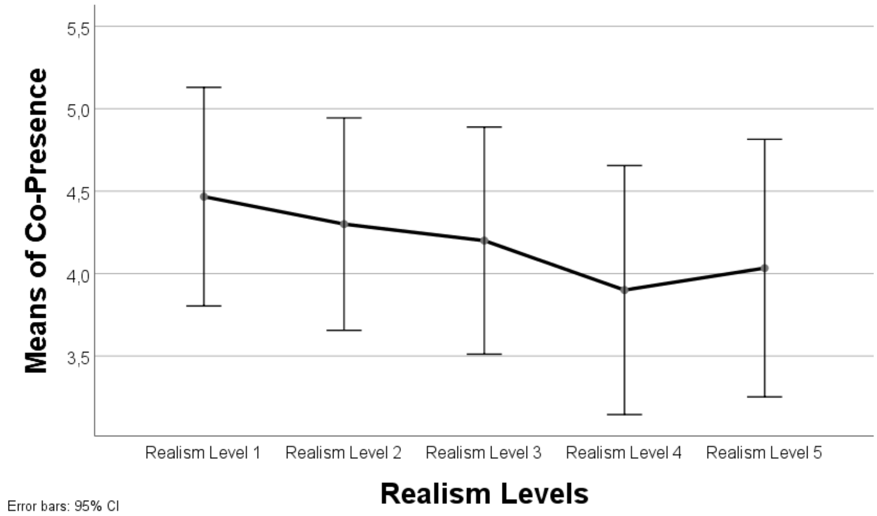


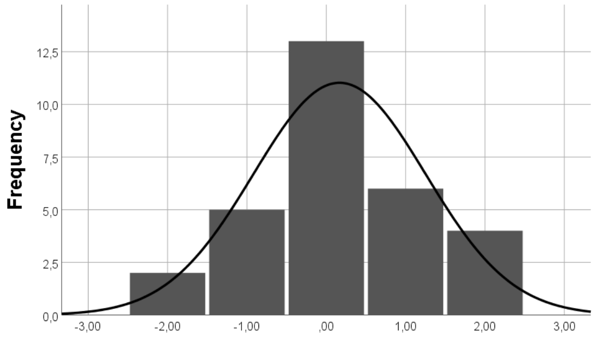
Figure 4.11: Mean of Co-Presence across realism levels

	Median	Mean	95% confidence interval	Standard deviation
Level 1	4.47	5.0	[3.80, 5.13]	1.776
Level 2	4.3	4.0	[366, 4.94]	1.725
Level 3	4.2	4.0	[3.51, 4.89]	1.846
Level 4	3.9	4.0	[3.14, 4.66]	2.023
Level 5	4.03	3.5	[3.25, 4.815]	2.092

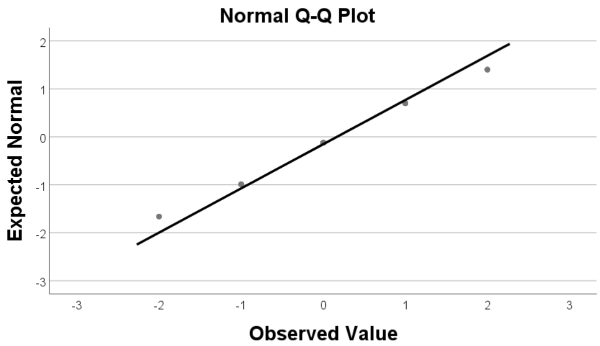
Table 4.6: Mean and standard deviation of CoPresence

The repeated-measures ANOVA showed that there were no statistically significant changes across the means, $F = 2.076$, $p = 0.088$. The assumption of normal distribution of the differences between the levels was fulfilled. The Shapiro-Wilk test for the differences from level 1 to level 2 returned a statistic value $SW = 0.91$, $p = 0.015$. Shapiro-Wilk of differences between level 2 and 3, $SW = 0.912$, $p = 0.017$. Shapiro-Wilk of differences between level 3 and 4, $SW = 0.868$, $p = 0.002$. Shapiro-Wilk of differences between level 4 and 5, $SW = 0.77$, $p <0.001$. Because of the low p-values, a graphical analysis was made. The graphical analysis showed that the statistical Shapiro-Wilk test is disturbed by outliers and a high quantity of specific differences. The graphical analysis in Figures 4.12, 4.13, 4.14, 4.15 show the histogram of the differences including a normal distribution curve, a normal Q-Q Plot, and a Box-Plot for each difference. The assumption of sphericity has not been violated. The Mauchly test shows significant variance changes, $p = 0.238$. The estimators of sphericity, Greenhouse-Geisser, $\epsilon = 0.85$, and the Huynh-Feidt, $\epsilon = 0.977$, showed a good fit. A value of 1 of a sphericity estimator would be perfectly spherical. Paired-sample t-test was used to follow up findings of the repeated-measures ANOVA test, which does not provide information which levels are actually not significantly different.

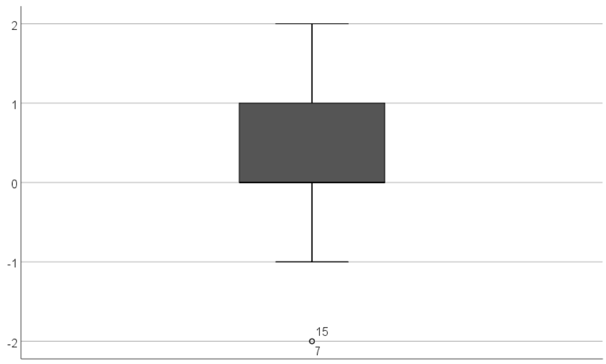
The difference of mean of level 1 and 2 was not significant, t = 0.841, p = 0.407, BCa 95% CI[-0.239, 0.572], with a difference of 0.167. The difference of mean of level 2 and level 3 was not significant, t = 0.474, p = 0.639, BCa 95% CI[-0.331, 0.531], with a difference of 0.1. The difference of mean between level 3 and level 4 was not significant t = 1.725, p = 0.095, BCa 95% CI[-0.056, 0.656], with a differences of 0.3. The difference of mean between level 4 and 5 was not significant, t = 0.643, p = 0.526, BCa95% CI[-0.558, 0.291], with a difference of -0.133.



