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Doctoral Dissertation

SOCIAL CONFORMITY IN IMMERSIVE VIRTUAL ENVIRONMENTS

Christos Kyrlitsias

Limassol, May 2021

CYPRUS UNIVERSITY OF TECHNOLOGY

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Approval Form

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Limassol, May 2021

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ABSTRACT

In our daily lives, our decisions are greatly influenced by others. Conformity, one of the most powerful forms of social influence, is the act of matching attitudes, beliefs, and behaviors to group norms. It is an indirect social influence that is caused by the desire of the individual to either "fit in" the group, avoid rejection in the case of normative conformity, or be correct, in the case of informational conformity. Due to the recent advances in immersive virtual reality (IVR) and other related technologies, we are not only interacting socially with physical/real humans but also through technology with virtual humans (VHs). The related literature suggests that interaction with VHs can replicate the effects of human-human interactions. However, regarding conformity in immersive virtual environments (IVEs), the literature is limited. This thesis presents the investigation normative and informational conformity with VHs within IVEs using three experiments.

In our first, experiment, we replicated the original Asch (1951) experiment within an IVE. The participants, immersed in a virtual room, were asked to state their judgments in a series of simple perceptual tasks (trials) either alone, or in the presence of five virtual confederates. In the latter condition, the confederates stated their estimates before the participant and were implemented programmatically to give a unanimous wrong judgment in some trials. The results showed that participants did not conform to the wrong confederates' judgments and responded correctly to the trials. However, an influence on the participants' response time by the virtual confederates' judgments was observed, indicating that some degree of social pressure was exerted on the participants. These results led us to conduct a second experiment in order to further investigate the social pressure from VHs within IVEs.

In the second experiment, additionally, we examined the impact of agency (i.e. the extent to which the user believes that a VH represents an avatar rather than an agent) and the virtual confederates' behavioral realism. The results showed that normative conformity can be caused by VHs in IVEs, as participants responses were at some degree distorted by the false VHs' answers. However, no effect of agency and behavioral realism was observed, even if participants in the high behavioral realism

condition reported a stronger sense of social presence (the sense of being together with others).

In our third experiment we focused on informational conformity. This was done by increasing the difficulty of the task in relation to the previous experiments by limiting the stimuli projection duration. Additionally, we investigated the impact of social presence of informational conformity using two levels of virtual confederates' behavioral realism (and specifically gaze behavior), as in the second experiment. The results showed that participants conformed with the virtual confederates, as the participants gave significantly more incorrect responses to the trials in which the confederates also gave an incorrect response, compared to those trials in which the confederates gave correct answers. Participants in the high behavioral realism condition reported stronger social presence than participants in the low behavioral realism condition. However, no difference in the level of conformity was observed between the two conditions, showing no impact of social presence on conformity. Additional results based on self-reported measures showed a number of social effects that occurred only in the high behavioral realism condition, such as participants' confidence, indicating that social presence has an impact on the participants' experience.

The outcomes of this research extended the existing literature with additional knowledge. We provided empirical evidence that a group of VHs can influence the user's decision making within IVEs through informational (to a greater extent) and normative (to a lesser extent) conformity. The implications of this study on the use of VHs in immersive applications as well as future research directions are also discussed within this dissertation.

Keywords: virtual reality, conformity, virtual humans, behavioral realism, agency, social presence

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LIST OF ABBREVIATIONS

CAVE:	Cave Automatic Virtual Environment
CI:	Conformity index
CUT:	Cyprus University of Technology
IVE:	Immersive virtual environment
IVR:	Immersive Virtual Reality
NPC:	Non-player character
RQ:	Research question
SCs	Sensorimotor contingencies
VH:	Virtual Human
VR:	Virtual Reality

1 Introduction

1.1 Social Influence and Conformity

In our daily lives, our decisions are greatly influenced by others. Our attitudes, our beliefs, and our behavior are influenced in a way that meets the demands of our social environment. Allport (1985) defined social psychology as “an attempt to understand and explain how the thought, feeling, and behavior of individuals are influenced by the actual, imagined, or implied presence of others” (p. 3). We refer to the process by which an individual's attitudes, beliefs or behaviors are modified by the presence and actions of real or imagined others as *social influence*. There are different types of social influence. This study focuses on conformity, which is one of the more important forms of social influence. Besides conformity, there are other forms of social influence such as compliance, obedience, and persuasion. In order to make a clear distinction between conformity and other forms of social influence, we explain each of them below.

Compliance is a change of an individual’s behavior as a result of a request from other(s). It is considered an active type of social influence as the person(s) are intentionally and consciously exerting it, in order to change the individual’s behavior. Even if sometimes compliance results in internal changes such as a change in beliefs and attitudes, it is not the primary goal for this form of influence. In compliance, it is up to the individual to comply, even if in some cases refusing to comply can lead to social punishment. For that reason, in some cases, the individuals comply with requests even if they do not want to.

Obedience is a change in an individual’s behavior due to instructions or orders derived from an authority figure. Similar to compliance, obedience is a direct form of influence targeting a change in behavior rather than internal changes such as beliefs or attributes. The power of obedience was demonstrated by a famous, yet controversial experiment conducted by Stanley Milgram (1963). The results of this experiment showed that most of the participants were willing to apply seemingly lethal electric shocks to a stranger if ordered by an authority figure, in that case by the experimenter.

Persuasion, in contrast with compliance and obedience, is a direct form of social influence attempting to change an individual’s beliefs or attitudes and not only the behavior. Persuasion is a process of trying to convince a person or persons to change their attitudes or behaviors through communication.

This study focuses on *conformity*, which describes the change in an individual's beliefs, attributes or behaviors as a result of group pressure. Conformity differs from other forms of social influence described above, as the members of the group do not actively attempt to influence the individual. Therefore, conformity is generally regarded as a passive form of social influence. Nevertheless, social conformity is one of the most powerful forms of social influence.

This effect was initially studied by Arthur Jenness (1932), who asked the participants to estimate the number of beans in a bottle, individually. Then, the participants were divided into small groups and asked to discuss the task and provide a common estimate. Finally, the participants provided with the opportunity to revise their initial individual estimates. The results showed that the majority of the participants changed their initial estimation towards that of the group. Muzafer Sherif (1935) conducted a series of experiments using the autokinetic effect, the illusion of movement in the absence of a reference point (spot of light in a dark room). When the participants were asked to individually estimate how far the light moved, their answers varied considerably. But when they were asked to do the same in groups of three, stating their estimates out loud, Sherif found that their estimates converged.

The most famous experimental approach of conformity, however, was the one carried out by Solomon Asch (1951; 1955; 1956). Asch conducted a series of experiments to investigate the extent to which social pressure from the majority can influence an individual and make them conform. Participants were placed in a room along with seven confederates and were asked to answer some simple line length comparison test. The confederates' responses had been agreed in advance. The participant was led to believe that the other seven attendees were also real participants and not part of the experiment's scenario. The results demonstrated that the participants were affected by the pressure of others. Approximately, one third of all estimates by the participants in the critical group were distorted in the direction of the confederates.

Depending on the reasons that people conform to the group's opinion, even if it is incorrect, social conformity can be distinguished into two types, normative and informational (Deutsch & Gerard, 1955). Normative conformity occurs when the person changes an attitude expression or behavior to avoid rejection and to be liked or accepted by the group. In such cases, the person's opinion is maintained privately. For example, in a variation of Asch's experiment, the conformity frequency was reduced when the participants had to write down their responses privately. On the contrary, when the individual accepts the majority's opinion as a fact or reality, usually due to the lack of knowledge, then informational conformity occurs. In these cases, the individual complies more easily when the situation is ambiguous (e.g. greater conformity to a harder task than to an easier one) or when the person feels that others have better knowledge.

Several studies were conducted in order to investigate the factors that influence the level of conformity. When Asch (1956) asked the participants to write down their responses instead of state them verbally, the conformity level was significantly reduced. This happened due to the absence of normative conformity (Deutsch & Gerard, 1955), associated with the fear of rejection, as participants were asked to express their disagreement privately than publicly.

Aligned with this, other studies showed that conformity is correlated with the level of the individual’s anonymity (Huang & Li, 2016).

One of the main factors that affect the level of conformity is group size. This means that the level of conformity is increasing, as the size of the majority increasing. However, studies showed that this seems to apply up to 3-5 persons, as a further increment of the group size did not increase the level of conformity (Asch, 1956; Bond, 2005). Instead, in studies where participants were asked to respond privately, further increments of the majority size led to a decrease of the conformity level. This negative effect was attributed to the participants’ suspicion (Bond, 2005) or their reaction to the majority’s pressure (Moscovici, 1980).

Another factor that affect the conformity level is the task difficulty or the ambiguity of the situation. The more ambiguous or unclear the task is, the more the people conform (Asch, 1956; Coleman, Blake & Mouton, 1958; Gergen & Bauer, 1967). A follow-up study by Asch (1956) showed that participants were more likely to conform to the wrong confederate judgments when the task difficulty was increased by making the comparison lines more similar to each other. The difficulty of the task is also associated with the type of the influence. In easy and obvious tasks, social conformity is attributed to normative influence (Deutsch & Gerard, 1955), as individuals change their judgment in order to match the group, but they keep their opinions private. On the other hand, with a difficult or unclear task, conformity can also be attributed to informational (Deutsch & Gerard, 1955) influence, as individuals change their judgment in order to be correct.

The level of conformity of an individual with the majority group is greatly affected by the unanimity of the majority. When the majority is not unanimous, the conformity level drops dramatically. Asch (1955) found that if one confederate went against the other confederates, by giving the correct answer, the conformity was reduced significantly. Even when a confederate went against both the participant and the majority, breaking the group unanimity, the conformity level also significantly dropped.

Expect of the above, the degree to which conformity occurs is also determined by individual differences. This means that some people are more likely to conform than others. Studies showed that women tend to conform to a greater extent than men (Eagly & Chrvala, 1986; Bond & Smith, 1996). Also, studies showed conformity decreases with age, as older people were less likely to conform. Personality traits of the individuals, such as self-esteem (Gergen & Bauer, 1967), is playing a role as well as their social status within the group. Cultural differences were also found to affect the conformity level as people from collectivistic countries were found to conform to a greater extent than people from individualistic countries (Bond & Smith, 1996).

1.2 Immersive Virtual Reality and Virtual Humans

1.2.1 Immersive Virtual Reality

With the term *virtual reality* (VR) we refer to the creation of simulated environments, also called *immersive virtual environments* (IVEs) with the use of computer technology, software and hardware. In contrast with traditional interfaces, VR not only displays the created environments to the users but gives them the feeling that they are “inside” the environment. This is achieved by “careful integration of hardware and software systems, including multimedia development software, databases, computers, rendering engines, and user interfaces” (Blascovich et al., 2002, p. 107).

Today, typical VR systems provide stereoscopic vision that is updated as a function of the user's head tracking and directional audio (Slater & Sanchez-Vives, 2016). It is also common for the VR systems to provide additional tracking technology (apart from the head) for the user's hands or even for the full body. In addition, some VR systems, using advanced devices, are able to simulate additional senses to the user such as touch, smell, temperature and even taste (Rubio-Tamayo, Gertrudix Barrio & García García, 2017).

An article by Slater and Sanchez-Vives (2016) presents an overview of the basic concepts and the technology of VR systems. A virtual environment with all its information (geometric, acoustic, radiant, natural and behavioral) is described in a database on a computer. Images created by the computer's graphic pipeline based on this database are shown on the display. This process is called rendering (two-dimensional projection of the three-dimensional geometry where objects are colored according to computer graphics lighting models). These images are updated in real time and determined by the position and orientation of the participant's head. Virtual objects are parts of the environment that typically include geometric descriptions along with radiant information in order to be displayed on the display, and programming codes that determine their behavior. These virtual objects are divided into passive (no behavior) and active (some degree of behavior). Active objects differ concerning the degree and nature of their behavior. Some objects can behave in relation to the participant. For example, a virtual representation of a human looks at the participant in the eyes and talks to him. The participant may be able to interact with some active objects, for example to move a chair or, in another common example, the virtual representation of the participant's body (or a body part) moving based on body movements of the participant. These examples require additional tracking technology. Important parameters of immersion include the extent of the field of view, the number of sensory systems that the system simulates, the quality of rendering in each sensory modality, the extent of tracking, the realism of the displayed images, the framerate and the latency. The most common VR systems are VR headsets, also called head-mounted displays (HMDs), and Cave Automatic Virtual Environment (CAVE) systems. In HMDs, the displays are mounted close to the eyes and head tracking ensures that the left and right images are updated according to the head movements of the participant with respect to the underlying virtual environment. The separated left and right images for each eye ensure stereo vision. Audio is delivered via earphones. The CAVE (Cruz-Neira, Sandin & DeFanti, 1993) is a system where between four and six walls of an approximately 3 m^3 room are projected by stereo projection screens. The projected images are determined as a function of head tracking so that, at least with respect to the visual system, participants can physically move through a limited space and orient their head freely to be able to perceive the surroundings (but not necessarily from all directions—depending on how many screens there are). Audio is typically delivered by a set of speakers in unobtrusive positions around the CAVE.

1.2.1.1 Immersion

The ability of the system to provide the user with an illusion of reality is called *immersion* and is defined as "the extent to which the computer displays are capable of delivering an inclusive, extensive, surrounding and vivid illusion of reality to the senses of a human participant" (Slater & Wilbur, 1997, p. 3). Consequently, immersion can be objectively assessed, based on technical parameters used to describe a system. A VR system can be characterized by a set of valid actions (Slater, 2009), which if executed by the participant will have an effect on the environment (valid effectual actions) or change in perception (valid sensorimotor actions). These actions that are meaningful in terms of perception in the virtual environment are defined by the *sensorimotor contingencies* (SCs) supported by the system. "SCs refer to the actions that we know to carry out in order to perceive" (Slater, 2009, p. 3550). The support of SCs by the system allows the user to perceive and interact with the virtual environment using natural actions (Christofi, Michael-Grigoriou & Kyrlitsias, 2020). For example, if the participant turns their head and the image rendered on the display changes the same way as if it would change in the real world, this is a valid sensorimotor action. To assume that a system has a higher level of immersion from another system, the valid actions of the first system must include at least all valid actions of the second system.

1.2.1.2 Non-Immersive Systems

As mentioned above, VR systems are not designed just to display the virtual environment to users but also attempt to induce the feeling that they are "inside" the environment, and that is what makes VR special. However, the term VR is sometimes used to describe systems that do not have the technical capability to induce the user with the sense of being inside the virtual environment that is displayed by the system. The terms *non-immersive VR* or *desktop VR* are also used to describe these systems. To avoid any misinterpretation with non-immersive systems, the term *immersive virtual reality* (IVR) will be used in this dissertation to describe VR systems.

1.2.1.3 Applications and Benefits of VR

Apart from the fact that VR technologies can simulate environments and situations in a realistic and believable manner, they offer several advantages that make their use very beneficial in various fields.

For example, many of the most widely used and promising VR applications concern training simulations that are used as a training tool for pilots and drivers of various vehicles, dangerous jobs such as mine workers (Bellanca et al., 2019) and the military (Koźlak, Kurzeja & Nawrat, 2013). A key advantage of using VR in these applications is that it provides realistic training conditions in a controlled and therefore, much safer environment, while significantly reducing the cost and increasing the efficiency of the training. Things that cannot be controlled in the physical world, such as the time of day, or are random, such as the weather conditions, in a virtual world are fully controllable. Moreover, VR offers the possibility of repeating scenarios and better evaluating the learner's performance.

The introduction of VR in education can enhance learning outcomes (Merchant, Goetz, Cifuentes, Keeney-Kennicutt & Davis, 2014). VR increases the learners' motivation and involvement. VR allows students to experience rather just watch and listen, in the same time that promotes complex learning (Villena Taranilla, Cózar-Gutiérrez, González-Calero & López Cirugeda, 2019). It gives students an opportunity to explore of objects or events that are not accessible such as the solar system, historical places and events (Villena Taranilla et al., 2019; Kyrlitsias, Christofi, Michael-Grigoriou, Banakou & Ioannou, 2020) or the inside of the human body (Parong & Mayer, 2018; Michael-Grigoriou, Yiannakou & Christofi, 2017). Also, VR can be beneficial for teacher training (Stavroulia et al., 2019).

Immersive virtual reality technologies are used in the fields of health on the part of education and training as well as in various kinds of therapies. The use of simulators in medical education protects patients while offering students a way to develop their skills, knowledge and confidence, as well as for evaluating their performance (Lateef, 2010; Pottle, 2019). Virtual reality therapies (Wiederhold & Riva, 2019) are used in patients with various phobias such as fear of heights (Rothbaum et al., 1995; Seinfeld et al., 2016), claustrophobia (Christofi, & Michael-Grigoriou, 2016; Rahani, Vard & Najafi, 2018), fear of public speaking (Nazligul et al., 2017; Takac et al., 2019), social anxiety (Chesham, Malouff & Schutte, 2018), post-traumatic stress (Botella, Serrano, Baños, & Garcia-Palacios, 2015) and depression (Falconer et al., 2016).

The above are just a few examples of applications of VR technologies in various fields, through which we can distinguish the advantages of this technology. To summarize, VR technologies can provide affordable, realistic, controlled, safe, interactive and accessible experiences to the user.

1.2.2 Virtual Humans

Virtual environments usually include virtual representations of humans called *virtual humans* (VHs). We define a VH as a “perceivable digital representation” of a human (Bailenson & Blascovich, 2004).

VHs are classified into avatars and agents (Bailenson & Blascovich, 2004; von der Pütten et al., 2010), depending on who directs their behavior. An *avatar* is a VH whose behaviors reflect those executed by a specific human being. On the other hand, an *agent* is a VH whose behaviors are determined by the computer algorithm.