(a) Histogramm with normal distribution curve

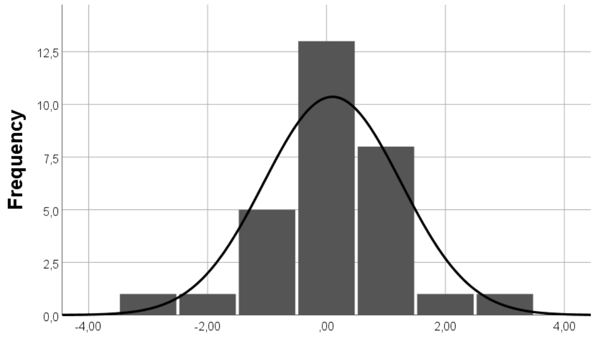


(b) Normal Q-Q Plot

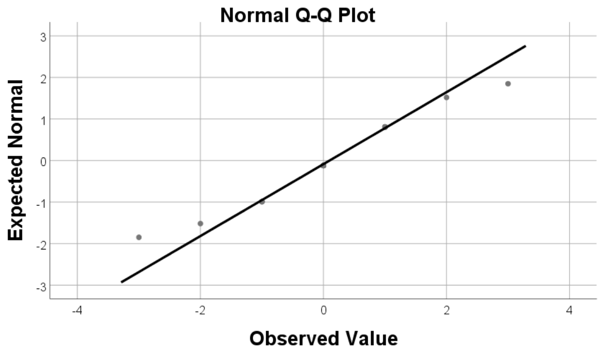


(c) Box-Plot

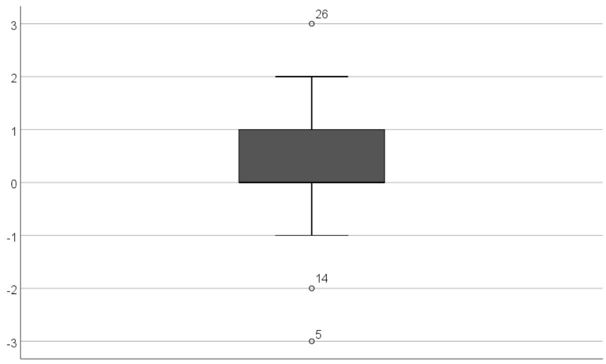
Figure 4.12: Graphical normal distribution analysis between differences between Co-Presence mean values of realism level 1 and 2



(a) Histogramm with normal distribution curve

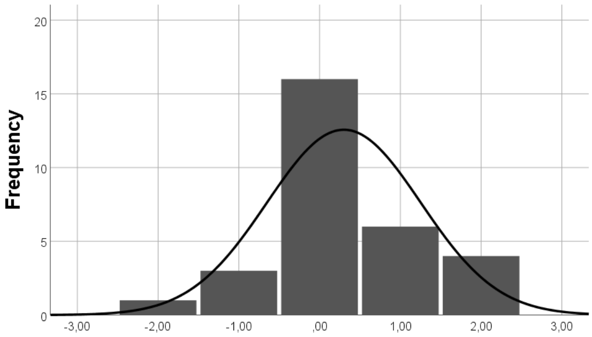


(b) Normal Q-Q Plot

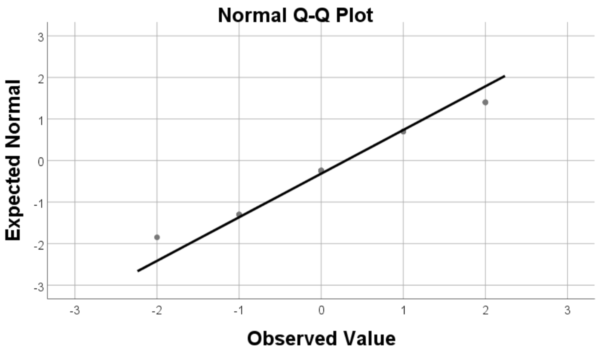


(c) Box-Plot

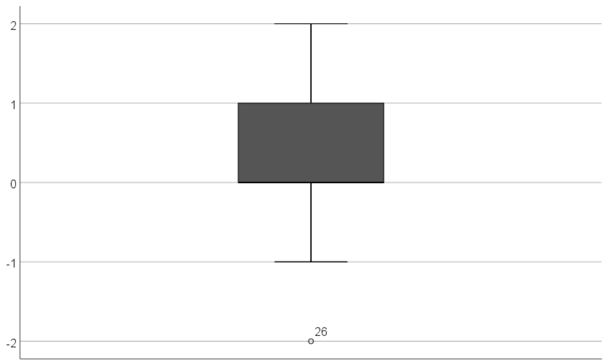
Figure 4.13: Graphical normal distribution analysis between differences between Co-Presence mean values of realism level 2 and 3



(a) Histogramm with normal distribution curve

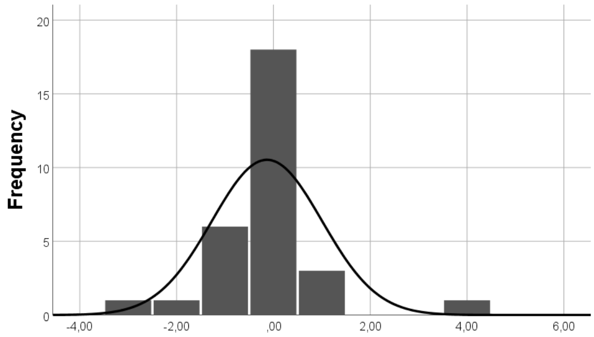


(b) Normal Q-Q Plot

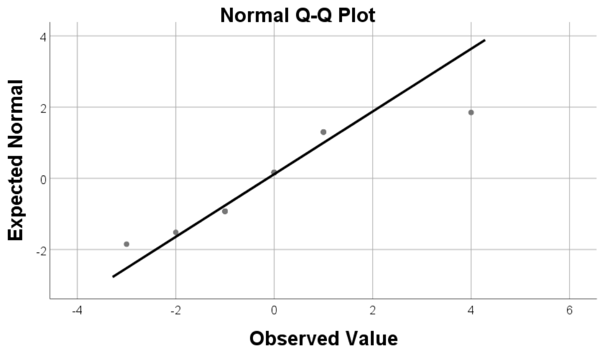


(c) Box-Plot

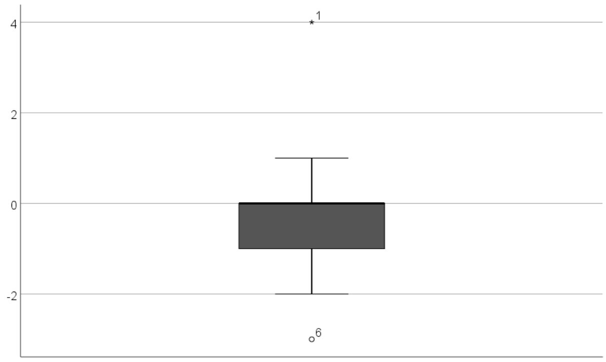
Figure 4.14: Graphical normal distribution analysis between differences between Co-Presence mean values of realism level 3 and 4



(a) Histogramm with normal distribution curve



(b) Normal Q-Q Plot

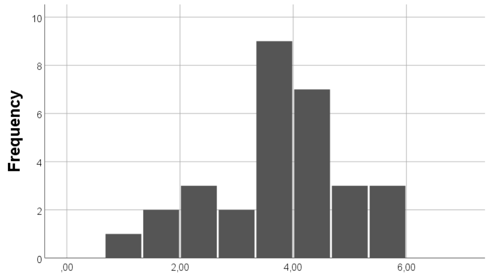


(c) Box-Plot

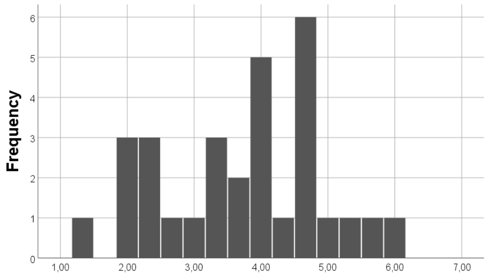
Figure 4.15: Graphical normal distribution analysis between differences between Co-Presence mean values of realism level 4 and 5

4.3.3 Social Presence

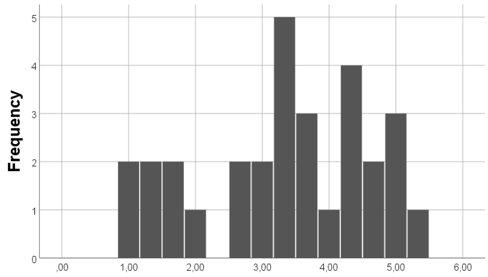
The questionnaire about the social presence consists out of three questions. Cronbach's alpha showed a low internal consistency of the presence questionnaire. Level 1 $\alpha = 0.440$, Level 2 $\alpha = 0.387$, Level 3 $\alpha = 0.311$, Level 4 $\alpha =$ -0.011, Level 5 $\alpha = 0.013$. Deleting the second question SP-2 "The thought that the guide is not a real person crosses my mind often.” results in higher Cronbach’s alpha values: Level 1 $\alpha = 0.713$, Level 2 $\alpha = 0.653$, Level 3 $\alpha = 0.760$, Level 4 $\alpha = 0.769$, Level 5 $\alpha = 0.572$. The means of the answers of each participant were calculated to analyze the data. The histograms in Figure 4.16 shows a wide range of answers in each level.



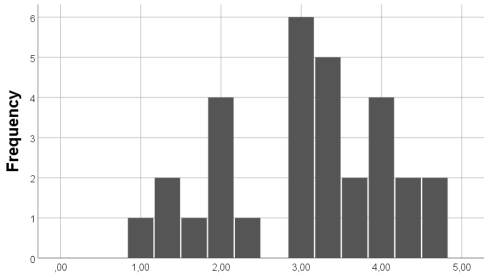
(a) Level 1



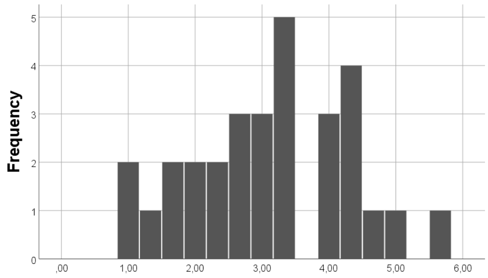
(b) Level 2



(c) Level 3



(d) Level 4



(e) Level 5

Figure 4.16: Social presence histograms

The overall mean of each level plotted in Figure 4.17 shows that the sense of presence decreases with a lower realism level, except for level 4 to 5. Table 4.7 shows the median, mean, confidence interval and standard deviation of each level.

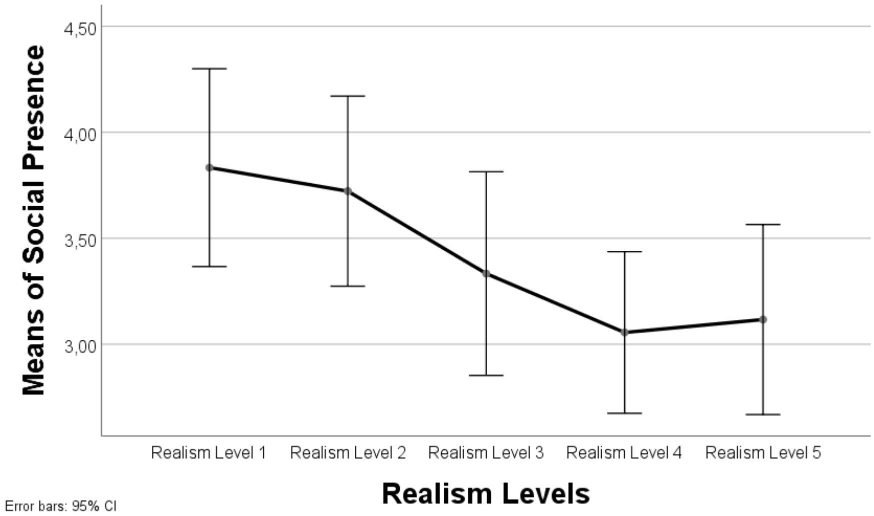


Figure 4.17: Mean of Social Presence across realism levels

	Median	Mean	95% confidence interval	Standard deviation
Level 1	4.0	3.83	[3.367, 4.3]	1.15
Level 2	4.0	3.72	[3.274, 4.171]	1.20
Level 3	3.33	3.33	[2.853, 3.814]	1.28
Level 4	3.16	3.06	[2.674, 3.437]	1.02
Level 5	3.16	3.12	[2.668, 3.565]	1.20