However, since today's technology is unable to reflect all human actions on avatars, the distinction between an agent and an avatar is not always clear (Bailenson and Blascovich, 2004). Various forms of communications (e.g., facial expressions, gaze behavior, tone of voice, or body language) that may not be tracked by the system and therefore not attributed to the avatar are omitted or alternatively rendered onto the VH. As a result, a VH usually constitutes a hybrid of an agent and an avatar. However, recent technological advances such as real-time body and facial expression tracking can provide affordable solutions so the behavioral resemblance of the user and the avatar can be extremely accurate. In the near future we expect to have photorealistic avatars whose voices, movements, facial expressions, and gaze are determined completely by the user in real-time.

Additionally, unlike the physical world where there are clear boundaries between human and not human, there are not necessarily any visible differences between human-controlled and computer-controlled VHs (Nowak & Fox, 2018). It is up to the developer of the VR application to conceal or inform (or even mislead) the user whether a VH is an avatar or an agent. Therefore, in a shared virtual environment, the user may not know which of the VHs are agents and which are avatars.

1.2.2.1 Avatars

In IVEs, an avatar is the (usually visual) representation of the user in a virtual world. An avataris perceivable by the user and/or by the other users, in the case of a multi-user virtual environments (Nowak & Fox, 2018). In the case of the self-representation, the users can observe their avatar form either a first-person or a third-person perspective (Gorisse, Christmann, Amato & Richir, 2017), while in some cases the use of avatars is implied or omitted. In CAVE systems, no avatars are required for self-representation since the users can observe their physical body. In HMD based VR settings, users are unable to see their physical body. In these cases, an avatar can be used to provide the users with a virtual body, usually with a first-person perspective. The degree to which the users can control their avatars varies, depending on the capabilities of the VR system. Under some situations (Kilteni, Groten & Slater, 2012), a sense of ownership over the virtual body can emerge to the user, which is called *sense of embodiment*. Studies (Slater & Sanchez-Vives, 2014) showed that people tend to alter their attitudes and behaviors to match the expectations that are implied by the attributes of their virtual body. This phenomenon is known as the Proteus effect (Yee, Bailenson & Ducheneaut, 2009).

1.2.2.2 Agents

With the constant advancement of technology in the fields of computer graphics, machine learning and artificial intelligence (Petrović, 2018), virtual agents are becoming more and more realistic in both appearance and behavior. At the same time, the opportunities and the efficiency of their use increase.

In VR entertainment applications, such as videogames, we refer to VHs that are used as actors in the game environment as non-player characters (NPCs). They act in the game as hostile, friendly or neutral characters to the player. Their behavior is most of the time scripted and limited to the level needed to support their role in the game. However, there are examples of NPCs that are able to interact in more complex ways with the player (Takahashi, Tanaka & Oka, 2018), such as expressing emotions (Li & Campbell, 2010), taking decisions autonomously (Xi & Smith, 2016), and acting independently. The NPCs are a crucial part of a VR game and can drastically impact the user's gaming experience (Petrović, 2018).

Using VR, agents can play the role of the audience in applications for practicing presentation skills and overcoming public speaking anxiety. Individuals can practice their presentations or speeches in an immersive virtual environment that includes real-life conditions. Studies (Nazligul et al., 2017; Takac et al., 2019) have shown that these applications are found to be beneficial in treating social anxiety disorders. Also, the number and the behavior of an audience consisting of agents, are highly flexible and customizable, allowing the gradation of the challenge level using different scenarios (Botella, Garcia-Palacios, Baños & Quero, 2009). In the same way, agents are used in the treatment of various types of phobias using VR. In some examples, agents are used to help, guide, encourage and motivate the patient, replacing the human therapist (Bălan et al., 2020), while sometimes replacing patients in training scenarios for doctors and therapists (Lok et al., 2006; Rizzo & Talbot, 2016), or motivate other patients (Najm et al., 2020). Agents are used as healthcare assistants (Kim et al., 2019) to support registered healthcare professionals in conducting clinical tasks and providing care to the patients. Also, a study (Lucas, Gratch, King & Morency, 2014) showed that VH-interviewers can increase willingness to disclose and elicit more honest responses in a clinical interview context. In educational VR applications, agents have a crucial role, either as teachers or students. Studies showed that using pedagogical (Johnson & Lester, 2018; Makransky, Wismer & Mayer, 2019) agents can improve students' learning experience in an educational VR environment, enhance their engagement and improve their knowledge construction and performance (Grivokostopoulou, Kovas & Perikos, 2020). Also, agents can play the role of students in teacher training scenarios (Stavroulia et al., 2018).

These were just a few examples of how the recruitment of virtual agents can be beneficial in an unlimited range of applications. They can be used in combination with other technologies to replace humans in social tasks efficiently. To summarize, some of the advantages of the use of virtual agents are that they are always available, even for multiple instances at the same moment, affordable, fully customizable and flexible, both on appearance and behavior, and fully controllable.

1.2.3 The Use of Immersive Virtual Reality and Virtual Humans in Research

We have previously referred to the benefits and possibilities that IVR technologies offer as well as to the solutions that these technologies provide in a wide range of fields. Besides that, researchers have come to realize early that IVR can be very useful as a research tool (Foreman, 2009; Blascovich et al., 2002; Tarr & Warren, 2002). In the last two decades, IVR technologies are used for the study of human behavior and cognition in fields of psychology (Wilson & Soranzo, 2015; Pan & Hamilton, 2018) and neuroscience (Bohil, Alicea & Biocca, 2011; Parsons, Gaggioli & Riva, 2017; Bell, Nicholas, Alvarez-Jimenez, Thompson & Valmaggia, 2020). IVR technologies not only can offer researchers solutions in order to address several methodological problems, but they create new research possibilities that were not possible in the past.

With IVR technologies, researchers can achieve realistic and complex environments that simulate accurately the experimental scenario, and therefore, high mundane realism (the degree to which the materials and procedures involved in an experiment are similar to events that occur in the real world; Kelly, 2007). At the same time, IVR provides the capability to induce to the participant the illusion of presence and elicit realistic (similar to real life) reactions (Slater, 2009), achieving high experimental realism (the extent to which situations created in experiments are real and impactful to participants; Kosloff, 2007). This applies also to experiments that include social interactions, through social presence, as subjective feelings, behavioral, and physiological reactions during human-VH interactions can be very similar to those shown during human-human interactions (Bombari, Schmid Mast, Canadas & Bachmann, 2015).

Consequently, VR offers the possibility to conduct experiments with high ecological validity, something that in the past was very difficult and required a high amount of resources to be achieved. For example, in experiments studying social influence, actors trained to maintain the same verbal and non-verbal behavior across sessions were used as confederates (Asch, 1951; Milgram, 1963). These solutions not only lead to more expensive experimental scenarios but are also difficult to implement and can often affect the level of experimental control. And this is one of the main methodological problems for researchers, the tradeoff between ecological validity and experimental control (Blascovich et al., 2002; Kothgassner & Felnhofer, 2020). VR technologies can provide a high level of ecological validity as they can generate stimuli that approximate the complexity of a real-life situation while allowing the investigator for near-perfect experimental control (Parsons, 2015; Bombari et al., 2015). The high level of experimental control and the flexibility offered to the experimenter by VR technologies "enables the researcher to selectively manipulate variables that in naturalistic situations cannot be independently investigated" (Parsons, 2015, p. 7).

In addition, using VR makes replication of studies easier. According to Blascovich et al. (2002), in domains such as social psychology, one of the reasons for the lack of replications is the difficulty for a researcher to implement and use the exact methods and procedures of other investigators. VR technologies, however, enables researchers to conduct perfect (or at least near-perfect) replications (Bombari et al., 2015).

Finally, using VR, researchers can conduct experiments with scenarios that are impossible (e. g., Friedman et al., 2014) or unethical (e.g., Gonzalez-Franco et al., 2018; Neyret et al., 2020) to be tested in real life. This is possible because participants react to virtual characters and events as if they were real, and at the same time they remain aware that there is no real danger and consequences as a result of their actions (Pan & Hamilton, 2018). For example, perception and behavior in dangerous or threatening situations can be studied, without participants being exposed to real danger (Kinateder et al., 2015; McCall, Hildebrandt, Bornemann & Singer, 2015). Even though the main effort in research and development focuses on the best possible simulation of the real world, VR has the possibility of going beyond the limits of physical reality (Slater & Sanchez-Vives, 2016). Rules that exist in the "real" world do not necessarily exist in a virtual world. The physical laws, the time continuity (Friedman et al., 2014), human body characteristics and limits (Slater & Sanchez-Vives, 2014) are manipulatable by the researcher, creating new research opportunities. For example, in a recent study (Friedman et al., 2014) the participants were given the illusion of traveling back in time, having the ability to prevent a tragic event in which they were present.

Using VR, researchers are able to dramatically alter the participants' self-representation by inducing them a sense of embodiment towards a virtual body with different characteristics. This ability created a wide range of opportunities for investigating the impact of self-representation on the individual's attitudes and behaviors (Maister, Slater, Sanchez-Vives & Tsakiris, 2015). Even if in experiments with such manipulations the ecological validity is typically low, researchers can investigate the interaction with different variables and expand the theoretical understanding of human cognition and behavior (Bombari et al., 2015). For example, a study (Yee & Bailenson, 2007) showed that participants embodied in taller avatars were more confident in a negotiation task (the ultimatum game; Forsythe, Horowitz, Savin & Sefton, 1994) with an agent confederate. A study by Kilteni et al. (2013) showed that participants embodied in a dark-skinned, casually dressed, virtual body expressed significantly greater body movement in a task that required playing drums than participants embodied in a light-skinned, formally dressed, body. This result was attributed to the stereotype that a dark-skinned, casually dressed, are expected to be more bodily expressive. Other studies (Peck, Seinfeld, Aglioti & Slater, 2013; Maister, Sebanz, Knoblich & Tsakiris, 2013) showed that embodiment in a dark-skinned body resulted in a reduction of the implicit racial bias towards dark-skinned people. Also, a study found that the impact on implicit racial bias remained even a week after the participants' embodiment experience (Banakou, Hanumanthu & Slater, 2016).

To summarize, VR technologies became a powerful tool for researchers and studying human behavior. They can provide a series of advantages, such as realistic and complex experimental scenarios with almost perfect experimental control of the environment and the VHs, allowing researchers to overcome methodological problems. Additionally, they create new research opportunities for testing scenarios that are difficult or even impossible to be conducted in real life settings.

2 Background Knowledge

2.1 Social Interaction with Virtual Humans

Numerous studies show that people react socially to VHs. While an individual interacts with an avatar (or believing that it is an avatar), social responses are expected, because such an interaction is perceived to be a human-human interaction mediated by the technology (Nowak & Fox, 2018). But why do individuals respond socially even if they know (or believe) that they are interacting with an agent, directed by a computer? Several theories attempt to explain social effects in interactions with computers. Earlier theories suggested that individuals socially react to computers temporarily due to the novelty of the situation (Kiesler & Sproull, 1997), or due to human deficits such as ignorance (Barley, 1988). Another approach suggests that social reactions are oriented towards the programmer rather than the computer itself (Dennett, 1987). However, the above theories have not been adopted and have become obsolete. The prevailing theory (Nass, Steuer & Tauber, 1994; Nass & Moon, 2000), known as the *computers are social actors* (CASA) paradigm, supports that social responses to computers result neither from the users' belief that they are interacting with the programmer nor from ignorance. Instead, the CASA paradigm argues that people unconsciously react to computers in the same way as they do towards humans. This can be attributed to the fact that the human brain is developed to automatically respond to social cues in order to deal successfully with daily life (Reeves & Nass, 1996). Since the computer provides social cues, people will treat them in a social way, and more specifically, "the more computers present characteristics associated with humans, the more likely to elicit social behavior" (Nass & Moon, 2000, p. 97).

2.2 Presence

The use of VR technologies in a wide range of fields as well as the use of VHs in many of these applications were discussed in the previous section. A crucial factor for the effectiveness of many of these applications is that the user perceives and responds to the events and situations taking place in the virtual environment as if they were real. Empirical studies have explored factors that contribute to realistic behavior in immersive virtual environments, while various theories have attempted to explain this phenomenon. Most of these theories are based on the concept of *presence*, the sense of "being" in the virtual environment, also referred to as telepresence or place illusion (IJsselsteijn & Riva, 2003; Sanchez-Vives & Slater, 2005; Slater, 2009). Slater (2009) defines presence as "the strong illusion of being in a place in spite of the sure knowledge that you are not there" (p. 3551).

Although it is strongly related to immersion (Slater, 2003), presence is a subjective perception determined by how the person perceives and interprets stimuli, defined by characteristics of the VR system and the level of immersion (IJsselsteijn & Riva, 2003). Consequently, two people may not experience the same level of presence with the same degree of immersion (Slater, 2009). This difference may be caused by their actions in order to perceive and interact with the environment (e.g. one moves in space and the other does not), and/or individual differences. The perceptual and effective actions can affect presence positively if they are valid (supported by the system) or negatively if not. For example, in a system with full body tracking, if the participant attempts to push a glass from the table with his hand and causes the glass to fall (valid effective action), this action will positively affect presence. If the participant does not attempt to push the glass, this feature of the system does not affect presence. Conversely, if the participant attempts to push the glass but his virtual hand passes through the glass without any effect (the system does not provide this feature), the sense of presence is affected negatively. But, this break in presence illusion does not occur if the participant does not attempt to push the glass, although this function is not offered by the system. The sense of presence may vary due to individual differences. For example, a study (Felnhofer, Kothgassner, Beutl, Hlavacs & Kryspin-Exner, 2012) showed that gender is a mediating factor, as men reported that they experienced significantly higher presence than women. The sense of presence is created by the person who experiences it, within the limits imposed by the system. System characteristics determine the boundaries (Slater, 2009) into which the person creates the illusion of presence and if these boundaries are exceeded, a break in presence occurs.

Presence has been the main focus of both applied and academic work on VR as it is associated with the effectiveness of a VR experience. The greater the sense of the user's presence in the virtual environment, the more realistic (similar to the real world) their reactions and behaviors are and, in turn, the more successful the VR application is (Cummings & Bailenson, 2016).

2.3 Social Presence

As described above, VR is capable of inducing to the users a sense of presence, which is the feeling of being in the virtual environment. The greater the sense of the user's presence in the virtual world, the more realistic (similar to the real world) their reactions and behaviors are. However, the sense of “being there” is not enough for a realistic perception and reaction towards VHs (Lee, Jung, Kim & Kim, 2006). In virtual environments, where the user coexists with VHs, it is important that the user perceives the presence of the VH not only physically, but also socially. *Social presence* (also referred to as co-presence) refers to the extent to which the user actively perceives a VH in a virtual environment and at the same time has the sense that the “other” perceives the presence of the user (Biocca, 1997; Oh, Bailenson & Welch, 2018). While presence describes the illusion of “being” in a virtual space that may include VHs, social presence refers to the experience of “being together” with a sentient social being, either an agent or an avatar (Biocca, Harms & Burgoon, 2003).

Social presence is important due to the impact it has on social influence (Blascovich, 2002) and is associated with a variety of positive communication outcomes (Oh et al., 2018). For example, the results of a study (Thellman, Silvervarg, Gulz & Ziemke, 2016) demonstrated the effect of social presence on social influence by VHs. Specifically, participants who reported a stronger social presence were more inclined to accept the VH’s offer in an ultimatum game. The impact of social presence on social influence is demonstrated by other studies (e.g., Hoyt, Blascovich & Swinth, 2003; Strojny, Dużmańska-Misiarczyk, Lipp & Strojny, 2020). Consequently, the greater the sense of the user's social presence for a VH, the more realistic (similar to human-human and face-to-face) their social reactions are. This makes social presence a vital component for the realism and the effectiveness of social interactions between the user and VHs in VR environments. Also, studies (Guimarães et al., 2020; Schroeder et al., 2001; Heldal et al., 2005) showed that the participant’s sense of social presence to VHs was higher for immersive VR compared to a non-immersive platform. This finding indicates the advantage of VR over non-immersive technologies in simulating social interactions with VHs.

2.4 Factors Affecting Social Interaction with Virtual Humans

The benefits of recruiting VHs in a wide range of applications are reviewed in a previous section. The effectiveness of these applications usually requires that the user perceive and interact with VHs as if they were real humans. For that reason, the investigation of the factors that enhancing social presence and increasing social influence with VHs has attracted great interest by the researchers. An overview of the main findings regarding the factors that affecting the social interaction with VHs are reviewed in this section.

2.4.1 Representation of the Virtual Humans

The way that VHs look and behave varies between different VR applications. These variations are due to the different capabilities of the VR systems regarding graphical quality and the interactivity, the effort and the skill the creators of the VR applications to provide convincing VHs, but also on the nature and purpose of the VR application. This results in VHs with different levels of realism. Several studies were conducted in order to investigate the impact of the VHs' visual and behavioral realism on social interactions.

2.4.1.1 Visual Realism

While studies showed that the presence of a VH's visual representation leads to higher level of social presence compared to the absence of any visual representation (e.g., voice only), the effect of VHs' visual (photographic and anthropomorphic) realism is not consistent (Oh et al., Bailenson & Welch, 2018). For example, a recent study (Zibrek, Martin & McDonnell, 2019) investigated the level of a VH's visual realism using thee render styles: realistic, simple and sketch style. The results showed that the level of a VH's visual realism did not have an impact on the participants' sense of the social presence of the VH. The impact of visual realism on participants' emotional response was attributed to the fact that realistic rendering of the VH's facial expressions was more perceivable compared to the less realistic rendering, which is not directly associated to the level of realism.