Table 4.7: Mean and standard deviation of social presence

The repeated-measures ANOVA showed that there were significant changes across the means, F = 7.013, p = <0.01. The assumption of normal distribution of the differences between the levels was fulfilled. The Shapiro-Wilk test for the differences from level 1 to level 2 returned a statistic value SW = 0.965, p = 0.404. Shapiro-Wilk of differences between level 2 and 3, SW = 0.946, p = 0.132. Shapiro-Wilk of differences between level 3 and 4, SW = 0.958, p = 0.272. The Shapiro-Wilk of differences between level 4 and 5, SW = 0.968, p = 0.497. The assumption of sphericity has not been violated. The Mauchly test shows significant variance changes, p = 0.354. The estimators of sphericity, Greenhouse-Geisser, $\epsilon = 0.836$, and the Huynh-Feidt, $\epsilon = 0.959$, showed a good fit. A value of 1 of a sphericity estimator would be perfectly spherical. Paired-sample t-test was used to follow up findings of the repeated-measures ANOVA test, which does not provide information which levels are actually significantly different. The difference of mean of level 1 and 2 was not significant, t = 0.691, p = 0.495, BCa 95% CI[-0.21793, 0.44015], with a difference of 0.11. The difference of mean of level 2 and level 3 was significant, t = 2.183 , p = 0.026, BCa 95% CI[0.05064, 0.72714], with a difference of 0.39. The difference of mean between level 3 and level 4 was not significant t = 1.664, p = 0.107, BCa 95%

CI[-0.06362, 0.61917], with a differences of 0.28. The difference of mean between level 4 and 5 was not significant, t = 0.364, p = 0.718, BCa95% CI[-0.40412, 0.2819], with a difference of 0.33.

4.4 Uncanny Valley

Cronbach's alpha first showed very low internal consistency of the questionnaire. Level 1 $\alpha = 0.494$, Level 2 $\alpha = 0.200$, Level 3 $\alpha = 0.038$, Level 4 $\alpha = 0.297$, Level 5 $\alpha = 0.314$. Deleting the eeriness values result in higher Cronbach's alpha values. Level 1 $\alpha = 0.700$, Level 2 $\alpha = 0.642$, Level 3 $\alpha = 0.753$, Level 4 $\alpha = 0.294$, Level 5 $\alpha = 0.572$.

The means of the answers of each participant were calculated to analyze the data. The histograms in Figure 4.18 shows a wide range of answers in each level.

The overall mean of each level plotted in Figure 4.19 shows that presence decreases with a lower realism, except a significant increase from level 4 to level 5. Table 4.4 shows the median, mean, confidence interval and standard deviation of each level.

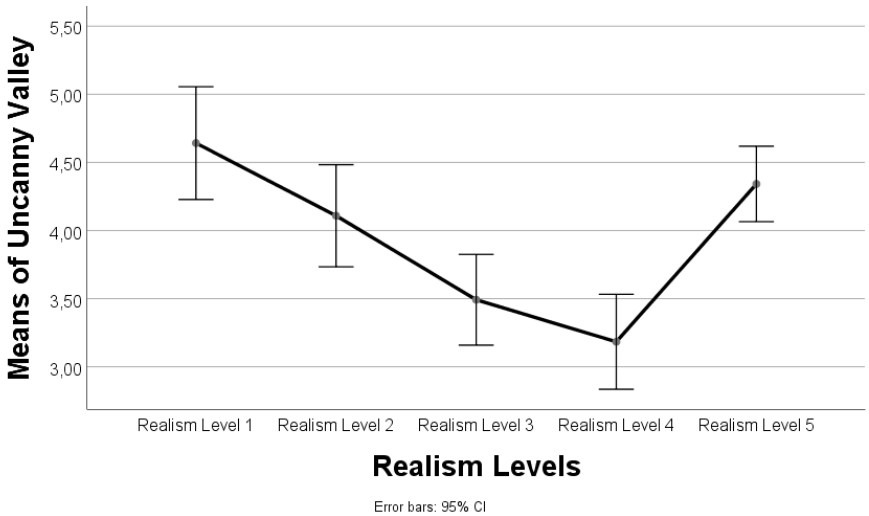
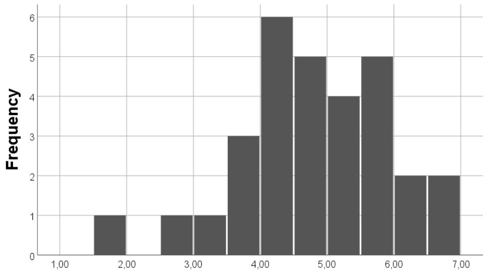


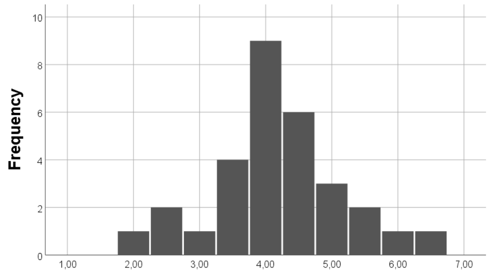
Figure 4.19: Means of Uncanny Valley scores across realism levels

	Median	**Mean**	**95% confidence interval**	**Standard deviation**
Level 1	4.64	4.64	[4.228, 5.0553]	1.11
Level 2	4.0	4.11	[3.7336, 4.4831]	1.0
Level 3	3.5	3.49	[3.1587, 3.8246]	0.89
Level 4	3.25	3.18	[2.835, 3.5317]	0.93
Level 5	4.0	4.34	[4.0649, 4.6185]	0.74

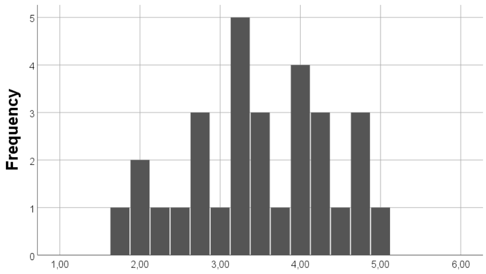
Table 4.8: Mean and standard deviation of Uncanny Valley scores



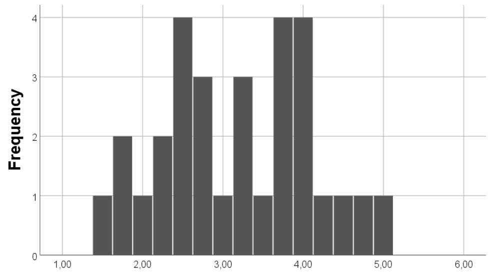
(a) Level 1



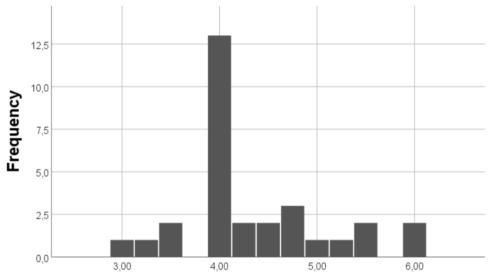
(b) Level 2



(c) Level 3



(d) Level 4



(e) Level 5

Figure 4.18: Uncanny Valley histogram

The repeated-measures ANOVA showed that there were significant changes across the means, F = 13.792, p = <0.01. The assumption of normal distribution of the differences between the levels was fulfilled. The Shapiro-Wilk test for the differences from level 1 to level 2 returned a statistic value SW = 0.949, p = 0.158. Shapiro-Wilk of differences between level 2 and 3, SW = 0.961, p = 0.333. Shapiro-Wilk of differences between level 3 and 4, SW = 0.934, p = 0.062. Shapiro-Wilk of differences between level 4 and 5, SW = 0.964, p = 0.383. The assumption of sphericity has not been violated. The Mauchly test shows no significant variance changes, p = 0.083. The estimators of sphericity, Greenhouse-Geisser, $\epsilon = 0.792$, and the Huynh-Feidt, $\epsilon = 0.9$, showed a good fit. A value of 1 of a sphericity estimator would be perfectly spherical. Paired-sample t-test was used to follow up findings of the repeated-measures ANOVA test, which does not provide information which levels are actually significantly different. The difference of mean of level 1 and 2 was significant, $t = 3.456$, $p = 0.002$, BCa 95% CI[0.21773, 0.84894], with a difference of 0.53333. The difference of mean of level 2 and level 3 was significant, $t = 2.873$, $p = 0.008$, BCa 95% CI[0.17762, 1.05571], with a difference of 0.61667. The difference of mean between level 3 and level 4 was not significant $t = 1.406$, $p = 0.17$, BCa 95% CI[-0,14016, 0.75683], with a differences of 0.30833. The difference of mean between level 4 and 5 was significant, $t = -4.897$, $p < 0.001$, BCa95% CI[-1.64215, -0.67452], with a difference of -1.15833.

4.5 Open Question

Participants were asked about the overall perception of the experiment using the question: "How would you describe the overall perception of the experiment? You can answer in keywords (of preferred)." The question was optional to answer. Is was answered 83 times of 155 (53.5%). Most of the participant answered the question using keywords. 16 participants answered the open question for level 1 (answers can be found in Table 4.9. Most of the keywords mentioned are interaction or movement (4/16) and realistic representation (4/16). 16 participants answered the open question for level 2 (answers can be found in Table 4.10. Most of the keywords mentioned are about that the virtual humans made the user unconformable (6/16) and about the realistic representation (4/16). 18 participants answered the open question for level 3 (answers can be found in Table 4.11. Most of the keywords mentioned are about that virtual humans made the user unconformable (8/18) and about the unrealistic representation (6/18). 16 participants answered the open question for level 4 (answers can be found in Table 4.12. Most of the keywords mentioned are about the unrealistic representation (9/16) and about that virtual humans made the user unconformable (5/16). 17 participants answered the open question for level 5 (answers can be found in Table 4.13). Most of the keywords mentioned are about the unrealistic or game-like representation (7/17), and the sympathetic or funny feeling participants had (4/17).

Level 1 involved more movement than level 2
Noticeable more interaction. Want to experiment with virtual human, i.e. I shook my head and waited until the avatar does the same
had the feeling that it imitated my movements
realistic
Interesting
more realistic
the eyes have often reminded that he was not real
best representation so far; best experience; However, the avatar (as well as all the others) seemed to shine, which unfortunately greatly reduces realism.
Most realistic representation. The more realistic the more sinister. Missing blink of the avatar looks spurious. General: Near Plane is too far away for a realistic feeling.
I would like to get in contact more
sympathetic but without movement feedback
Above all, I felt strangely watched
Better than the level 3
Preppy dressed, thus competent charisma. nice facial features
no occlusion -> that makes it less present in the same room.
more realistic

Table 4.9: Answers to the open question - Level 1

eyes did not move or blink; proportion between shoes and body is not correct (shows are too small)
he eyes have stared at me unpleasant
enjoyable
exciting
Maybe little more realistic, one realized that the object itself was strange
impressive
no difference to Level 3
Compared to the previous Avatar, the eyes were more conspicuous here
Avatar is clearly artificial. More interaction would improve the presence
unusual, impressive that a human is standing with me in the room
strange
surreal
Black background and thus less transparency have made the experience "real".
Same as Level 3
eerie
Hardly any interaction, slow response to my position

Table 4.10: Answers to the open question - Level 2

Head is moving, this was not the case in previous levels
something scary avatar due to the eyes
normal
disappointed
you could see the pixels and notice that it is not real
first not sure if it the same, little bit more impressive than the last one
same as level 2?, except the eyes were strange, the shape a bit 'angular' / 'edgy'
looks like previous level 2, but less quality
surrealistic, exciting, wanted to try how the avatar react
Low poly makes him very unrealistic
edgy
unpleasant
From a distance, not sure if is the same, it seems the avatar had no eyes. Something scary
the starring was strange
Very distorted facial structures, eerie overall appearance
least interesting avatar
Eerie face
scary, because black face, if you are close