2.4.1.2 Behavioral Realism

In contrast with visual realism, the VH's behavioral realism consists of an important factor for social interactions and a powerful predictor of social presence (Oh et al., 2018). *Behavioral realism* refers to the extent to which a VH behaves in the way an actual person would behave. Several studies showed that increasing the VH's behavioral realism leads to a stronger sense of social presence, especially when the VH's behavior indicates awareness of the user's presence (e.g., mutual gaze) and provides interactivity. The interactivity of a VH behavior is an important factor for creating social presence (Oh et al., 2018) as it gives the impression that the VH is aware of the user's presence and actions. For example, a study (von der Pütten et al., 2010) showed that participants felt higher levels of social presence, mutual awareness and talked more when the VH show feedback behavior (head nodding) than when the VH did not show any feedback behavior. Another study (Guadagno, Blascovich, Bailenson & McCall, 2007) showed that VHs with more realistic gaze behavior led to a higher sense of social presence. Additionally, male participants reported more attitudes change after interacting with male-like VHs with behavioral realism compared to male-like VHs with lower behavioral realism. A study (Pan, Gillies Slater, 2008) focused on the effects of a VH's blushing during an embarrassing situation on participants' reaction. Especially, the effects of no blushing, cheek blushing and whole face blushing were compared. The results of the study showed that VHs whole-face blushing improved participants' degree of social presence, while participants in the cheek blushing condition tended to withdraw earlier from the VH's presentation.

2.4.1.3 The uncanny valley

Additionally, the *uncanny valley* theory (Mori, MacDorman & Kageki, 2012) that initially referred to humanoid robots but also applies to VHs, suggests that the relation between a VH's realism and the perceiver's affinity for it are not linear. Instead, as VHs appear more human-like, they become more appealing up to a certain point. When a VH looks and moves to an almost life-like degree, but not yet as a human, it is perceived as creepy and unsettling. Only when the realism of a VH is fully convincing will elicit positive responses. Consequently, this effect can have a negative impact on social interactions with VHs (Nowak & Fox, 2018). The results of a study (Groom et al., 2009) support the uncanny valley theory, as the VH received lower evaluations by the participants when exhibited more realistic behavior (i.e., lip synch and body movement). The persuasiveness of the VH is not affected by the level of realism.

2.4.2 Agency

Agency is the extent to which the user believes that a VH is controlled by another user (avatar) rather than a computer through an algorithm (agent). When the user has the impression that a VH is controlled by another user, the level of agency is high. Instead, when the user believes that a VH is controlled by the computer, the level of agency is considered to be low. It is important to be stated that the level of agency describes the user's perception of the VH as an agent or an avatar, rather than the VH's actual state (Fox et al., 2015). Additionally, agency is a continuum, as individuals perceive a VH to be partially controlled by a human and the computer (Blascovich, 2002).

The impact of agency on social interactions with VHs is not clear in the literature. According to the CASA theory, the responses to computers that exhibit human characteristics, are mindless and automatic (Reeves & Nass, 1996; Nass & Moon, 2000) and, therefore, people will respond socially to VHs regardless of the level of agency. On the contrary, the *Threshold Model of Social Influence* (Blascovich, 2002; Blascovich et al., 2002) argues that agency, along with behavioral realism, are the major factors that affects social presence.

According to the Threshold Model of Social Influence, an increase in agency and/or behavioral realism leads to the increase of social presence. If/when social presence meets a threshold value, social influences begin to operate. Specifically, when the user believes that the VH is controlled by the computer (low agency), the VH must behave very realistically in order for the social influence threshold to be met and social influence to occur. If the individual believes that the VH represents a real person (high agency), then behavioral realism does not need to be high to cause a social reaction. According to the authors, the location of the social influence threshold varies as a function of two moderating factors which are the *interpersonal self-relevance* and the *response system*. Interpersonal self-relevance is the importance of the interaction to the individual’s sense of self. In a social interaction that requires a discussion of one’s beliefs and attitudes (e.g., participating in a job interview) the interpersonal self-relevance is expected to be high. In social interactions that do not involve central or core aspects of an individual (e.g., making a small withdrawal from a bank) the interpersonal self-relevance is expected to be low. According to the model of social influence, when self-relevance is low, the threshold’s slope is shallow, which means that lower behavioral realism is required for social influence to occur. Instead, in high self-relevance interactions the slope is steep and, therefore, higher behavioral realism is required for the threshold to be crossed and social influence to occur. The second factor that moderates the social influence threshold is the level of the behavioral response system of interest. For low-level response systems such as unconscious reflexes, the threshold is lower compared to high-level response systems such as verbal communication. Therefore, a lower level of agency and behavioral realism is required for low level, implicit or automatic social responses than for high level response systems involving purposeful and conscious actions.

Several studies explored the impact of agency on social interactions with VHs. The perceived agency was manipulated generally by introducing the VH as an agent or an avatar prior to the interaction. For example, a study by Guadagno, Swinth and Blascovich (2011) examined the social evaluations (i.e., empathy and positivity) for a virtual peer counselor, who was introduced as either an agent or an avatar. The VH had two levels of behavior (i.e., smile and not smile). The results showed that the VH’s smile affected the social evaluations, however, the level of agency moderated this effect. Specifically, the social evaluations were enhanced by the smile behavior for participants in the low agency condition but were degraded in the high agency condition. Using two experiments, de Melo, Gratch and Carnevale (2014) examined the effect of the VH’s emotional expressions on participants’ behavior. The results of the first experiment showed that the participants collaborated more with the VH who exhibited collaborative instead of competing expressions in a social dilemma, and this effect was more intense in the high agency condition. In the second experiment, the participants who were led to believe that they were interacting with an avatar conceded more in a negotiation task when the VH showed angry expressions. Instead, in the low agency condition, the participants conceded the same regardless of whether the VH showed neutral or angry emotions. The results of a study (Felnhofer et al., 2018) that examined social avoidance tendencies and prosocial behaviors towards VHs were contradictory regarding the impact of agency. While presence, social presence, social interaction anxiety and stress were not affected by agency, participants in the avatar condition showed more social avoidance and prosocial behavior. The results of a study by von der Pütten et al. (2010) showed no effect of agency on participants' social behavior and evaluations.

As shown above, there are several examples in the literature aiming to compare the usage of agents versus avatars with many studies proving that avatars affect the social behavior of participants to a greater extent than agents, whereas others demonstrated no significant difference between the two. A meta-analysis by Fox et al. (2015) showed that perceived avatars produced stronger responses than perceived agents. A systematic review (Oh et al., 2018) reported that approximately half of the studies surveyed showed an impact of agency on social presence, while in the remaining half of the studies the participants perceived similar levels of social presence regardless of the level of agency.

2.4.3 Level of Immersion

Regarding social presence, the level of immersion does not seem to be as crucial as it is for presence (Oh et al., 2018), although some studies (Schroeder et al., 2001; Heldal et al., 2005) showed that participants reported stronger sense of social presence when using an immersive compared to a non-immersive platform. However, a recent study (Bailey et al., 2019) showed that children in an IVR condition demonstrated grater social influence (compliance) from a virtual character than children in a non-immersive condition, suggesting that IVR may elicit differential cognitive and social responses compared to less immersive technologies.

2.5 Conformity with Virtual Humans

Several experimental studies examined how social pressure from a group of VHs can elicit conformity behavior. In the majority of these studies, the VHs was presented using non-immersive technologies such as desktop PCs and robots, while a couple of studies used IVR technologies. An overview of these studies is presented below.

2.5.1 Conformity in Non-Immersive Environments

A study by Rayborn-Reeves, Wu, Wilson, Kraemer and Kraemer (2013) replicated the Asch experiment in Second Life, an online application that enables users to create virtual representations of themselves (avatars) and interact with other users in a virtual space. Participants were given a series of perceptual judgment trials in which they chose one out of three stimuli that matched the length of a target stimulus. The target stimulus appeared on the screen for 3 seconds and then disappeared. Participants were tested either alone or with three other confederates. The confederates in that study were avatars, controlled by other users, and the participants were aware of that. The participant and the confederates were expressing their choices by moving their avatar towards one of three rugs corresponding to the three comparison lines. In two of the trials, named critical trials, the confederates unanimously chose an incorrect answer before the actual participants made their choice. The results showed that the participants conformed with the confederates' wrong choice in the first critical trial but not in the second one.

A study by Midden, Ham and Baten (2015) compared conformity within a group of real people, a group of boxed PCs and a group of VHs previewed through computer screens. In the PCs and VHs conditions, a web camera was attached to each computer in order to stimulate the capability of the computer to see the stimulus. A similar procedure to the classic Asch paradigm was used. The results showed conformity within the group of people but not with computers and agents. In a follow-up study, a similar procedure was followed, but this time, without including a group of real people. The effect of task difficulty has also been studied. In the low difficulty condition the comparison lines remained visible, as opposed to the high difficulty condition in which the tasks appeared for a short period of time (3.5 seconds). The results showed that in the high task difficulty condition, participants conformed to the group of PCs and VHs. However, no differences in the level of conformity between the PCs and the VHs conditions were observed.

A study by Hertz and Wiese (2016) investigated whether VHs can influence human decision making. Three levels of human-likeness were used for the VHs (i.e., computer, robot and human). The VHs' images were displayed on a computer screen. In contrast with similar studies, a group size of zero (i.e., only one VH) was used. Participants were asked to respond to the line length comparison task based on the classic Asch paradigm. Then, after the VH's response was presented on the screen, participants had the opportunity to change their initial response. Each participant performed the tasks with all three types of VHs, either in the high task difficulty or in the low task difficulty condition. In the high task difficulty condition, the stimuli were presented for 400ms while in the low task difficulty the stimuli were presented for 1000ms. The results showed greater conformity in the high task difficulty condition. Conversely, no effect of human-likeness on conformity was observed.

2.5.2 Conformity in Immersive Virtual Environments

A study by Swinth and Blascovich (2001, as cited in Blascovich, 2002) examined conformity in terms of risk-taking behavior in virtual environments. Initially, the participants immersed in a virtual casino played a round of 20 hands of blackjack alone with the dealer, and then, they played a second round with two other players. The other players' bets were manipulated to be either lower, the same, or higher than the participant's average bets in the first round. The results showed that participants conformed with the other players by increasing and decreasing their bets in the higher or lower condition respectively.

In a study by Bailenson et al. (2008), the impact of virtual co-learners' behavior on the participants' behavior in a virtual classroom was tested. The participants were randomly assigned in one of the three experimental conditions. In the first condition, the virtual classmates exhibited a positive learning behavior such as looking at the teacher and taking notes. In the second condition, the classmates showed a negative learning behavior such as watching outside the class at destructive events or looking at their watches. In the third-control condition, no other virtual students were in the classroom. The results showed that participants in the second condition (distracting behavior) performed better in a test regarding minor details in the virtual classroom than in a test regarding the lecture. Instead, in the other two conditions (control and positive), the participants performed better in the lecture related test than in the classroom related test. This result suggests that the VHs' behavior can influence learning performance in an immersive VR classroom.

2.6 Conclusions of the Literature Review

In this section, an overview of the theoretical background of social interaction with VHs was presented. Additionally, basic concepts, such as social presence, that are related for studying human-VH interactions, as well as the most important factors that impact social effects towards VHs according to the literature, have been reviewed. The literature suggests that conformity can occur not only with human majorities, but this effect is expanded with a group of VHs as in immersive as well as in non-immersive scenarios. However, these results are limited to informational conformity. While studies using groups of humans demonstrated conformity caused by normative influence, failed to replicate this effect using groups of VHs in a non-immersive setup (Midden et al., 2015), suggesting that conformity with artificial majorities can be caused only by informational influence. However, studies (e.g., Bailey et al., 2019) suggesting that IVR may elicit differential cognitive and social responses compared to less immersive technologies. Using IVR, the effects of human-VH interactions can be very similar to those of human-human interactions (Bombari et al., 2015). Despite that, only two studies (Swinth & Blascovich, 2001, as cited in Blascovich, 2002; Bailenson et al., 2008) have been conducted to demonstrate conformity with a group of VHs in IVR. Additionally, the factors that are important on social interactions with VHs, such as the VHs' behavioral realism and the level of agency, have not been studied in terms of their effect on conformity. Finally, social presence, the sense of "being together" with a sentient social being, is considered in the literature as the "absolute good" for emulating face-to-face communications (Oh et al., 2018). Many examples in the literature demonstrated the importance of social presence in replicating social effects with VHs. However, the relation of social presence and conformity has not been tested.

3 This Study

3.1 Aim of the Study and Research Questions

This study investigates social conformity with VHs within IVEs. The use of IVR and VHs are used in a wide range of applications due to the several advantages they offer, as reviewed in Sections 1.2.1.3 and 1.2.2. Empirical evidence showed that social interaction with VHs, avatars or agents, may elicit social influence on individuals, similar to human-human interaction, as explained in Section 2.1. Conformity, an indirect but powerful form of social influence, can impact an individual's behavior and decision making, as described in Section 1.1. However, the evidence that VHs can cause normative or informational conformity within IVEs is limited in the literature (see Section 2.5.2). The first aim of the study is to provide empirical evidence of normative and informational conformity with a majority of VHs within IVEs. Additionally, this study aims to study the impact of several factors on conformity with VHs.

Social presence, the sense of being there with others, is considered an important factor for the prediction of social effects in IVEs. Specifically, as explained in Section 2.3, the higher the user's sense of social presence towards a VH, the more realistic (similar to human-human) the effects of the interaction are. This study aims to investigate the relationship between social presence and conformity with a group of VHs in IVEs.

The impact of agency, the extent to which the user believes that a VH is an avatar rather than an agent, on social interactions with VHs remains disputed in the literature. According to the CASA theory (Nass & Moon, 2000), the social reactions towards VHs are automatic and implicit and, therefore, the level of agency does not have an impact on social influence. According to the threshold model of social influence (Blascovich, 2002), agency is an important factor for social influence for VHs in IVEs, as it claims that people are more likely to react socially to a VH when they believe that it is represented by a real person. Empirical studies on the impact of agency on social effects on human-VH interaction are also divided. However, the impact of agency on conformity with VHs has not been tested in the literature. More information about agency is available in Section 2.4.2. This study aims to investigate the impact of agency on conformity with a group of VHs in IVEs.

Another factor that is considered important in social interactions with VHs, is the level of the VHs' behavioral realism, the extent to which a VH behaves in the way an actual person would behave. Literature suggests that the higher the realism of the VH's behavior, the higher the sense of the user's social presence is and the stronger the social effects are. More information about behavioral realism is available in Section 2.4.1.2. One of the aims of this study is to investigate the impact of VHs' behavioral realism on conformity in IVEs.

To address the objectives set for this study the following research questions (RQs) and hypotheses were formulated:

RQ 1: *Can social pressure from a group of VHs in an IVE lead to normative conformity?*

Hypothesis 1: Social pressure from a group of VHs in an IVE will lead to normative conformity.

RQ 2: *Can social pressure from a group of VHs in an IVE lead to informational conformity?*

Hypothesis 2: Social pressure from a group of VHs in an IVE will lead to informational conformity.

RQ 3: *Does the level of agency affects conformity with a group of VHs in an IVE?*

Hypothesis 3: The conformity with VHs in an IVE will be stronger when the participants believe that they are interacting with avatars rather than agents.

RQ 4: *Does the level of VHs' behavioral realism affects conformity in an IVE?*

Hypothesis 4: The conformity with VHs in an IVE will be stronger when the VHs exhibit higher behavioral realism.

RQ 5: *Does the sense of social presence affects conformity with VHs?*

Hypothesis 4: The conformity with VHs in an IVE will be stronger for participants who will experience a stronger sense of social presence.

3.2 Contribution of the Study

This study aims to contribute both on a theoretical and applied level. Studying conformity with VHs requires a theoretical background from different scientific fields which are VR and computer graphics, social psychology, as well as human-computer interaction. Social conformity is an important form of social influence that attracted great research attention and was widely studied since the Asch (1951) experiment. However, regarding VHs in IVEs, conformity did not receive as much focus as other forms of social influence, such as persuasion and obedience. On the contrary, the literature on conformity with VHs is limited and superficial. At a theoretical level, the results of this research will expand the existing literature with additional knowledge in the relevant fields, by providing a more in-depth understanding of human-VH interaction.

Additionally, at the applied level, the outcomes of this study will be useful for designing immersive VR applications involving social interaction with VHs. As reviewed in a previous section, immersive VR and VHs are used already in a wide range of fields, from serious applications such as healthcare assistance and training to educational applications and entertaining computer games. Better understanding of the interaction with VHs in IVEs, and more specifically on how VHs can influence the users' decision making and behavior is important for the design, use, and effectiveness of these applications.

Finally, the understanding of human-VH social interaction is an important prerequisite for the use of VR technologies as a research tool in social psychology. As explained in a previous section, immersive VR became a very useful research tool for researchers in fields such as social psychology and neuroscience, due to the several advantages over traditional methods. However, the understanding of social interactions with VHs in IVEs, and how these can realistically resample the interactions with humans in the real world, is crucial for the validity and the effectiveness of the experimental procedures and the generalization of the results.

3.3 Methodology

This study focused on social conformity with VHs within IVEs. For the investigation of conformity with VHs within IVEs and the answering of the research questions formulated and explained above, a series of three experiments were conducted. This section provides an overview of the materials and methods employed in the experiments that are conducted in this study. Brief information on these experiments can be found in Table 1. More detailed information about the materials and methods for each experiment is provided in the relevant section of each experiment.

3.3.1 Overview of the Experiments

The first experiment (Experiment 1; Kyrlitsias & Michael, 2016; Kyrlitsias & Michael-Grigoriou, 2018) reported in this study (Section 4) is an immersive VR version of the classic Asch (1951) experiment. The aim of this experiment was to investigate whether social pressure from a group of VHs in an IVE can lead to normative conformity, which corresponds to the RQ1. A simple between-group experimental design was used where participants were randomly assigned in either the social pressure or the no social pressure condition. In the social pressure condition, the virtual confederates gave the wrong answer in 8 out of the 12 trials. The no social pressure condition was used as a control condition where the virtual confederates gave the correct answer in all trials. The data collected in this experiment consisted of the participants' answers in each trial, the response time for each trial, as well as questionnaire data. The results showed that the participants did not conform to the virtual confederates' false answers. However, the social pressure for VHs affected the participants' response time.