Table 4.11: Answers to the open question - Level 3

seemed a bit nervous
Due to the lack of eyes, a feeling of discomfort arose
very pleasant presence
strange
boring
not so realistic
the avatar did not have eyes
Less details on the avatar. Clearly artificial. Reminiscent of [Nitendo] Wii graphic.
edgy person
slippery
As if watching a mannequin.
Similar to other Avatars
I was not sure how I should behave during the study
Spooky, the lack of shadows hampers the credibility of the Avatar's existence through its low-detail appearance - I noticed more in Level 4 than in the others
Weird, emotionless face
because of closed eyes / missing pupils I do not feel looked at, clearly non-human (it looks like the avatar should not represent a human being)

Table 4.12: Answers to the open question - Level 4

Lego-avatar is looking towards me
computer generated figure, nice representation but nevertheless never perceived as real
absolutely neutral
funny, playful
cheerfully
imperceptible
interesting life experience
Minecraft style. Seems like being part of a game.
very unrealistic
unreal character
unrealistic
Because the Avatar did not try to look like a real person, his presence was a lot more believable.
surreal, avatar seems like a ghost
Nice, playful, sympathetic
looks wobbly, depicts people (as lego), disappointing that Level 5 does not close his eyes when approaching
Very interesting, human movements depending on how I moved were impressive
unusual, new experience

Table 4.13: Answers of open question - Level 5

In Section 4.2 no significant differences of perceived realism between level 2 to level 3 could be found. The answers of the open question of participants which consumed these realism level in this order is additionally discussed in the following. These participants stated that they had problems to see the differences. 4 out of 31 participants consumed level 2 and 3 (or vice versa) in this order during the experiment. Table 4.14 shows the answers to the open question of these 4 participants.

	Level order	Answer level 2	Answer level 3
1	3 -> 2	"Maybe little more realistic, one realized that the object itself was strange"	"you could see the pixels and notice that it is not real"
2	2 -> 3	"impressive"	"first not sure if it the same, little bit more impressive than the last one"
3	2 -> 3	"Compared to the previous Avatar, the eyes were more conspicuous here"	"same as level 2?, except the eyes were strange, the shape a bit 'angular' / 'edgy'"
4	2 -> 3	"Black background and thus less transparency have made the experience "real"	From a distance, not sure if is the same, it seems the avatar had no eyes. Something scary."

Table 4.14: Answers of participants which consumed level 2 and level 3 in this order (or vice versa)

CHAPTER 5

Discussion

The main goal of this thesis was to develop an AR rendering system with varying levels of realism and to use it to study the effect of increasing realism on the perception of presence and on the convenience of users in AR. Therefore, two hypotheses were created and studied. The first Hypothesis "Increasing the level of realism increases the sense of presence and convenience of users." was partially supported by the significant differences in the results. Nevertheless, tendencies can be shown. The second hypothesis "The Uncanny Valley effect can be observed within the experiment." was not supported. To conduct the experiment an AR rendering system with varying levels of realism was implemented and a questionnaire was developed (Subjection 3.3). In Subsection 3.4 the visual realism factors for the different realism level were created. The results of the experiment are discussed in the following chapter.

5.1 Collision

The results in Section 4.1 show that there are no real tendencies recognizable. The mode values visibility does not have any correlation with the realism levels, which is why no further statistical tests were carried out. It is assumed that technical limitations (also see Subsection 6.1.1) of the used AR headset and especially the limited field of view prevented the participants from seeing the whole virtual avatar at once. It could be that the user looked at the floor and so lost sight of the virtual human when heading to the questionnaire. Nevertheless, some participants unconsciously went around the virtual human without even noticing it. These observations give a hint that a virtual human somehow was perceived as 'real' spatial object.

5.2 Perceptions of Realism

For the majority, perceived realism levels match with the predetermined realism level, and the differences were significantly different (except for between level 2 and level 3). The results of the perception of realism followed the expected results as well as the result of the prestudy (also see 3.5). The perception of realism between level 2 and level 3 was not significantly different. Looking at the histogram in Figure 4.3b and Figure 4.3c and the frequencies in Table 4.3 it can be seen that the answers are diversified, and no real tendency is recognizable. It is assumed that the visual differences between these realism level were not different enough or the participants may not be able to see the differences due to technical limitations (discussed in Section 6.1.1). Looking at the answers to the open questions (Section 4.5) some participants who consumed the realism levels in this order (level 2 to level 3 or vice versa) stated that they could not see any differences or at least they were not sure if there were any. Most of them automatically moved closer, but then they could not see the whole virtual human. One participant stated the reason why he could immediately see that the virtual human is not real that he could see the pixels.

5.3 Presence

As mentioned in Subsection 3.7.3 the presence questionnaire can be broken down into three categories: General presence, Co-Presence and Social-Presence. The following section discusses the results of the overall merged representation of presence (also see Subsection 4.3) as well as the results of the subcategories (also see Subsections 4.3.1, 4.3.2, 4.3.3).

The positive influence of visual realism on the sense of presence was studied to clarify how important visual realism for future AR applications is and which influencing factors should be taken into account. Additionally, the correlation between the sense of presence and visual realism was evaluated. The results in subsection 4.2 suggest that there is an effect of visual realism on the sense of presence. The presence decreases with a lower realism level. However, a specific analysis of the differences between the realism levels shows that only one difference (between realism level 2 and 3) is statistically significant. Interesting is the difference between the sense of presence from realism level 4 to 5. The gradient becomes much flatter than the differences before. The mean values between realism level 4 and 5 are clearly not statistically significant and also a graphically very close together. This is notable because it seems like that a virtual human with clearly unrealistic geometry like the virtual human used in realism level 5 can score almost the same sense of presence than a low-quality virtual human with more realistic geometry. Looking at the answers to the open question (Section 4.5) some participants stated that they clearly recognized the unrealistic or game-like representation. At the same time, they liked the virtual human in level 5 often more than the others. An interesting statement was made about virtual human used in realism level 5 "Because the avatar did not try to look like a real person, his presence was a lot more believable."