The aim of the second experiment (Experiment 2; Kyrlitsias & Michael-Grigoriou, 2018) reported in this study (Section 5) was, similarly to Experiment 1, to investigate whether social pressure from a group of VHs in an IVE can lead to normative conformity, which corresponds to the RQ 1. Additionally, the impact of agency and behavioral realism on conformity was examined. The assessment of whether the level of agency and behavioral realism affects conformity within a group of VHs corresponds to RQ 3 and RQ 4, respectively. This study is based on a 2 (social pressure) × 2 (agency) × 2 (behavioral realism) between groups experimental design, where each participant was randomly assigned to one of the conditions. The data collected were similar to those of

Experiment 1. The results of the experiment showed that normative conformity can be caused by VHs within IVEs. However, no effect of agency and behavioral realism on conformity was observed. No relation between social presence and conformity was observed (RQ 5). The sense of social presence was higher on participants in the high behavioral realism condition. The agency manipulation does not affect social presence.

The third experiment (Experiment 3; Kyrlitsias, Michael-Grigoriou, Banakou & Christofi, 2020) reported in this study (Section 6) investigated whether social pressure from a group of VHs in an IVE can lead to informational conformity, which corresponds to the RQ 2. Additionally, the impact of the VHs behavioral realism on conformity was examined (RQ 4). A between-group experimental design was used, and participants were randomly assigned to one of the two conditions, the high behavioral realism, or the low behavioral realism condition. In this study the level of conformity was calculated between social pressure and no social pressure trials. In order to focus on informational conformity, the task difficulty was increased in relation to the previous experiments by limiting the trial card projections' duration. Limiting the of stimulus projection duration is a common way for increasing the task difficulty (Midden et al., 2015). In addition to the data collected in the first two experiments, in this study, the participants' self-esteem and their gaze behavior were recorded. The results showed that social pressure from a group of VHs can lead to informational conformity as participants gave significantly more incorrect responses to the trials in which the agents also gave an incorrect response, compared to those trials in which the agents gave correct answers. However, no impact of the virtual confederates' behavioral realism on conformity was observed, even if the participants in the high behavioral realism condition reported a higher sense of social presence (RQ 5).

Table 1: Overview of the experiments

	N	Type of Conformity	Type of the Task	Independent Variable(s)	Dependent Variables	RQs
Experiment 1	22	Normative	Objective	Social Pressure	Conformity Level, Reaction Time	RQ 1
Experiment 2	52	Normative	Objective	Social Pressure, Agency, Behavioral Realism	Conformity Level, Reaction Time	RQ 1*, RQ 3, RQ 4, RQ 5
Experiment 3	38	Informational	Objective (higher difficulty)	Social Pressure (within subjects), Behavioral Realism	Conformity Level, Reaction Time, Look at Duration, Mutual Gaze Duration	RQ 2*, RQ 4, RQ 5

* RQ supported

4 Experiment 1: Replication of the Asch Experiment using Immersive Virtual Reality

The primary aim of Experiment 1 was to investigate normative conformity within a group of VHs in an IVE. To test that, we followed a procedure similar to the original Asch (1951) experiment, using the line-length comparison task. We designed an IVR version of Asch's experiment, with five VHs as confederates.

4.1 Experiment 1 Methodology

4.1.1 Experimental Design

A VR version of the Asch experiment with a between group experimental design was conducted. Each participant was assigned either to the No Social Pressure condition, where the participant's avatar was in the virtual room alone (Figure 1, top), or the Social Pressure condition, where the participant's avatar was in the virtual room with five agents (Figure 1, bottom). The participants observed the virtual environment from a first-person perspective of their avatar. Each participant experienced one session of the experiment with 12 trials in total per session (Figure 2). Each trial was a simple visual test with line length comparison. The trial cards with the lines appeared on two boards in the virtual environment. A video showing the two experimental conditions can be found at this link: https://youtu.be/M_fNnL8APzM.

Figure 1: The virtual environment in the control group (top) and the experimental group (bottom) used in Experiment 1

In the Social Pressure condition, the participant and the five confederates were answering in turn to each trial. The participants' avatars were always positioned at the end of the row; thus, their turn to respond was coming up after they were listening to the answers of all five virtual confederates.

The five confederates gave a wrong answer on 8 out of the 12 trials, whereas the rest gave the correct answer (Table 2). The visual test of each trial was predefined, and the trials appeared in the same order in all sessions. The answers of the confederates were also predefined and always unanimous.

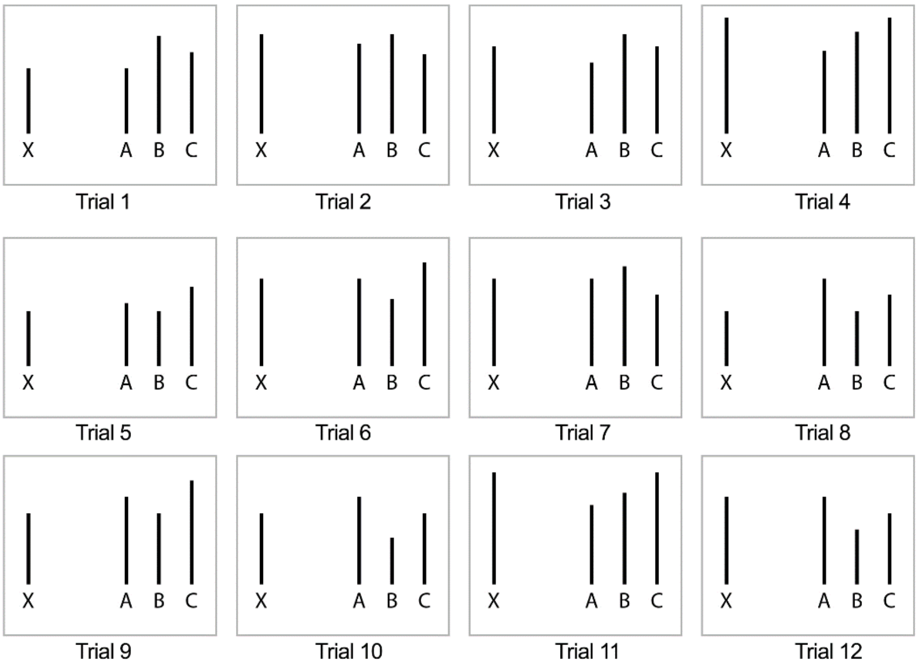

Figure 2: The 12 trial cards used in Experiment 1 and Experiment 2

A label with a number on it was placed in front of each participant (the participant's avatar and the five agent confederates) in order to make clear to the participant when it was their turn to give an answer. The numbers on the labels indicated the order in which the participants (i.e., the participant of the experiment and confederates) should give their answer. To make the order even clearer, a lamp was placed in front of each one and it was lit when they had to give their answers.

In the No Social Pressure condition, the setup, the process, and the trials were identical to the Social Pressure condition besides the fact that there were no agent confederates in the virtual room.

Table 2: Visual tests' trial number with the correct answers and the answers given by the confederates in Experiment 1 and Experiment 2

Trial number	1	2	3*	4	5*	6*	7*	8*	9*	10*	11	12*
Correct answer	A	B	C	C	B	A	A	B	B	C	C	A
Agents' answer	A	B	A	C	C	B	B	C	A	B	C	C

* Critical trials.

This experiment focused on normative conformity. As explained in Section 1.1, as a result of normative conformity, the individuals change their behavior to avoid rejection and to be liked or accepted by the group, but they maintain their opinion privately. For that reason, we used an obvious and undeniable task, so a possible distortion on the participants' responses in the Social Pressure condition in function with the absence of responses in the No Social Pressure condition can be attributed on normative rather than on informational influence. The only reason that a distortion on the participants' responses in the Social Pressure condition can be attributed to informational conformity, is that is that doubts to be emerged to the participants about the objective of the task. To avoid this possibility, detailed instructions were given to participants explaining the objective. To confirm that, after the experiment, the participants were asked to evaluate the extent to which they understand the objective (see Section 4.1.5).

4.1.2 Virtual Humans

The five virtual confederates were represented by two male-like and three female-like VHs. Each agent had two animation clips. The first clip was played repeatedly. It included small movements that gave a feeling of liveliness to the characters. The second animation clip was playing while the virtual confederates were giving their answers. The voices used for the confederates were recorded in advance.

The participant’s avatar was selected in advance by the experimenter for each session, between a male-like and a female-like character, depending on the gender of the participant (Figure 3). The user's avatar was not animated. However, the movement of the participant's head was tracked by the tracker integrated into the HMD, and it was mapped to the virtual camera. The camera was in a position where the participant could see through the eyes of the avatar. In this way, the participants, by moving their head around, could observe and explore the environment, their virtual body, and the virtual confederates.

Figure 3: The male-like and the female-like VHs created and used as participants' avatar

4.1.3 Technical Setup

The experiment was performed using a PC equipped with an NVidia GeForce GTX 770 graphics card[1]. The setup included an Oculus Rift DK2 HMD[2] for 3D immersive viewing and head tracking. The application was created using the Unity[3] game engine and the environment using Autodesk Maya[4] and Adobe Photoshop[5]. The virtual characters were designed and rigged using Autodesk Character Generator[6].

4.1.4 Procedure

After being informed about the experiment, the participants signed a consent form. After that, they completed the pre-VR questionnaire with demographics and virtual environments/computer games literacy and with a question if they suffered from a vision problem. Then, they were given written instructions concerning the process.

[1] https://www.nvidia.com/geforce/

[2] https://www.oculus.com/

[3] https://unity.com/

[4] https://www.autodesk.com/products/maya/

[5] https://www.adobe.com/products/photoshop.html

[6] https://www.autodesk.com/products/character-generator/

After the HMD and the headphones were fitted on each participant (Figure 4), the experimenter started the application.

The participant observed the IVE from a first-person perspective of his avatar while sitting in front of a desk in a virtual room. In the case of the Social Pressure condition, the participant's avatar was sitting next to the five virtual confederates, whereas in the case of the No Social Pressure condition, no other VH besides the participant's avatar was in the room. The application started with a familiarization phase, where participants had 60 seconds to visually explore the environment, the virtual room, their virtual body, and the virtual confederates; the latter only in the case of the Social Pressure condition.

After the familiarization phase elapsed, the first trial card appeared on the boards and the agents began to respond in turn. The virtual confederates were programmed to answer in 3 seconds after the previous confederate completed their answer. The participants had no evidence about whether the confederates are controlled by real people or not. Once the participants stated their answer for each trial, the researcher noted their answer and the process continued with the next trial. The virtual confederates responded correctly in four of the trials (trials 1, 2, 4, 11). In the remaining eight trials, their responses were wrong (Table 2).

After the completion of all trials, the HMD and the headphones were removed from the participants who were asked to complete a post-VR questionnaire. The questionnaire included 12 five-point Likert-style questions related to their subjective experience of presence within the virtual environment, ownership over the avatar, and the confidence with which they replied to the visual tests (Table 3).

Figure 4: Participants in Experiment 1 were fitted with an HMD for stereo display and head tracking, and headphones for stereo sound

4.1.5 Data Collection

The experimental data consisted of the participants' answers in each trial, which were recorded by the experimenter, along with the response time for each trial, and the pre-VR and post-VR questionnaires.

The pre-VR questionnaire was used to assess the participants’ demographics as well as their virtual environments and computer games literacy. In addition, the participants were asked to indicate if they were suffering from a vision problem.

The post-VR questionnaire (Table 3) was used to assess the participants' feeling of owning the virtual body, their sense of presence within the virtual environment, and their confidence while answering the visual trials. The questions used on this questionnaire to measure the above scales were created for the purposes of this study, and therefore there is no evidence of their validity. The internal consistency of these measures is reported in the Questionnaire Results section (4.2.1). All the questions were measured on a Likert scale with values of 1 representing the highest level of disagreement at each question and 5 representing the highest level of agreement.

The participants’ responses to the trials were given verbally and recorded manually by the experimenter during the experimental sessions.

Table 3: The post-VR questionnaire given to participants in Experiment 1

Question	Med	M	SD
a. Instructions Understanding	**5**	**4.73**	**0.61**
1. The instructions of the study were not clear.	5	4.45	1.22
2. The study process was understood.	5	5	0
b. Presence	**4**	**4.23**	**0.61**
3. I felt that I was in the place / environment that I saw.	4	4.23	0.61
c. Sense of Body Ownership	**3.5**	**3.31**	**1.13**
4. I felt that the body I saw when I looked down it was mine.	4	3.55	1.14
5. The body I saw when I looked down, I belonged to someone else.	3	3.09	1.27
d. Confidence	**4.75**	**4.48**	**0.54**
6. The answers I gave in the test were correct.	5	4.55	0.59
7. The trials were difficult.	5	4.59	0.67
8. I have doubts about the correctness of the answers I gave.	4.5	4.14	1.13
9. I felt confident about my answers.	5	4.64	0.58
e. Self-Reported Conformity*	**1**	**1.35**	**0.47**
10. The answers given by the other participants (confederates) affected my own answers.	1	1.54	0.78
11. The answers I gave were mainly based on my own opinion.	1	1.11	0.32

Note. The questionnaire was in the participants' native language (Greek).

*Questions given only to participants in the experimental group.

The response time for each trial was recorded. Response time was the time distance between the moment the participants were called to respond (indicated by the light of the virtual lamp) and the moment they gave their answer in each trial. The moment that the participants were called to respond, a timer in the application was starting to count. As soon as the participants stated their answer, the experimenter pressed a button on the keyboard and the response time was recorded. Upon the participants' response to the last trial, the response time to each trial was saved automatically in a text file.

4.1.6 Participants

The recruitment of participants was done mainly through e-mail and the social media of the department. All those interested declared their participation and chose day and time by using an online calendar tool. The inclusion criteria required the participants to be over 18 years old and to have Greek as their mother tongue. 24 volunteers participated in the study. An important prerequisite was that the participants should not have been familiar with the original Asch (1951) experiment, and for this reason, two participants were not included in the sample. No power analysis was performed prior the experiment to determine the size sample. The sample size was determined based on relevant studies using similar experimental design in the VR literature.

22 valid participants between 20 and 42 years old volunteered and took part in the experiment: 14 males and 8 females. The median age was 24 years old. Moreover, 13 of the 22 participants were placed in the Social Pressure condition (7 females, 6 males). The remaining nine participants were placed in the No Social Pressure condition (seven females, two males). The analysis mainly concerned the Social Pressure condition and the interaction of the participants with the agents, whereas the No Social Pressure condition data were used to validate the results. Thus, it was considered appropriate to place more participants from the available sample in the Social Pressure condition, as in the original study (Asch, 1951). This allocation was considered during the statistical analysis, and the results were not affected.

4.1.7 Ethics Statement

Ethical review and approval were not required for the study on human participants in accordance with the institutional requirements. The participants provided their written informed consent to participate in this study. The participants were fully informed of the risks that may arise from the use of VR.

4.2 Experiment 1 Results

The analysis of the data was performed using the IBM SPSS Statistics (Version 21). Parametric tests were preferred for the analysis and used when the assumptions were met. Otherwise, non-parametric tests were performed.

4.2.1 Questionnaire Results

More than 80% of the participants answered that they used VR technology at least once in the past. We suppose that this high percentage occurred because most of the participants were students from our academic department.

The sense of body ownership, as assessed in questions 4 and 5, was quite high. The answers to these questions were grouped together after a reliability test (Cronbach's alpha = 0.856) was performed in order to prove that the two questions measure the same construct. In the reliability test and the body ownership assessment, the answers to question 12 were reversed due to the negative way the question is stated. The median score, for body ownership, as an average in both groups, was 3.5 out of 5. The sense of presence, as measured in the post-VR questionnaire based on the answers to question 3, was high with a median score of 4 and minimum recorded value of 3. In addition, participants in both groups stated that the process and instructions of the test were fully understood. The median scores of the relevant questions (question 1 reversed and question 2) were 5 in both cases.

Participants declared that they were confident in their estimates for the visual tests. This was assessed with the post-VR questionnaire (questions 6, 7 reversed, 8 reversed, and 9; Cronbach's alpha = 0.646). More than 45% were absolutely confident, whereas the lowest score was 3.5 on a scale from 1 to 5. The median score was 4.75.

4.2.2 Participants' Answers

By analyzing the data, results demonstrated no significant distortion in participants' responses. Furthermore, 90.91% of the participants responded correctly to all questions. In a total of 264 trials in both groups, only 3 gave a wrong answer (1.14%).

4.2.3 Participants' Response Time

As a next step, we would like to examine whether the participants' average response time is affected by the responses of the virtual confederates in the Social Pressure condition. A t-test was performed in order to compare means of the average response time of participants in the trials in which the confederates gave a wrong answer (M = 0.94, SD = 152) with the average response time in those trials in which the confederates gave a correct answer (M = 1.053, SD = 0.199). The results demonstrated no statistically significant difference between the two, $t(10) = -0.950$, $p = .364$.

4.2.3.1 Post-hoc Analysis on Response Time

By plotting the average response times of participants in each trial (Figure 5), we observed a pattern in the Social Pressure condition while this was not happening in the No Social Pressure condition. In Figure 5, the trials in which the agents in the Social Pressure condition gave a correct answer are marked with a green line, whereas the red lines mark the incorrect answers. In our observations, blue rectangles (Figure 5, middle) indicate that whenever a trial in which confederates responded with an incorrect answer (red line) was followed by a trial where the confederates responded with a correct answer (green line), and the average response time of the participants increased drastically. Moreover, these observations were not valid in the corresponding trials in the No Social Pressure condition (Figure 5, top).

To further investigate this, we created the ordinal variable “change of agents' error”, which is directly computed from the “agents' error” variable. The “agents' error” is a variable that takes the value 0 in trials in which the agents answered correctly (trials 1, 2, 4, 11), and 1 in trials where the answers of the agents were wrong (trials 3, 5, 6, 7, 8, 9, 10, 12). The “change of agents' error” describes the variation of “agents' error” in each trial.

When the “agents' error” value is not changed as compared with its value for the previous trial, the value of “change of agents' error” is computed to 0. In the trials in which the “agents' error” is 1 (agents answered wrong) and was 0 in the previous trial (agents answered correctly), the value of the “change of agents' error” is 1. In the same manner, in trials in which the “agents' error” is 0 and was 1 in the previous trial, the value of “change of agents' error” is −1.

The “change of agents' error” is an ordinal variable because it indicates the agent's consistency toward answering correctly. The “change of agents' error”, as computed based on the “agents' error” of two consequent answers, is plotted in the graph of Figure 5 (bottom). The “change of agents' error” for the first trial cannot be computed, as there is no previous trial. Thus, this value is handled as a missing one in the analysis that follows.

The similarity of the two graphs, plotting the “participants' average response time” (Figure 5, middle) and “change of agents' error” (Figure 5, bottom) for each trial, can be easily observed. In order to prove it, the appropriate statistical analysis was performed. Spearman's rank-order correlation was run to determine the relationship between the two variables: “participants' average response time” and “change of agents' error”. There was a highly significant correlation between the two variables in the Social Pressure condition, $r_s = 0.905$, $n = 11$, $p < .001$. This proves that the greater the value of “change of agents' error”, the more time is needed for the participants to respond.

In order to verify that this observation was due to the existence of agents and their answers, a similar test, a Spearman's rank-order correlation between “participants' average response time” and “change of agents' error”, was also performed for the No Social Pressure condition. The results for the No Social Pressure condition demonstrated no significant correlation ($r_s = 0.166$, $n = 11$, $p = .626$).

Moreover, to double check that the significant correlation observed in the Social Pressure condition was due to the social influence from the confederates and not due to other external factors (e.g., difference in the difficulty of the visual test of each trial), we also performed a partial correlation. We controlled the “participants' average response time” in the No Social Pressure condition and the relation between “change of agents' error” and the “participants' average response time” in the Social Pressure condition. The results demonstrated a partial correlation of $r = 0.904$, $p < .001$. This proves that the correlation between the two variables (“change of agents' error” and “participants' average response time”) in the Social Pressure condition is significant, even if the values of the variable “participants' average response time” in the No Social Pressure condition are being kept constant.

4.3 Experiment 1 Discussion

This experiment was designed to investigate whether VHs may push social pressure to the participants and influence their judgment within an IVE. The correct answers, as in the original Asch (1951) experiment, were deliberately obvious and undeniable, so the possible distortion on the participants' responses would constitute an extreme form of social conformity. We speculated that this was the reason that participants did not conform to the responses of the agent confederates.

Although the correctness of the participants' responses was not affected by the virtual confederates, the time it took the participants to respond to the trials has been affected. In the trials in which the confederates gave the wrong answer, while in the previous test, they answered correctly (“change of agents' error” = 1), the “participants' average response time” was increasing significantly. The reverse is also observed. In the trials in which the agents gave a correct answer, while in the previous trial they gave wrong answers (“change of agents' error” = −1), the “participants' average response time” was decreasing significantly.

This could be interpreted as a momentary force on the participants' answers, affected by the reliability of the virtual confederates and their consistency in providing correct or wrong answers. When the confederates appeared to be non-reliable, that is, in consequent trials, the participants replied in a different manner (i.e., in one trial with a correct answer and the other with a wrong answer or vice versa), a big variation in participants' response time is observed between the times of consequent trials. When the confederates break the reliability (the previous answer was correct and the current answer is wrong), then the response time of the participants increases drastically. Moreover, if the confederates are recovering the reliability (the previous answer was wrong and the current answer is correct), the response time of the participants decreases drastically. However, if the confederates are consistent in the manner of giving an answer to consequent trials, that is, either they give continuously correct answers or they give continuously wrong answers, the response time of the participants does not change significantly.

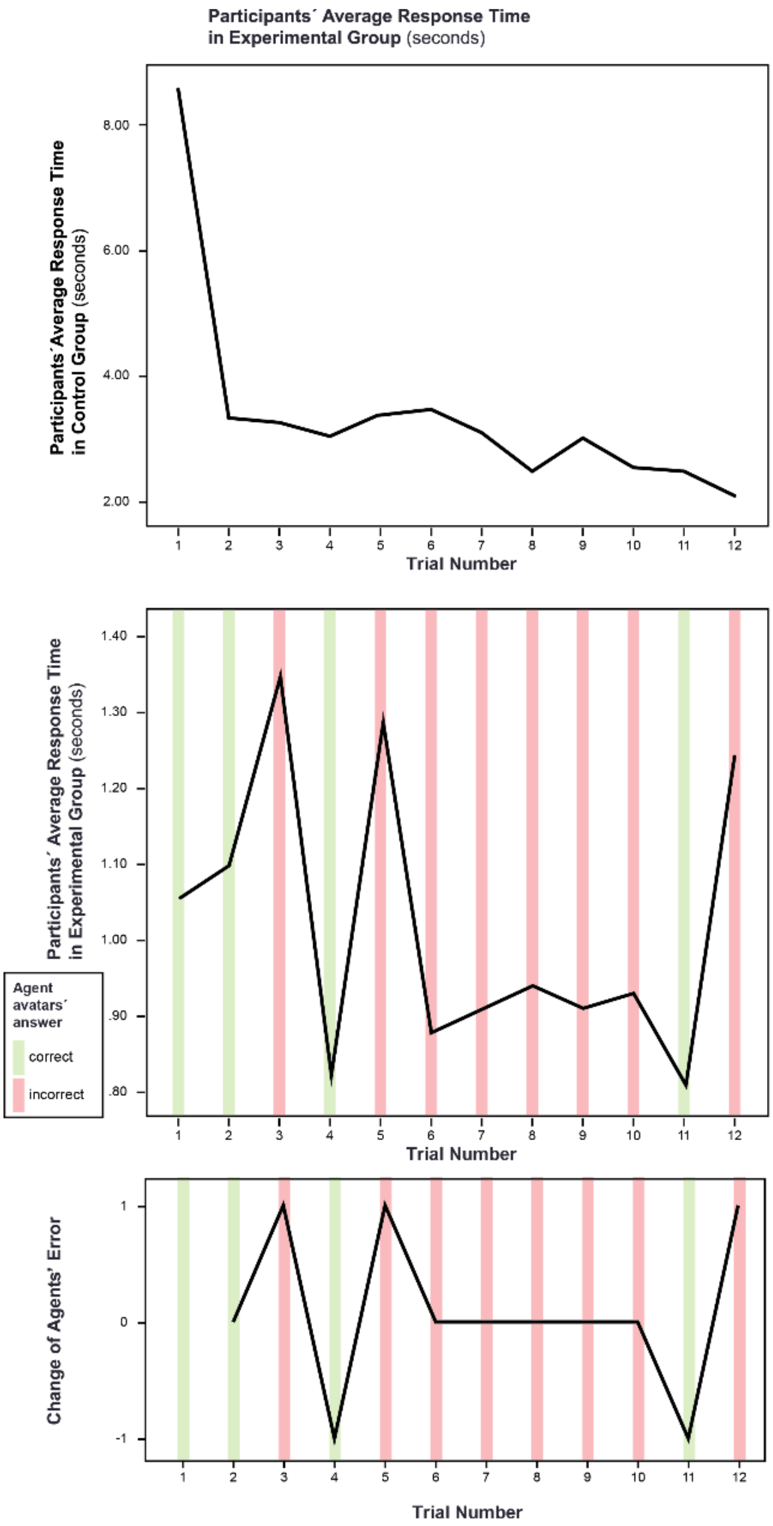

Figure 5: Participants' average response time in each trial for the No Social Pressure condition (top) and the Social Pressure condition (middle) with the corresponding "change of agents' error" (bottom) in each trial in Experiment 1

5 Experiment 2: Normative Conformity with Virtual Humans in Immersive Virtual Environments

Although the results of Experiment 1 showed that some degree of social pressure was exerted on the participants, this pressure did not lead to conformity with the majority's opinion, as in the original Asch (1951) study. These results led us to conduct a second experiment in order to further investigate the social pressure from VHs within IVEs. According to the literature (Blascovich, 2002), an important factor for social influence is the extent to which the user believes in interacting with an avatar instead of an agent (agency). In Experiment 2, we tested the factor of agency by having a Low Agency and a High Agency condition. Another factor that we examined in Experiment 2 is the behavioral realism (Blascovich, 2002) of the VHs. Nonverbal behavior such as gaze direction and the reactions to the participant's actions are important social cues, and we are expecting that they will have a great impact on social influence. We tested this factor by having a Low Behavioral Realism and a High Behavioral Realism conditions. This manipulation of the agent confederates' gaze behavior is an example of the advantage of the use of IVR technologies for similar of experiments. By using human confederates, it would be almost impossible to control their gaze behavior between the trials and the experimental sessions. Here the recruitment of virtual agents allowed us to have total control over the experimental protocol and study the impact of the confederates' gaze behavior on the participants' conformity.

5.1 Experiment 2 Methodology

5.1.1 Experimental Design

The purpose of this experiment was to examine whether social pressure from VHs, the level of agency and the VHs' behavioral realism can affect the participants' responses. To do so, we designed an experiment with 2 (social pressure) × 2 (agency) × 2 (behavioral realism) between groups design. Each participant was asked to respond to a series of 12 trials, after they first heard the answers of the four confederates. The 12 trials were the same as those used in Experiment 1 and they are shown in Figure 2.

The social pressure manipulation was different from Experiment 1 as in the No Social Pressure condition, the virtual confederates were also present, similarly to the Social

Pressure condition. The difference between the two conditions was that in the No Social Pressure condition, the confederates were always giving the correct answer. This change was made for two reasons. Firstly, to allow a direct comparison of the response time between the two conditions. The second reason was to examine whether the responses of the confederates would affect their evaluation by the participants. In the Social Pressure condition, the confederates gave the same wrong answers as in the first experiment and these answers are shown in Table 2.

Like the Experiment 1, this experiment also focused on normative conformity, which is the change on behavior (in this case the participants’ responses) to conform with the group, while knowing that the group is incorrect. For that reason, the answer to the task used was always obvious and undeniable, so a possible distortion on the participants' responses in the Social Pressure condition can be attributed on normative rather than on informational influence. To avoid the possibility of informational conformity due to misconception or doubts about the objective of the task, detailed instructions were given to participants explaining the objective. To confirm that participants had no doubts regarding the task objective, after the experiment, the participants were asked to evaluate the extent to which they understand the objective.

In order to test the factor of agency, each participant was randomly assigned to either the Low Agency or the High Agency condition. Even though all the virtual confederates were agents, as their behavior was predetermined, we differentiated the agency factor by changing the prerecorded instructions given to the participants before the study started. This is a common way for the manipulation of agency in the literature (Oh et al., 2018). More specifically, in the Low Agency condition, the instructions were saying that the confederates were controlled by a computer through an algorithm. In the High Agency condition, the instructions were saying that the confederates were controlled by other participants in different labs in real time.

Figure 6: The virtual environment and the virtual confederates in the Low Behavioral Realism condition (left-top, middle, and bottom) and in the High Behavioral Realism condition (right-top, middle, and bottom) in Experiment 2

In addition, in order to test the impact of the agents' behavioral realism, we created two levels of behavior. Each participant was randomly assigned either in the Low Behavioral Realism or in the High Behavioral Realism condition. The difference between the two conditions was the gaze behavior of the virtual confederates. This operationalization of the VHs' behavioral realism is common in the literature (e.g., Guadagno et al., 2007) In the High Behavioral Realism condition, the virtual confederates were looking straight in the eyes of the person who was answering (Figure 6, right-middle), including the participant (Figure 6, right-bottom). This was done by turning both the head and the eyes of the confederates. In the Low Behavioral Realism condition, the confederates were looking at the board of the trial (Figure 6, left-middle)., and the rest of the time they were looking ahead without focusing anywhere (Figure 6, left-bottom). A video showing the experimental procedure can be found at this link: https://youtu.be/-n7jaYiPtBs.

5.1.2 Virtual Humans

The virtual confederates in this experiment were more realistic in appearance than in Experiment 1. Specifically, four virtual confederates were created, two male-like and two female-like. Each one of them had a looped animation that included small movements. A lip synchronization algorithm was also added for the movement of the lips. The lip-movement animation was synchronized with the audio to simulate speaking. Also, eye blinking animation was added to the virtual confederates. The head movement was done with the use of code and inverse kinematics. Gaze movements were also scripted. For the lip movements and eye blinking, we used blend-shapes animation.

The participant's avatar was selected in advance by the experimenter for each session, between a male-like and a female-like character, depending on the gender of the participant, and they were same as those used in Experiment 1 (Figure 3). The camera was in a position where the participants could see through the eyes of the avatar, and, by moving their head around, could observe and explore the environment, their virtual body, and the virtual confederates.

5.1.3 Technical setup

The experiment was performed using a PC equipped with an NVidia GeForce GTX 1060 graphics card[7]. The setup included the Oculus Rift CV HMD[8] for 3D immersive viewing, head rotational and positional tracking, and audio. The graphics and the application were created the same way as in Experiment 1. For the lip synchronization feature, the SALSA[9] plug-in for Unity[10] was used.

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[7] https://www.nvidia.com/geforce/

[8] https://www.oculus.com/

[9] https://crazyminnowstudio.com/unity-3d/lip-sync-salsa/

[10] https://unity.com/

Table 4: The post-VR questionnaire given to participants in Experiment 2

Question	Med	M	SD
a. Instructions Understanding	**5**	**4.86**	**0.49**
1. The instructions of the study were clear.	5	4.87	0.52
2. The study process was understood.	5	4.85	0.50
b. Presence	**4.33**	**4.21**	**0.67**
3. Evaluate your sense of presence in the virtual room.	5	4.58	0.82
4. To what extent, during your experience, the virtual world has become the "reality" for you, and you have almost forgotten the real world in which the study was conducted?	4	4.02	1.04
5. During your experience, what feeling was stronger, the feeling that you were in the virtual room, or the feeling that you were in the real world?	4	4.02	1.11
c. Sense of Body Ownership	**3**	**3.30**	**1.19**
6. I had the feeling that the body I was seeing when I looked down was mine.	3.5	3.33	1.28
7. I had the feeling that I had the control of the body I was seeing when I looked down.	3	3.27	1.34
d. Social Presence	**3.75**	**3.52**	**1.06**
8. I had the feeling that I was alone in the room.	4	3.71	1.47
9. I had the feeling that there were other people in the room.	4	3.97	1.17
10. I had the feeling that the other participants understood my presence in the room.	4	3.04	1.58
11. I had the feeling that the other participants were real people.	3	3.52	1.30
e. Confidence	**5**	**4.59**	**0.67**
12. The answers I gave to the tests were correct.	5	4.69	0.67
13. The tests were difficult.	5	4.73	0.66
14. I have doubts about the correctness of the answers I gave to the tests.	5	4.35	1.13
15. I felt confident about my answers.	5	4.58	0.87
f. Self-Reported Conformity	**5**	**4.56**	**0.96**
16. The answers I gave to the examination were mainly based on my own opinion.	5	4.67	1.02
17. The answers given by the others to the tests affected my own answers.	5	4.44	1.13

Note. The questionnaire was in the participants' native language (Greek).

5.1.4 Procedure

After being informed about the experiment, the participants signed a consent form and completed a pre-VR questionnaire. After the HMD was fitted on each participant, the experimenter started the application. At the beginning of the application, there was a 150 second familiarization phase. During this period, the prerecorded instructions were played, which had a duration of 60 seconds. The instructions included the differentiation for agency. In the High Agency condition, participants were told that the virtual confederates were controlled by people in other labs in real time. The participants of the Low Agency condition were told that the virtual confederates were controlled by a computer through an algorithm. After the familiarization period, the trial procedure started, as well as in Experiment 1. After the completion of all trials, the HMD was removed from the participant who was asked to complete a post-VR questionnaire.

5.1.5 Data Collection

The experimental data that were collected were similar to Experiment 1. The data consisted of the participants' answers in each trial, which were recorded by the experimenter, the participants’ response time for each trial, and the data from the pre-VR and the post-VR questionnaire.

The pre-VR questionnaire was identical to the one in the first experiment. It contained six questions about demographics and virtual environments/computer games literacy and with a question if they suffered from a vision problem.

The post-VR questionnaire (Table 4) included 17 five-point Likert-style questions related to the participants' subjective experience of presence in the virtual environment, their sense of social presence of the confederates, their confidence about their responses as well as a self-reported conformity statement. The questions used on this questionnaire to measure the above scales were created for the purposes of this study, and therefore there is no evidence of their validity. The questions assessing the sense of presence were based on the Slater–Usoh–Steed presence questionnaire (Slater, Usoh & Steed, 1994; Usoh, Catena, Arman & Slater, 2000). The questions on social presence were based on a questionnaire by Bailenson, Blascovich, Beall and Loomis (2003). The internal consistency of these measures is reported in the Results section (5.2).

Table 5: Distribution of participants over conditions in Experiment 2

		No Social Pressure	Social Pressure
High Behavioral Realism	**Low Agency**	7	7
	High Agency	7	6
Low Behavioral Realism	**Low Agency**	7	6
	High Agency	6	6

5.1.6 Participants

The recruitment of participants was done mainly through e-mail and the social media of the department. All those interested declared their participation and chose day and time by using an online calendar tool. The inclusion criteria required the participants to be over 18 years old and to have Greek as their mother tongue. 56 volunteers participated in the study. As in Experiment 1, an important prerequisite was that the participants should not have been familiar with the Asch experiment, and for this reason, four participants were excluded from the sample. No power analysis was performed prior the experiment to determine the size sample. The sample size was determined based on relevant studies using similar experimental design in the VR literature.