The results of the categories of overall presence show similar trends, but also some interesting differences. The mean values of the category 'General Presence' show that presence decreases with a lower realism level and also shows statistically significant differences only between level 2 and 3 (same as the overall merged presence results). The results of the category 'Co-Presence' show also the trend that presence decreases with a lower realism level, except for realism level 4 and 5. Here it is called a 'trend' because the repeated-measures ANOVA test shows that there were no statistically significant changes across the means. Nevertheless, the mean values between realism level 4 and 5 are interesting because they are actually increasing with a lower realism level. Even if the difference is statistically not significant, it seems like that a virtual human with cleary unrealistic geometry can score a higher Co-Presence than a low-quality virtual human with more realistic geometry. The category 'Social Presence' also shows that the sense of presence decreases with a lower realism level, except between the realism level 4 to 5. The results show statistically significant differences only between level 2 and 3 (same as the overall merged presence results). Same as in the category 'Co-Presence', the mean values between realism level 4 and 5 are interesting because they are actually increasing with a lower realism level. Even if the difference is statistically not significant, it seems like that a virtual human with cleary unrealistic geometry can score a higher Social Presence than a low-quality virtual human with more realistic geometry. Sadly the reliability of the questions in this category was too low. If the second question SP-2 "The thought that the guide is not a real person crosses my mind often." is left out of the reliability test the reliability increases dramatically, so it can be assumed that participants misunderstood this question due to its negative nature (also see Subsection 3.7).

Also interesting is to map the overall presence score to the hypothesized Uncanny Valley graph by Mori [MMK12]. It roughly followed the original hypothesized Uncanny Valley graph, except that the slope may not be that steep as in the original graph (Figure 2.3). The theoretical background of the Uncanny Valley effect is discussed in Section 2.6. We mapped the original term 'Familiarity' to the means of the overall sense of presence. Figure 5.1 shows the mapping of the overall presence score to the Uncanny Valley graph. The mapping has been done by calculating the presence percentage values (y-axis) and calculating the realism value based on the means of perceived realism (x-axis).

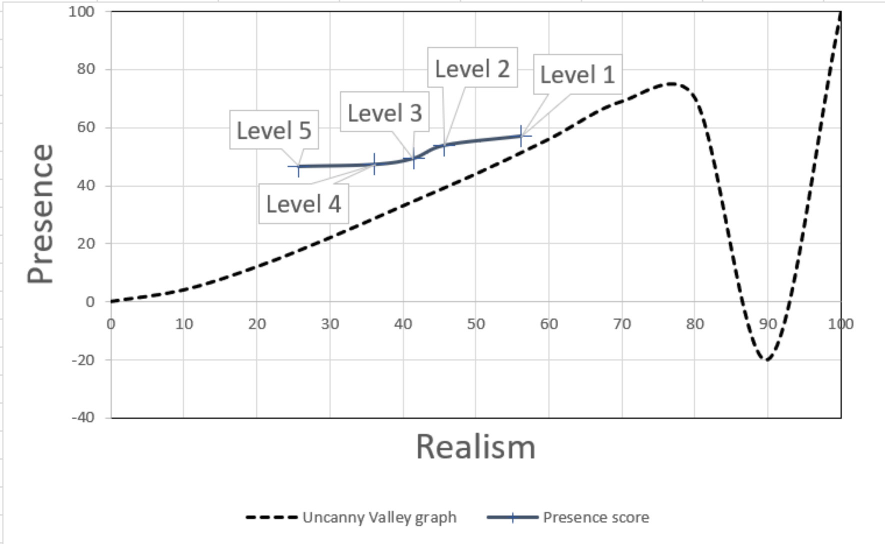


Figure 5.1: Hypothesized mapping of the mean of overall sense of presence to the Uncanny Valley graph

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All in all, the hypothesis H1 was partially supported. These results show a clear trend and indicate partly significant differences between the realism levels. These results are different from results in the past from Lee et al. [LRM+13] and Slater et al. [SKMY09].

5.4 Uncanny Valley

During the experiment design (also see Subsection 3.3) the original scales designed by Ho and MacDorman [HM10, HM17] were reduced to three questions about the overall sense of *Humanness*, *Eeriness*, and *Attractiveness*. Sadly, this attempt was not successful, and the reliability of the questions was too low. It could also be that participants misunderstood the questions since question number two and three were recoded due to their negative nature (also see Subsection 3.7). Nevertheless, the results of the mean value analysis in Subsection 4.4 is discussed in the following section. Additionally, this section discusses the possibility to map the scores to the original assumed plot of the Uncanny Valley effect by Mori [MMK12]. The theoretical background of the Uncanny Valley effect is discussed in Section 2.6. In the original plot (Figure 2.3) Mori used the terms 'Human likeliness' and 'Familiarity'. In this discussion, we understand 'Human likeness' as visual realism levels of the virtual human and 'Familiarity' as the mean scores of the Uncanny Valley questionnaire.

Even if a form of the Uncanny Valley effect could not be observed the results allow other interesting interpretations. The results suggest that there is an effect of visual realism on the familiarity of the user. The repeated-measures ANOVA test showed significant changes across the means. Nevertheless, a specific analysis of the differences between the realism levels shows that only the differences of the means between realism level 3 and 4 were not significant. From realism level 1 to 4 it can be seen the higher the realism, the higher is the familiarity score. Interesting is the difference between the realism level 4 to 5 as well as the mean value from realism level 5 itself which is about as high as the value of realism level 2. It is statistically significant that a virtual human with clearly unrealistic representation (realism level 5) can score a higher familiarity than low-quality virtual human with more realistic representation (in this case level 2,3 and 4).

Mapping the results to the hypothesized graph of the Uncanny Valley effect by Mori [MMK12] indicate that the first part of the curve may not be as steadily rising as assumed by Mori [MMK12]. This thesis hypothesizes that the curve from 0% realism to about 50% is not steadily rising, but could include a hump (something like a local maximum). Figure 5.2 shows the mapping of the relative familiarity score with the Uncanny Valley graph. The mapping has been done by calculating the familiarity percentage values (y-axis) and calculating the realism value based on the means of perceived realism (x-axis). Apparently, the is shows no tendencies of an Uncanny Valley effect.