52 valid participants (25 males and 27 females) took part in the experiment and they were randomly assigned to the experimental conditions. The distribution of participants in the eight conditions is shown in Table 5. The median age was 25 years old, and the age range was from 18 to 60 years old.

5.1.7 Ethics Statement

Ethical review and approval were not required for the study on human participants in accordance with the institutional requirements. The participants provided their written informed consent to participate in this study. The participants were fully informed of the risks that may arise from the use of VR.

5.2 Experiment 2 Results

The analysis of the data was performed using the IBM SPSS Statistics (Version 21). Parametric tests were preferred for the analysis and used when the assumptions were met. Otherwise, non-parametric tests were performed.

5.2.1 Trial Error

There were 48 out of 52 participants (92.3%) who responded correctly to all trials. The remaining four participants gave a wrong reply to at least one trial, following the mistaken reply of the confederates. Nobody taking part in the control conditions gave a wrong reply. All the wrong responses were given to critical trials (trials where the confederates gave a wrong reply) in the experimental conditions. Table 6 shows the number of incorrect responses in each condition.

A three-way analysis of variance was conducted on the influence of the three independent variables (social pressure, agency, and behavioral realism) on the number participants' wrong replies. The social pressure variable included two levels (no social pressure and social pressure), agency consisted of two levels (low agency and high agency), and behavioral realism also consisted of two levels (Low Behavioral Realism and high behavioral realism). The main effect of social pressure yielded an F ratio of $F(1, 48) = 4.837$, $p < 0.05$, indicating a significant difference between participants in no social pressure ($M= 0$, $SD = 0$) and in social pressure ($M = 0.28$, $SD = 0.68$). The effects of agency ($F(1, 48) = 2.721$, $p = .106$) and behavioral realism ($F(1, 48) = .84$, $p = .364$) were not statistically significant. The interaction effect was not significant; $F(1, 48) = 0.134$, $p = .716$.

Table 6: Distribution of incorrect responses by participants over conditions in Experiment 2, out of 264 responses in total

		No Social Pressure	**Social Pressure**
High Behavioral Realism	**Low Agency**	0	0
	High Agency	0	2
Low Behavioral Realism	**Low Agency**	0	1
	High Agency	0	4

5.2.2 Response Time

We looked at the response time in the critical trials. A simple main effects analysis showed no significant effect of the three independent variables (social pressure, agency, and behavioral realism) on average response time in critical trials. We then separately tested the participants' average response time for each trial. A three-way analysis of variance was conducted on the influence of the three independent variables (social pressure, agency, and behavioral realism) on the average response time in each trial separately. Effects on social pressure on response time were only found in trials 5 and 6. In trial 5 a main effect of social pressure was shown with $F(1, 48) = 7.88$, $p < .01$. The participants in the no social pressure condition replied faster ($M = 0.8$, $SD = 0.27$) in trial 5 than the participants in the social pressure condition ($M = 1.22$, $SD = 0.37$). The same significant difference between no social pressure ($M = 0.99$, $SD = 0.17$) and social pressure condition ($M = 1.29$, $SD = 0.50$) was also shown in trial 6 with $F(1, 48) = 7.58$, $p < .01$.

5.2.3 Social Presence

The sense of participants' social presence was assessed using four items (questions 8 reversed, 9, 10, and 11; Cronbach's alpha = 0.76) on a scale from 1 to 5. Participants stated they had a moderate sense of social presence with a median of 3.75.

A three-way analysis of variance was conducted on the influence of the three independent variables (social pressure, agency, and behavioral realism) on social presence. The main effect of behavioral realism yielded an F ratio of $F(1, 48) = 5.236$, $p < .05$, indicating a significant difference between participants in Low Behavioral Realism ($M = 3.16$, $SD = 1.04$) and High Behavioral Realism conditions ($M = 3.81$, $SD = 1.02$). The effects of social pressure and agency were not statistically significant. This result indicates that the participants in the High Behavioral Realism condition reported stronger social presence than the participants in the Low Behavioral Realism condition.

5.2.4 Presence

For the sense of presence in the virtual environment, we used three items (questions 3, 4, and 5 reversed) based on the Slater–Usoh–Steed presence questionnaire (Slater et al., 1994; Usoh et al., 2000). The reliability of the scale was not good (Cronbach's alpha = 0.437). Participants stated they had a high sense of presence in the virtual world as the median value was 4.15 on a scale from 1 to 5.

5.2.5 Confidence

34 out of 56 participants (60.7%) stated that they were absolutely confident about their responses to the trials. Confidence was measured using four questions (questions 12, 13 reversed, 14 reversed, and 15; Cronbach's alpha = 0.795) in the post-VR questionnaire. The confidence reported by the participants appeared to be associated with the way they responded to the trials. A Spearman's rank-order correlation was run to determine the relationship between confidence and trial error, $r_s = -0.336$, $n = 52$, $p = .015$. A similar correlation also occurred between confidence and response time, $r_s = -0.301$, $n = 52$, $p = .03$. These findings indicate that participants who were less confident gave more wrong responses and spent more time answering critical trials.

5.2.6 Self-reported Conformity

The participants stated how much they responded autonomously to the trials, using two questions (questions 16 and 17 reversed) in the post-VR questionnaire. We constructed a scale that shows the independence (Cronbach's alpha = 0.795) of the replies. Moreover, 73% of the participants (38 out of 52) said they were totally autonomous with a median of 5 on a scale from 1 to 5. A Spearman's rank-order correlation was run to determine the relationship between self-reported conformity and average response time in the critical trials. There was a negative correlation between the two variables, which was statistically significant, $r_s = -0.304$, $n = 52$, $p = .029$. This result indicates that participants who reported less conformity, responded more rapidly.

The self-reported conformity and confidence also seemed to be correlated, $r_s = 0.511$, $n = 52$, $p < .01$. Participants who declared more confidence also said they were more independent in their responses.

5.3 Experiment 2 Discussion

The purpose of Experiment 2 was to study whether social pressure from a group of VHs can lead to conformity in IVEs. We also wanted to investigate the role of agency and the VHs' behavioral realism in provoking this phenomenon.

The results of the experiment showed that normative conformity can be caused by VHs in IVEs, even when the stimulus is unambiguous. The validity of this result is reinforced by the fact that no wrong answer was given in the absence of social pressure when the confederates gave the correct answers.

This result contrasts with that of Experiment 1 where no conformity was observed although the trials and the confederates' responses of the two experiments were identical. The differences between the two experiments were the equipment used, the confederates' representations, the instructions, and the familiarization period. Experiment 2 used an improved HMD version and an upgraded technical setup with respect to Experiment 1. The human representations used as confederates in Experiment 2 were more realistic in appearance than in Experiment 1. The improvement in the realism of the virtual confederates was made so that it is possible to integrate lip synchronization and gaze behavior and was made possible due to the upgraded VR setup. The familiarization period prior to the testing differed between the two experiments. In Experiment 2, the familiarization period lasted 150 seconds, whereas, in Experiment 1 it lasted 60 seconds. This was done in order to include the pre-recorded instructions phase in the familiarization period. In Experiment 1 the instructions were given on paper to the participants before wearing their VR exposure. In contrast, in Experiment 2, the participants were listening to prerecorded instructions while they were immersed in the virtual environment.

Also important is the fact that the wrong answers were given in the first critical trials, whereas no wrong answer was given in the last three critical trials. In particular, conformity was mainly observed (four out of seven wrong answers) in the second and third critical tests (trials 5 and 6). In these two trials, a significant effect of social pressure on the response time was also observed.

The results of this study support the hypothesis that social pressure from a group of VHs in an IVE lead to normative conformity. This result comes in contrast with previous studies (e.g., Midden et al., 2015) using non-immersive technologies, showing that conformity with VHs occurs only as a result of informational influence. However, the level of normative conformity observed int this study is evidently low compared to the level of conformity reported in studies using human majorities (e.g., Asch, 1951), and this is something that can be tested in a future study. The study did not produce significant results in relation to the impact of agency and behavioral realism on conformity. Although the factor behavioral realism significantly affected the sense of social presence, it did not have the same impact on the participants' responses. This outcome means that social presence and the level of the VHs' behavioral realism may not be so important factors for influencing the user's behavior in IVEs. This result comes in contrast to the literature showing that with other forms of social effects, social presence and the level of the VHs' behavioral realism are important factors and suggests that may not be the case with normative conformity. The factor of agency had also no impact on the sense of social presence. Participants who were informed that the confederates were being controlled by other participants stated the same degree of social presence as those who were informed that the confederates were controlled by the computer through an algorithm. This result is in line with studies suggesting that people are responding socially to VHs regardless of whether they believe that they are interacting with agents or avatars. The ability of virtual agents to elicit social reactions is crucial for a wide range of IVR applications (see Section 1.2.1.3) due to the many advantages they offer that are discussed in Section 1.2.2.2 and Section 1.2.3.

6 Experiment 3: Informational Conformity with Virtual Humans in Immersive Virtual Environments

The results of Experiment 2 showed that normative conformity can be caused by VHs in IVEs, even though the stimulus is unambiguous. Experiment 3 focused on informational influence. As presented in Section 1.1, informational conformity occurs when an individual accepts the majority's opinion in order to be correct, due to uncertainty or the belief that others have better knowledge. According to relevant studies (Midden et al., 2015; Hertz and Wiese, 2016) using non-immersive technologies, people are more likely to conform to VHs as a result of informational rather than normative influence. In order to focus on informational influence, the task difficulty was increased in relation to Experiments 1 and 2. The task difficulty was increased by limiting the trial cards projection duration, which is a common way of increasing the task difficulty in such experiments (e.g., Midden et al., 2015). We also tried to reduce the participants' sense of anonymity in relation to Experiments 1 and 2, as studies showed that conformity is negatively correlated with the level of the individual's anonymity (Huang & Li, 2016). In order to achieve that, participants were asked to introduce themselves to the agents before the procedure began. Our prediction was that participants would conform to the virtual humans' judgments by giving more incorrect answers to the trials where the confederates gave a wrong response, than to the trials where the confederates answered correctly.

Additionally, we used the same manipulation as in Experiment 2 in order to investigate the impact of the VHs' behavioral realism on informational conformity. Specifically, this was done by manipulating the virtual confederates' non-verbal behavior, namely the gaze behavior. Non-verbal behavior (such as eye contact, interpersonal distance, facial expressions, and gestures) is an important component of human communication (Bente, Eschenburg & Aelker, 2007) and, therefore, an important factor for the creation of social presence (Oh et al., 2018). As in Experiment 2, we crated two levels of behavioral realism. In the Low Behavioral Realism condition, the confederates had no gaze behavior, and therefore they did not make any eye contact with the participant or between them (Figure 7, left). In the High Behavioral Realism condition, during the answering phases of the procedure, the confederates turned their gaze toward the one who was responding at that moment, whether that was the participant or another confederate (Figure 7, right). We presume that by adding an extra social cue, such as eye contact, a stronger sense of social presence will be induced to the participants, and as social presence has an impact on social influence (Oh et al., 2018), we predicted that conformity in the High Behavioral Realism condition would be greater than in the Low Behavioral Realism condition.

Figure 7. The virtual environment in the Low Behavioral Realism condition (left) and in the High Behavioral Realism condition (right) in Experiment 3

6.1 Experiment 3 Methodology

6.1.1 Experimental Design

This was a between-group design, and participants were randomly assigned to one of the two conditions, the High Behavioral Realism, or the Low Behavioral Realism condition (Table 7). All participants signed a consent form which was a prerequisite for participation in the study.

Table 7: Distribution of participants over conditions and summarized pre-VR questionnaire measures in Experiment 3

	Condition	
	Low Behavioral Realism	**High Behavioral Realism**
N (Males)	12 (6)	14 (6)
Mean ± S.E. Age	27.88 ± 1.845	24.4 ± 3.872
Median VR Experience (IQR)	2 (3)	3 (4)
Median 3D Experience (IQR)	2 (3)	2 (2)
Mean ± S.E. Self-Esteem	33.06 ± 0.979	29.05 ± 1.05

Table 8: Trials with the correct answers and the answers given by the confederates in Experiment 3

Trial Card	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Trial Number	**1***	**2***	**3**	**4**	**5***	**6**	**7**	**8**	**9**
Correct Answer	A	B	A	C	A	C	C	B	A
Agents' Answer	A	B	A	A	A	C	A	B	B
Trial Number	**10***	**11***	**12**	**13**	**14***	**15**	**16**	**17**	**18**
Correct Answer	A	B	A	C	A	C	C	B	A
Agents' Answer	A	B	C	C	A	B	C	C	A

*Non-Critical trials.

Overall, there were 18 line-length comparison trials. Each trial card was presented for 5 seconds and had only one correct answer. The projection duration of the size of the trial cards was decided using pilot tests. Specifically, we balanced the task difficulty (projection duration and trial card size), so that it was challenging enough, but the participants could still figure out the correct answer. The agents gave their answers in all trials unanimously.

Six of the trials (trials 1, 2, 5, 10, 11, and 14) were "non-critical", and the agents gave the correct answer to all of them. The noncritical trials were used as training trials and were not considered in the analysis. The use of non-critical trials is a technique used in similar of experiments (e.g., Asch, 1956; Hertz and Wiese, 2016), and their purpose was to avoid causing any confusion to the participants regarding the length comparison task and generate some trust towards the virtual confederates. This is the reason that the opening trials are non-critical.

The remaining 12 trials (3, 4, 6, 7, 8, 9, 12, 13, 15, 16, 17, and 18) were the "critical" trials. The confederates gave the correct answer to the 6 critical trials (3, 6, 8, 13, 16, and 18) and a wrong answer to the other 6 (4, 7, 9, 12, 15, and 17). The correct answers to each trial as well as the answers given by the virtual confederates are summarized in Table 8.

The first 9 trials were identical with the other 9 in the same order (trial 1 was the same as trial 10, trial 2 as trial 11, and so on). In this way, each participant was asked to respond to each critical trial twice, once after the confederates gave the correct answer and once after they unanimously gave a wrong answer. This was done in order to balance the task difficulty between the critical trials that the confederates responded correctly to, and the critical trials where they gave a wrong answer. Participants were not aware of this manipulation. A video showing the two experimental conditions can be found at this link: https://youtu.be/o2otBdHoOFs.

6.1.1 Virtual Humans

For Experiment 3, the four virtual confederates created for Experiment 2, two male-like and two female-like, were used. Two body animation clips were used for each confederate, an "idle" and an "answering" animation. The "idle" animation included breathing movements and was repeated most of the time. The "answering" animation clip included some movement of the body and the hands and was playing each time the agents were giving their answers. The above animation clips were slightly different for each confederate. Also, to improve realism, the confederates performed blinking and lip movement animations using blend-shapes. The lip-movement animation was synchronized with the audio to simulate speaking. The audio clips used for the virtual confederates' voice were pre-recorded.

An inverse kinematic technique directed by a script was used for the confederates' head movement and gaze manipulation. When the trials were projected, in both conditions the confederates turned their heads toward the board. During the answering phase, in the High Behavioral Realism condition, all the confederates turned their heads toward the one answering, including the participant (Figure 7Figure 6, right), performing eye contact. The participants' head position was being tracked dynamically using the HMD's positional tracking. During the answering phase in the Low Behavioral Realism condition, the confederates were looking straight ahead (Figure 7, left). An amount of randomness was applied to the delay and the speed of the confederates' head movement in order to make it look more natural and less robotic.

The participant's avatar was selected in advance by the experimenter for each session, between a male-like and a female-like character, depending on the gender of the participant, and they were same as those used in Experiments 1 and 2 (Figure 3). The camera was in a position where the participants could see through the eyes of the avatar, and, by moving their head around, could observe and explore the environment, their virtual body, and the virtual confederates.

6.1.2 Technical Setup

The experiment was performed using a PC equipped with an NVidia GeForce GTX 1060 graphics card[11]. The setup included the Oculus Rift[12] HMD with 2160 × 1200 resolution (1080 × 1200 per eye), 110º field of view, and 90 Hz refresh rate for 3D immersive viewing, head rotational, and positional tracking, and providing spatialized audio. The application was created using the Unity[13] (version 2018.2.1) game engine and the environment using Autodesk Maya[14] and Adobe Photoshop[15]. The virtual characters were designed and rigged using Autodesk Character Generator[16]. For the lip synchronization feature, the SALSA[17] plugin for Unity was used.

6.1.3 Procedure

Upon their arrival at the laboratory, the participants received written information about the study and filled in the consent form. Then, they were asked to complete a pre-VR questionnaire that included demographic information as well as the Rosenberg self-esteem test.

After they were fitted with the virtual reality HMD and the necessary calibration was done, the virtual room with the 4 virtual confederates (Figure 7) was presented and a familiarization period of 30 seconds began. Next, the instructions phase began, where

[11] https://www.nvidia.com/geforce/

[12] https://www.oculus.com/

[13] https://unity.com/

[14] https://www.autodesk.com/products/maya/

[15] https://www.adobe.com/products/photoshop.html

[16] https://www.autodesk.com/products/character-generator/

[17] https://crazyminnowstudio.com/unity-3d/lip-sync-salsa/

prerecorded instructions explaining the task and the process of the study were played back to the participant. During this phase, which lasted 2 minutes, the virtual confederates and the participant were asked to verbally introduce themselves by stating their first names, their age, and their occupation. This was done so that the participants could better understand the order and the way in which they would give their responses during the different trials, and to reduce the sense of the participants' anonymity. Thirty seconds after the instruction phase was completed, the trial session began. Each trial card was presented on the virtual boards for 5 seconds and then the virtual confederates and the participant gave their judgments in sequence. The participant was placed in the last (fifth) position and, therefore, gave their judgment after listening to the other four confederates' judgments. This procedure was repeated for all 18 trials. More details about the trials are presented in the Trials section and Table 2. During this session, the participants' answers to each trial and the participants' response time to each trial were automatically recorded by the software. Also, using the head tracking provided by the HMD, the participant's eye contact duration, and mutual gaze duration (in the High Behavioral Realism condition only) with the confederates were recorded. More information about the recorded data can be found in section 6.1.4.

After the trials' session, participants were asked to complete a post-VR questionnaire regarding their experience (Table 9). Finally, the participants were verbally asked whether they were familiar with the original Asch's (1951) conformity experiment and they were debriefed.

6.1.4 Data Collection

Using a questionnaire that was given to the participants before their exposure to the virtual environment (pre-VR), we recorded various data on demographic characteristics such as gender, age and intimacy with 3D environments and virtual reality, and self-esteem. These are summarized in Table 7.

Table 9: The post-VR questionnaire given to participants in Experiment 3

Variable Name	Question	Med	M	SD
a. Presence				
there	How do you assess your sense of presence in the virtual room where the trials were carried out?	6	6.18	0.98
real	To what extent, during your experience, the virtual world has become the "reality" for you?	5.5	5.24	1.40
lab*	During your experience, which sensation was stronger, the feeling that you were in the virtual room, or the feeling that you were in the laboratory where the study was being carried out?	5	4.55	1.75
b. Perceived Behavioral Realism				
behave	The other participants in the study behaved like real people.	5	4.92	1.53
move	The other participants were moving like real people.	4.5	4.37	1.53
talk	The other participants spoke as real people.	6	6.03	1.05
feel	I had the feeling that the other participants were real people.	5	4.63	1.51
c. Social Presence				
sameRoom	I had the feeling that the other participants were with me in the same room.	6	5.37	1.70
otherPerceived	I had the feeling that the other participants were aware of my presence.	5	4.29	2.13
otherListen	I had the feeling that the other participants were listening to my answers.	5	4.37	2.22
alone*	I had the feeling that I was alone in the room.	5	4.92	2.05
d. Responses Confidence				
correctAnswers	The answers I gave to the study were correct.	6	5.53	1.03
difficult*	The tests were difficult.	6	5.63	1.24
doubts*	I have doubts about the correctness of the answers I gave to the examination.	4	3.92	1.60
confidentAnswers	I felt confident about my answers.	6	5.24	1.50
e. Self-Reported Conformity				
myOppinion*	The answers I gave to the study were mainly based on my own opinion.	2	2.03	1.51
otherOppinion	The answers given by the other participants in the study affected my own.	2	3.11	2.12

Note. The questionnaire was in the participants' native language (Greek).
*Reverse interpretation

In addition, we measured the participants' self-esteem (Rosenberg, 1965), a personality characteristic that is related to conformity (Gergen & Bauer, 1967), in order to understand how a person's individual characteristics may affect social behavior with agents in IVEs. Participants' self-esteem was measured using the Greek version (Galanou, Galanakis, Alexopoulos & Darviri, 2014) of the Rosenberg Self-Esteem Scale (Rosenberg, 1965). It includes a total of ten questions on a 1–4 consensus scale, and the score ranges between 10 and 40. Higher scores are interpreted as higher self-esteem.

After their virtual exposure, participants were asked to complete a questionnaire (post-VR questionnaire) on their experience in the virtual environment. The participants were asked to assess their sense of presence in the virtual environment and evaluate the agents' behavioral realism. Moreover, we asked the participants to state how confident they felt about their answers and whether they were influenced by the responses of the virtual humans. All questions, which were evaluated on a 1–7 Likert scale, are presented in Table 9. The sense of presence (Slater, 2009), the subjective sense of being in the virtual world, was recorded using three questions (Table 9, a) based on the Slater–Usoh–Steed (Slater et al., 1994; Usoh, et al., 2000) questionnaire. Four additional questions (Table 9, b) rated the realism of the agents' behavior. Social presence was measured using four questions (Table 9, c) based on a questionnaire by Bailenson et al. (2003). With the use of 4 questions (Table 9, d), the participants stated the degree of confidence they felt about the answers they gave to the study, whereas two questions (Table 9, e) addressed whether they were influenced by the agents' responses. The questions used on this questionnaire to measure the above scales were created for the purposes of this study, and therefore there is no evidence of their validity. The internal consistency of these measures is reported in Table 10.

The responses given by the participants in each trial were recorded. Using these responses, a Conformity Error scale and a Non-Conformity Error scale were created. The Conformity Error represents the number of incorrect answers given by the participants in the trials that the virtual confederates gave the wrong answer. The Non-Conformity Error represents the wrong answers given in the critical trials where the confederates gave correct answers. Additionally, a Conformity Index (CI) was constructed. The CI is a scale that describes the conformity magnitude in the confederates' responses. This scale was calculated from the difference of the Conformity Error and Non-Conformity Error (CI = Conformity Error – Non-Conformity Error) and describes the level of the participant's conformity.

Participants' response time in each trial was recorded. Response time was the time distance between the moment the participants were called to respond and the moment they gave their answer in each trial.

The total duration that the participants were looking at the confederates (we refer to this as Look-At Duration) was recorded. Due to the fact that the participants wore the VR headset, which is not equipped with an eye tracker, a separate eye tracker could not be used. Thus, this measurement relied on the direction of the participant's head, using the head tracking feature of the VR headset. Finally, the duration in which each participant was looking at the confederates when it was the turn of the participant to respond was recorded. At that time, in the Eye-Contact condition the agents also looked at the participants, which we refer to as Mutual Gaze Duration.

6.1.5 Participants

The recruitment of participants was done mainly through e-mail and the social media of the department. No power analysis was performed prior the experiment to determine the size sample. The sample size was determined based on relevant studies using similar experimental design in the VR literature. All those interested declared their participation and chose day and time by using an online calendar tool. The inclusion criteria required the participants to be over 18 years old and to have Greek as their mother tongue. Individuals suffering from epilepsy or receiving psychoactive medication were excluded from the sample. Overall, 41 volunteers over 18 years of age participated in the study. As in Experiments 1 and 2, an important prerequisite was that the participants should not have been familiar with the original Asch (1951) experiment. One of the participants withdrew and did not complete the experiment, while two participants were excluded as they were aware of the original Asch (1951) experiment on which the study was based, and which could have biased their responses.

Therefore, in total, data collected from 38 valid participants, of whom 26 were female, were used in this study. Each participant was randomly assigned to one of the two experimental conditions. All participants provided their written informed consent to participate in this study.

6.1.6 Ethics statement.

The participants provided their written informed consent to participate in this study. The participants were fully informed of the risks that may arise from the use of VR. The research ethics committee of the Cyprus University of Technology reviewed the research protocol and considered that no further actions was required.

6.2 Experiment 3 Results

The analysis of the data was performed using the IBM SPSS Statistics (Version 21). Parametric tests were preferred for the analysis and used when the assumptions were met. Otherwise, non-parametric tests were performed.

6.2.1 Pre-VR Questionnaire

In the Low Behavioral Realism condition, the mean value of self-esteem was 33.06 while in the High Behavioral Realism condition it was 29.05. The mean and the standard error of self-esteem score for each condition are shown in Figure 8. The mean value for both experimental conditions was 30.89, which is considered to be a moderate self-esteem. Cronbach's alpha for the self-esteem items was .866, suggesting that the items have relatively high internal consistency.

An unexpected statistically significant difference was observed between the two conditions. A Mann–Whitney test showed that Self-Esteem was higher among participants in the Low Behavioral Realism ($M = 33.06$, $SD = 4.038$) than those in the High Behavioral Realism condition ($M = 29.5$, $SD = 4.696$); $U = 85.0$, $p = .009$. This difference is taken into account in further analysis. Specifically, to exclude the possibility that the results were biased due to this baseline difference, a correlation analysis was performed between self-esteem and each dependent variable under investigation. The analysis showed no correlations between Self-Esteem and any other dependent variable (e.g., conformity), except for the case of the two variables related to the participants' gaze behavior (Look-At Duration and Mutual Gaze Duration). Given this, the possibility that the results (e.g., for conformity) could be attributed to the difference in Self-Esteem can be rejected and safely attributed to the different conditions.

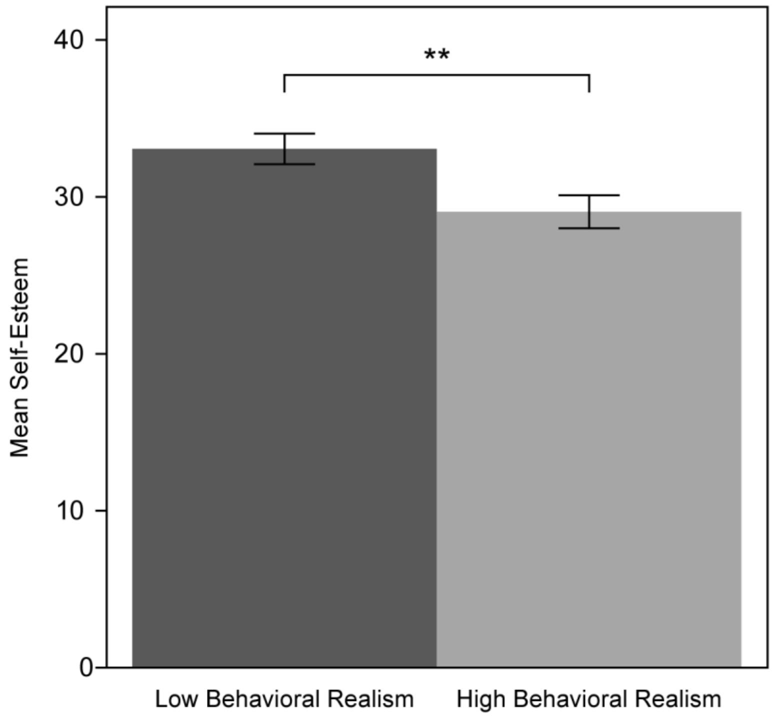

Figure 8: Means and standard errors of self-esteem in both experimental conditions

6.2.2 Post-VR Questionnaire

In order to reduce the number of variables from the post-VR questionnaire (Table 9), a principal component analysis (PCA) was performed. A single factor emerged from each set of variables and the factor loadings in the scoring variables Presence, Perceived Behavioral Realism, Social Presence, Responses Confidence, and Self-Reported Conformity are shown in Table 10. The scoring coefficients are the coefficients of the equations describing the factor scores in terms of the linear combination of the original variables. The factor that emerged from the questions about presence (Table 9, a) is interpreted as “the feeling of ‘being’ in the virtual room.” The factor that emerged from the questions on agents’ behavioral realism (Table 9, b) is interpreted as “the extent to which the virtual confederates behaved like real people.” The factor that resulted from the social presence questions (Table 9, c) is interpreted as “the sense of being together with the virtual confederates.” The factor that emerged from the questions regarding participants’ responses confidence (Table 9, d) is interpreted as “the participants’ confidence in their responses." Questions about self-reported conformity (Table 9, e) resulted in a single factor interpreted as "the statement that they were influenced by the agent's answers."

Table 10: Factor loadings and corresponding scoring coefficients for the factors resulted from principal component analysis

Variable	**Cronbach's α**	**Factor Loadings**	**Scoring Coefficients**
a. Presence	.621	F1	Presence
there		0.858	0.467
real		0.830	0.452
lab		0.641	0.349
b. Perceived Behavioral Realism	.852	F1	Perceived Behavioral Realism
behave		0.895	0.320
move		0.821	0.293
talk		0.773	0.276
feel		0.852	0.305
c. Social Presence	.830	F1	Social Presence
sameRoom		0.830	0.309
otherPerceived		0.866	0.322
otherListen		0.893	0.333
Alone		0.670	0.249
d. Responses Confidence	.597	F1	Responses Confidence
correctAnswers		0.724	0.389
difficult		0.666	0.358
doubts		0.725	0.390
confidentAnswers		0.605	0.326
e. Self-Reported Conformity	.802	F1	Self-Reported Conformity
myOpinion		0.924	0.541
otherOpinion		0.924	0.541

There was a statistically significant difference in Social Presence between the two experimental conditions. Specifically, participants in the High Behavioral Realism condition reported a higher sense of Social Presence (0.337 ± 0.187) than those in the Low Behavioral Realism condition (±0.374 ± 0.249). An independent sample t-test showed that the above difference is significant; $t(36) = -2.311$, $p = .027$. An independent samples t-test showed a statistically significant difference in Response Confidence between the two conditions; $t(36) = 2.485$, $p = .018$. Participants in the High Behavioral Realism condition (-0.358 ± 0.238) reported lower confidence about their responses than those in the Low Behavioral Realism condition (0.398 ± 0.181). The means and standard errors of the derived variables are shown in Figure 9.

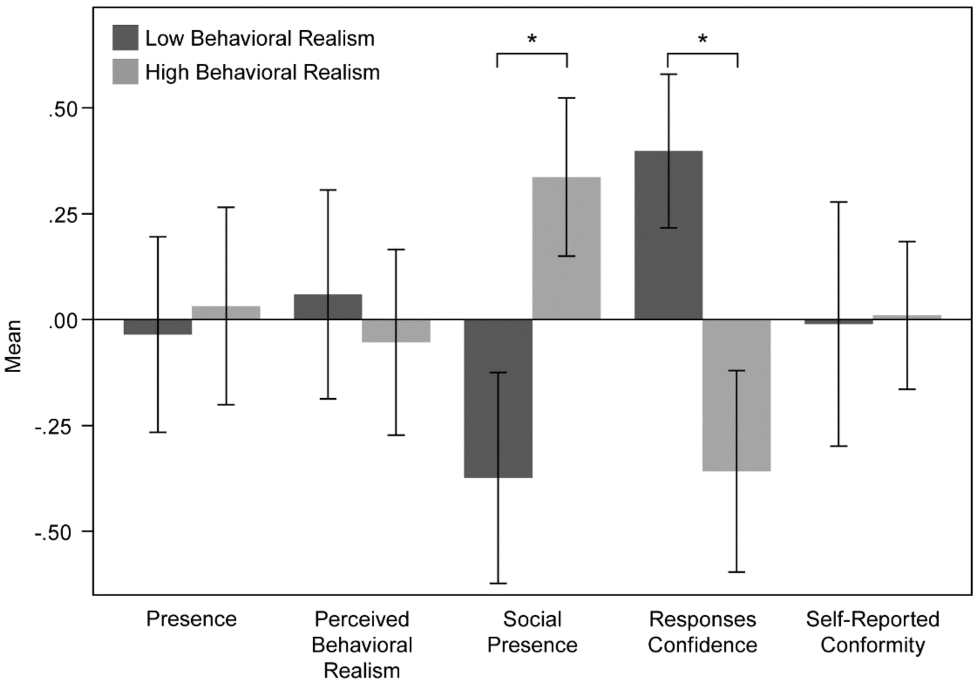

Figure 9: Means and standard errors of the variables resulted from factor analyses

6.2.3 Conformity

Initially, it was examined whether the participants' responses were influenced by the confederates' responses in the critical trials. In order to do that, we compared the participants' wrong answers in the trials where the confederates replied correctly (Non-Conformity Error) with the participants' wrong answers in the trials where the confederates also replied wrongly (Conformity Error). A Wilcoxon signed-rank test showed a statistically significant difference between Conformity Error and Non-Conformity Error in both Low Behavioral Realism condition; Z = -2.113, p = .035, and High Behavioral Realism condition; Z = -3.001, p = .003. This result suggests that participants in both conditions conformed with the confederates' judgments, as the participants made wrong estimates more often in the trials where the confederates gave a wrong answer, than the trials where confederates gave a correct answer. The means and standard errors of Conformity Error and Non-Conformity Error in the two experimental conditions are shown in Figure 10.

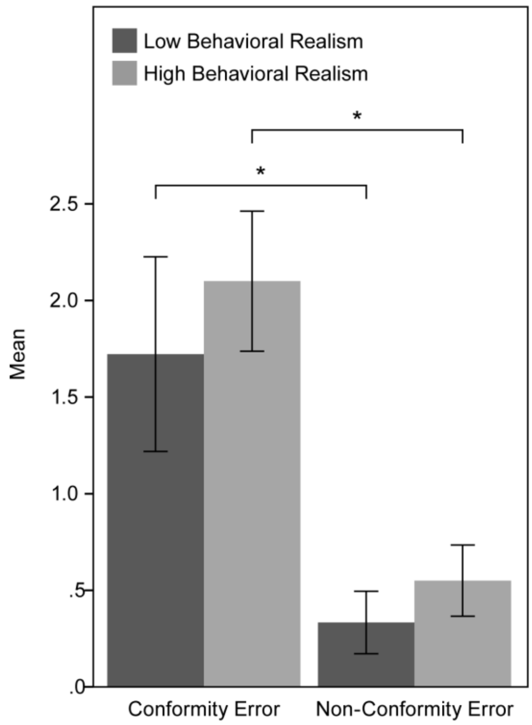

Figure 10: Means and standard errors of Conformity Error and Non-Conformity Error in both experimental conditions

For the purposes of the analysis, we built the CI scale (described in Section 6.1.4) to describe the level of the participants' conformity. The median of the CI was 1, while the mean was 1.47. In the Low Behavioral Realism condition, the median was 1 (mean = 1.39) while in the High Behavioral Realism condition the median was 1.5 (mean = 1.55). An independent samples t-test indicated that this difference was not statistically significant; t(36) = -0.225, p = .823. This result suggests that the virtual confederates' behavioral realism did not affect the conformity level. The mean and the standard error of CI for the two conditions are shown in Figure 11.