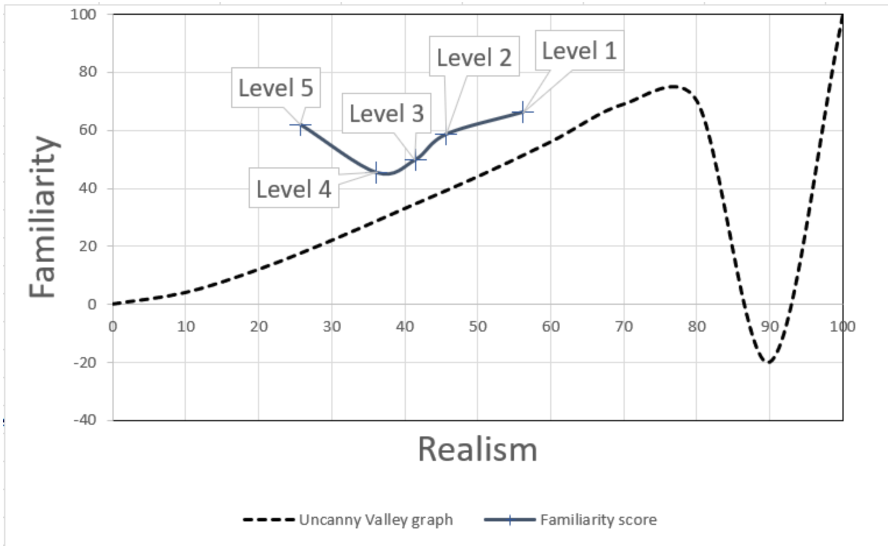

Figure 5.2: Hypothesized mapping of the quentionnaire score to the Uncanny Valley graph

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The results do not support hypothesis H2 since no tendencies of the Uncanny Valley effect is detectable. Nevertheless, the findings support the findings stated in Section 5.3 and further also partly supports hypothesis H1. Further, a new hypothesis for future studies was created.

CHAPTER 6

Conclusion

6.1 Summary

The main goal of this thesis was to study the effect of increasing realism on the perception of presence and on the convenience of users in AR. To evaluate the effect of visual realism to the sense of presence, an experiment was conducted in which each participant experienced a virtual human for each realism level. The results indicate that visual realism is an important factor to reach a higher sense of presence within AR application.

6.1.1 Technical limitations

The technical setup of the used AR system (HoloLens) stresses some technical limitations which could potentially lead to biased answers. Perhaps the most important lesson learned was the difficulty to assess what kind of experimental design is actually possible due to technical possibilities.

Providing the same performance and user experience in all realism levels is a challenge. Initially, it was planned that participants should be navigated through a building with the help of a virtual human. The feature 'Navigation' and 'Walking' are with no doubt possible if drawbacks due to realism and animation are acceptable. In the case of this thesis, we could not provide these features at the highest visual realism level without frame drops and further loose user experience. For the same reason, neither global illumination nor shadows could be used.

Additionally, the limited field of view of the HoloLens in combination with a walking virtual human in space cause that the participant could lose sight of the virtual human. This would most likely break the presence and produce biased answers. Most of the participants claimed about the limited field of view. The limited field of view prevented the participants from seeing the whole virtual human during the whole experiment. Some participants reported that the virtual humans seems to be transparent or would shine.

This is due to the light-based displays build into the HoloLens. These displays add virtual objects into the field of view of the user by adding light to the real-world, but it cannot reduce light. If the surrounding environment is too bright, the virtual objects can appear transparent. If the surrounding environment is too dark virtual objects tend to look like they would shine. Before the study other optical as well as video see-throw HMD systems were tested, but no system provided a tracking system as robust as the HoloLens offers.

After several tests and due to the technical problems mentioned above the navigation and walking features were discarded. It was decided to concentrate on a standing virtual human which looks at the participant at any time of the experiment.

The technical capabilities of today's AR systems limit the experiment design possibilities. In 2007 Guadagno et al. [GBBM07] pointed out that the available technology is not capable of creating highly realistic virtual humans. Ten years later the technology has developed rapidly, but this problem still exists today. Especially the limited field of view most probably causes biased measurements. The ideal AR system for such a study should be a mobile head held AR system which at least provides accurate tracking, powerful high-quality rendering, shadows, global illumination, at least three times wider field of view, etc. Future research should consider repeating this user study as soon as new AR systems solve the above mentioned technical problems. The influence of field of view on the presence could also be validated in the future.

6.2 Future Work

During the implementation, we ran into some technical problems due to the technical limitations of the used AR system. Also, a part of the questionnaire was not reliable enough. Further, some participants of the user study provided feedback which uncovered potential improvement. This section discusses these and other problems and suggestions for future research.

6.2.1 Uncanny Valley

During the discussion of the results in Section 5.4 we hypothesized that the curve from 0% to 50% is not steadily rising but could include a hump. Future work should focus on this finding to validate the occurence of this 'hump'. This could be done by conducting a user study which focus on the human likeness between 0% to 50% of the Uncanny Valley graph.

6.2.2 Virtual human

The realism levels among the virtual humans differ in a few factors which were changes in each realism level. Although this approach produces useful different realism levels it is not possible to determine which factor exactly scored a different sense of presence afterwards. Additionally, the visual differences between level 4 and 5 maybe were too big. Future work could provide finer gradations between the low poly, no texture only colour virtual human (level 4) and a game-like, block style virtual human (level 5). Future work should address these circumstances.

A limitation of this research was that only one male virtual human was used for the study. Studies in the past have shown a significant difference in perception and task performance of a virtual human with a different gender than the participant was used [BBBL03, ZPP03, GBBM07, SSSVB10, LLL15]. To minimize the influence of unequal gender, future work should consider having multiple virtual humans of each gender.

6.2.3 Measuring experience

Past studies mentioned the problematic of biased measures if perception and presence or even experience overall is measured through a questionnaire. There are other approaches to measure experiences like EEG, brainwaves, etc. but so far no standard procedure has been developed. These measurement could be very interesting for future work.

The attempt to create a reduced version of the Uncanny Valley scales created by Ho and MacDorman [HM10, HM17] did not show enough reliability in our study. Future work should either use with all available dimensions or, if a reduced version is necessary, should test the reduced version before using it in further studies.

List of Figures

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