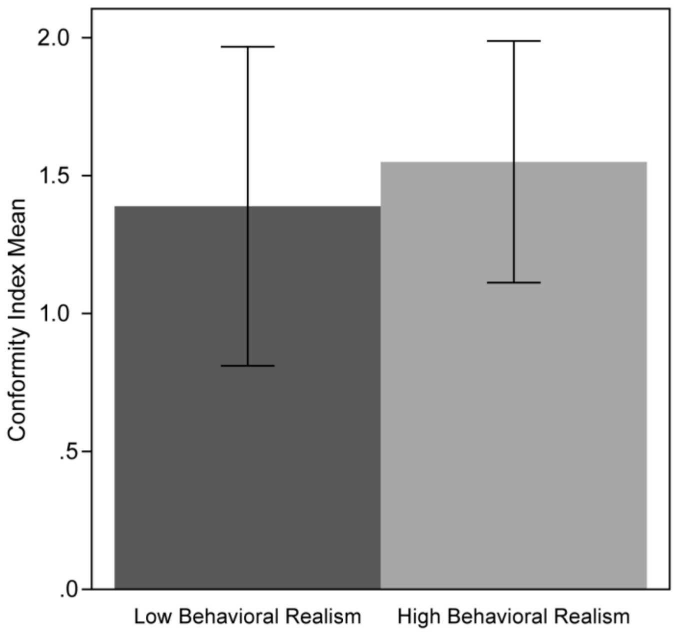

Figure 11: Means and standard errors of Conformity Index in both experimental conditions

6.2.4 Response Time and Participants' Gaze Behavior

The response time of the participants' answers in each of the critical trials was recorded, and the Mean Response Time was calculated. The mean response time of the participants in the Low Behavioral Realism condition was 1.6 seconds, while in the High Behavioral Realism Group it was 1.75 s. No significant difference in response time was observed between the two experimental groups; $t(26) = -1.285$, $p = .210$.

For the Look-At Duration, in the Low Behavioral Realism condition the mean was 205.32 s while in the High Behavioral Realism condition the mean was 192.8 s. This difference between the two conditions was not statistically significant ($t(36) = 0.232$, $p = .818$). However, this comparison between the two conditions could be influenced by the baseline difference in Self-Esteem (reported in Section 6.2.1), as the Look-At Duration was found correlated (reported in Section 6.2.5) with the participants' Self-Esteem in the High Behavioral Realism condition. For Mutual Gaze in the High Behavioral Realism condition, the mean was 8.34 s. At the corresponding periods of the process, in the Low Behavioral Realism condition, the participants looked at the confederates altogether for an average of 8.26 s.

6.2.5 Correlations

The participants' Self-Esteem did not seem to be associated with the level of participant conformity. A Pearson product–moment correlation coefficient does not reveal any correlation between Self-Esteem and CI in any of the two experimental conditions. This result is important as it indicates that the difference in the baseline level of Self-Esteem that emerged between the two experimental conditions does not impact the results. Self-Esteem was only correlated with Look-At and Mutual Gaze duration in High Behavioral Realism condition.

Table 11: Correlations between dependent variables in Low Behavioral Realism condition

	1	2	3	4	5	6	7	8	9
1. Conformity Index	-								
2. Self-Esteem	-.132	-							
3. Social Presence	-.247	-.228	-						
4. Presence	-.386	-.241	.433	-					
5. Self-Reported Conformity	.801**	-.246	-.322	-.308	-				
6. Perceived Behavioral Realism	-.272	.261	.560*	-.026	-.362	-			
7. Responses Confidence	-.356	.133	.346	-.076	-.316	.327	-		
8. Mean Response Time	-.516	-.426	.007	.403	-.111	-.524	-.055	-	
9. Look-At Duration	.072	-.092	.344	-.044	-.138	.321	.200	-.288	-
10. Mutual Gaze Duration	.020	-.033	.410	-.049	-.155	.369	.219	-.283	.918**

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Table 12: Correlations between dependent variables in High Behavioral Realism condition

	1	2	3	4	5	6	7	8	9
1. Conformity Index									
2. Self-Esteem	.306								
3. Social Presence	-.120	-.375							
4. Presence	.014	-.118	.498*						
5. Self-Reported Conformity	.575**	.026	-.160	.117					
6. Perceived Behavioral Realism	.156	-.357	.660**	.503*	.123				
7. Responses Confidence	-.123	.050	.327	.094	-.256	.293			
8. Mean Response Time	.020	-.282	-.068	.334	.200	-.182	-.700**		
9. Look-At Duration	.300	.484*	.007	.189	.232	-.154	.203	.074	
10. Mutual Gaze Duration	.281	.467*	.134	.184	.148	-.075	.277	-.048	.921**

*Correlation is significant at the 0.05 level (2-tailed).

**Correlation is significant at the 0.01 level (2-tailed).

Finally, we looked at the correlations between the dependent variables in both experimental conditions and some interesting results have emerged. The variables used for the correlations were derived from the PCA that was carried out for the post-VR questionnaire data and reported in Section 6.2.2. This is a common method used to both reduce the number of questionnaire variables that address similar components but also has the advantage of transforming ordinal variables to continuous ones. In such cases the use of a parametric test is indicated. In both experimental groups, a correlation between conformity (CI) and Self-Reported conformity was found (Low Behavioral Realism: $r = 0.801$, $n = 18$, $p < .001$; High Behavioral Realism: $r = 0.575$, $n = 20$, $p =$

.008), indicating that participants' conformity was conscious. Another interesting result was that, in the High Behavioral Realism condition, participants who stated that they were more confident about their responses responded more rapidly to the trials ($r = -0.700$, $n = 15$, $p = .004$). This correlation was not presented in the Low Behavioral Realism condition. The correlation values and significance levels for the dependent variables in Low Behavioral Realism and High Behavioral Realism conditions are summarized in Table 11 and Table 12 respectively. Since Mutual Gaze Duration is a subset of the value of Look-At Duration, the strong correlation observed between the two variables was expected in both conditions and does not provide any useful information.

6.3 Experiment 3 Discussion

The first goal of this study was to investigate whether informational conformity occurs within a group of virtual confederates in an IVE. Our prediction was confirmed as the participants' judgments were significantly influenced by those of the virtual confederates. The participants gave significantly more incorrect responses to the trials where the confederates gave an incorrect response than the trials where the confederates gave a correct response. This result has shown that within IVEs, conformity can be caused by the false judgments of a unanimous majority, even if the majority consists of artificial agents. In addition, the correlation between conformity and self-reported conformity, in both experimental conditions, indicates that the participants were consciously affected by the virtual confederates. This finding is in line with the results of the Experiment 2 where a similar result occurred. However, in the present study, the level of conformity is evidently higher, as only 7.69% of the participants in Experiment 2 conformed to the confederates, a percentage that is fairly small, in contrast to the 63.16% of Experiment 3. We speculate that the increased level of conformity can be attributed to several differences between the two studies, which include the increased task difficulty and the decreased sense of anonymity. With respect to task difficulty, the literature has shown that the ambiguity of the task is a critical factor affecting the degree of conformity (Coleman, Blake & Mouton, 1958). Specifically, participants tend to yield more easily to social pressure in a more difficult or ambiguous task than in an easier task. The difficulty of the task is also associated with the type of influence. In easy and obvious tasks, social conformity is attributed to normative influence (Deutsch & Gerard, 1955), as individuals change their judgment in order to match the group, but they keep their opinions private. On the other hand, in a difficult or unclear task, conformity can also be attributed to informational (Deutsch & Gerard, 1955) influence, as individuals change their judgment in order to be correct. In this experiment, we increased the difficulty of the task by projecting the stimulus for a limited duration (5 seconds), in order to target informational conformity.

Instead of the type of conformity, another factor that may have affected the level of conformity is anonymity. Studies showed that conformity is negatively correlated with the level of the individual's anonymity (e.g., Huang & Li, 2016). In VR, users are usually represented by virtual characters different from one's own self-representation, which may give them the perception of some kind of anonymity. In this study, the participants were deliberately asked to verbally introduce themselves by stating their first names, their age, and their occupation, in order to decrease any sense of anonymity. Further studies need to investigate the impact of the user's sense of anonymity on conformity in IVR.

Our second prediction, that the inclusion of eye contact would increase the level of conformity with the confederates, was not confirmed. This result replicates the outcome of another non-IVR research (Davey & Taylor, 1968), in which the authors attribute it to the fact that eye contact is only effective when combined with other social cues such as posture changes, gestures, and facial expressions. On the contrary, we confirmed our hypothesis that the eye contact manipulation can affect the sense of Social Presence. Specifically, participants in the High Behavioral Realism condition stated significantly higher social presence than the participants in the Low Behavioral Realism condition. However, the higher sense of social presence did not translate into a higher conformity level. Literature suggests that a higher sense of social presence is related to higher social influence (Oh et al., 2018), but it did not occur in this study on conformity, contrary to our prediction. An explanation of that is relevant to the type of conformity, which depends on the motives that led the participants to conform. Specifically, as mentioned above, the conformity in this case was informational, as the participants adopt the confederates' opinions in order to fulfill their desire to be correct, rather than to fit in, which is the case of normative conformity. An interpretation could be that informational conformity with virtual agents does not depend on the humanization of the computer (which is the case of social presence), but on the belief that the agents are reliable regardless of the extent to which they are perceived as social entities. In this case, the type of the task (line length comparison) may contribute to informational conformity, as computers are considered to be reliable in these types of tasks (Weger, Loughnan, Sharma & Gonidis, 2015). This could be studied by testing the impact of social presence on conformity with virtual agents in a task that humans are considered to be more reliable than computers (e.g., moral judgment). In that case, we believe that the sense of social presence could affect the level of conformity.

Interestingly enough, the inclusion of eye contact as a social cue appears to influence the participants' overall subjective experience. Participants expressed more doubts (lower responses confidence) about their responses when social pressure was exerted by confederates who made eye contact. This finding suggests that although that the level of the virtual confederates' behavioral realism had some influence on participants' decision-making process, it was probably not strong enough as there was no impact on their final responses. This finding can also be explained by the stronger sense of social presence that is associated with social influence (Oh et al., 2018).

Nonetheless, no significant differences regarding the evaluation of the agents' behavioral realism emerged between the two conditions. Participants in the High Behavioral Realism condition, even though they stated that the agents felt more socially present, did not rate them as more realistic than the participants in the Low Behavioral Realism condition.

Some additional findings regarding the participants' response times emerged between the two experimental conditions. Even though the participants' response time did not appear to be influenced by the eye contact manipulation, in the High Behavioral Realism condition it was found to be associated with the participants' confidence. Specifically, participants in the High Behavioral Realism condition who stated lower confidence in their responses took significantly longer to respond. This result is in line with the literature that suggests that post-decisional confidence is negatively correlated with choice latency (e.g., Zakay & Tuvia, 1998).

An unexpected setback of the study was the difference that arose in the reported Self-Esteem between the two experimental conditions. Participants in the Low Behavioral

Realism condition reported higher Self-Esteem than participants in the High Behavioral Realism condition. In order to exclude the possibility that the results were biased due to these baseline differences, a correlation analysis was performed between self-esteem and each dependent variable under investigation. The analysis showed no correlations between Self-Esteem and any other dependent variable (e.g., conformity), except for the case of the two variables related to the participants' gaze behavior (Look-At Duration and Mutual Gaze Duration). Given this, the possibility that the results (e.g., for conformity) could be attributed to the difference in Self-Esteem can be rejected and safely attributed to the different conditions. Regarding the measures related to the participants' gaze behavior mentioned above (Look-At Duration and Mutual Gaze Duration) that were found to be correlated with Self-Esteem, it was shown that, in the High Behavioral Realism condition, participants with higher self-esteem tended to turn their gaze more frequently towards the agents and performed more mutual gaze with the agents than the participants with lower self-esteem. This association is supported in the literature (Fugita, Agle, Newman, & Walfish, 1977; Vandromme, Hermans & Spruyt, 2011).

The impact of the participants' Self-Esteem on their gaze behavior, observed in the High Behavioral Realism condition, consists of an interesting result that needs further investigation. The participants' gaze behavior was not the focus of this study, and the collected data were not very accurate compared to the data provided by available eye tracking HMDs (e.g., [18]). Hence, a more in-depth analysis of the participants' gaze behavior was not possible. However, this study shows that the use of IVR and virtual agents can be ideal for such of experiments, thanks to its ability to provide a high level of experimental control between multiple experimental sessions.

[18] vive.com/eu/product/vive-pro-eye

7 Conclusions

7.1 General Discussion

Throughout this study we demonstrated how VHs can influence the user's decision making within IVEs through conformity. Three experiments were conducted and presented in section 4, 5 and 6 in order to answer the research questions that had been identified. The individual conclusions of each experiment were presented in the respective sections. In this section we will summarize the conclusions drawn from the whole of this study, in conjunction with research questions raised and described in Section 3.1.

RQ 1: *Can social pressure from a group of VHs in an IVE lead to normative conformity?*

The first attempt to answer whether VHs can elicit social conformity was made in Experiment 1. However, the results of Experiment 1 showed that participants did not conform to the wrong answers given by the group of virtual confederates. It is important to state that the correct answers in the trials used for the study were deliberately obvious and undeniable, so any possible distortion on the participants' responses would constitute an extreme form of normative conformity. We speculated that this was the reason that participants did not conform to the responses of the agent confederates. The results, however, showed that the participants' response time to the trials was affected by the virtual confederates' responses, indicating some form of social pressure. However, the hypothesis (Hypothesis 1) that social pressure from a group of VHs in an IVE lead to normative conformity was supported by the results of Experiment 2. Even though the majority of participants did not yield to social pressure, a significant portion of the participants did. It is also important that normative conformity occurred in the first critical trials, where a significant effect of social pressure on response time was also observed in line with the results of Experiment 1. These findings indicate that the impact of the VHs' social pressure on conformity and the participants' response time was fading by the time. This effect can be explained by the CASA (Nass & Moon, 2000) theory which argues that social responses to VHs is mindless and automatic. The unexpected behavior of the group of VHs to give an obviously incorrect answer to the trial, exerted social pressure towards the participants causing them to delay their responses or even to conform. But as this situation recurred, participants had time to familiarize themselves with the situation so that they could respond consciously. This explanation is also in line with the threshold model of social influence (Blascovich, 2002) arguing that social influence threshold for high-level response systems, such as conscious actions is much higher than for low-level response systems such as unconscious actions and reflexes.

RQ 2: *Can social pressure from a group of VHs in an IVE lead to informational conformity?*

In Experiment 3, we test the hypothesis that social pressure from a group of VHs in an IVE lead to informational conformity. In order to target on informational influence, we increased the task difficulty by limiting the stimuli projection duration. The hypothesis (Hypothesis 2) was supported by the results as the participants' judgments were significantly influenced by those of the VHs. The extent of conformity in Experiment 3 was evidently higher than Experiment 2.

RQ 3: *Does the level of agency affect conformity within a group of VHs in an IVE?*

The hypothesis (Hypothesis 3) that agency, the extent to which the user believes that a VH is controlled by another user (avatar) rather than a computer through an algorithm (agent), has an impact on conformity with VHs was tested in Experiment 2. However, the results did not support the hypothesis. The participants conformed to the same extent regardless of whether the virtual confederates were introduced as avatars or agents. This result is in line with the theory that responses to computers that exhibit human characteristics are mindless and automatic (Reeves & Nass, 1996; Nass & Moon, 2000) and, therefore, people will respond socially to VHs regardless of the level of agency.

RQ 4: *Does the level of VHs' behavioral realism affect conformity in an IVE?*

The impact of the virtual confederates' behavioral realism was tested in Experiment 2 as well as in Experiment 3. The hypothesis (Hypothesis 4) that increased behavioral realism will lead to increased conformity was not supported in either experiment. Interestingly enough, in Experiment 3 the behavioral realism manipulation had an influence on the participants' confidence. Participants expressed more doubts about their responses in the High Behavioral Realism condition. This finding suggests that behavioral realism had some influence on the participants' decision-making process.

RQ 5: *Does the sense of social presence affects conformity with VHs?*

The participants' sense of social presence towards the virtual confederates was assessed in Experiment 2 as well as in Experiment 3. Although, in both experiments, social presence was found to be associated with the VHs' behavioral realism (higher level of behavioral realism led to a stronger sense of social presence), the hypothesis (Hypothesis 5) that increased social presence will lead to stronger conformity was not supported. These results are not in line with the literature that suggests that increase in social presence is related to a stronger social influence.

7.2 Summary of Contributions

On a theoretical level, the results of this study extended previous research human-VH interaction in IVEs, by expanding the existing literature with additional knowledge. We provided empirical evidence that a group of VHs can influence the user's decision making within IVEs through conformity. In contrast with previous studies (Midden et al., 2015) using non-immersive technologies, this study provides evidence that normative influence from a group of VHs in IVR environments may lead to conformity. However, the impact of normative influence demonstrated in this study (on participants' responses and response times) was short-lasting, since it was observed mainly in the initial critical trials. This result indicating that normative conformity with VHs may affect only low-level reactions but not conscious behaviors.

Additionally, the work conducted in this thesis provides evidence that a group of VHs in IVR environments can induce informational conformity, in line with previous studies (Swinth & Blascovich, 2001, as cited in Blascovich, 2002). Also, we showed that increasing behavioral realism, by adding an additional social cue such as eye contact, has an impact on the users' sense of social presence as well as their overall experience in the virtual environment, regardless that the level of conformity was not affected. This study confirms previous findings (e.g., Guadagno, Blascovich, Bailenson & McCall, 2007) on the importance of designing VHs with realistic behavior toward the users in order to enhance one's experience in IVEs.

Finally, the outcomes of this study highlight the need for further investigation in order to understand the factors that affect conformity with VHs in IVEs. Some possible directions for further research that emerged from this study are discussed in Section 0.

7.3 Impact of Outcomes & Potential Uses

The outcomes of this work can be exploited by the creators or the moderators of IVR applications using VHs in order to influence and direct the users' decision-making, through conformity. Social conformity is not limited to simple perceptual tasks, as in this experiment, but extends to other forms of behaviors and attitudes. The rapid increment of the use of consumer IVR technologies, beyond entertainment and video games, leads to the re-creation of many real-world activities in IVEs. An important outcome of this study was that conformity was the same regardless of whether the VHs were introduced as agents or avatars. Therefore, the recruitment of virtual agents for indirectly influencing the user could be used in various ways in different kind of VR applications. For example, in an IVR games, virtual agents can be used to indirectly influence the users' in-game behavior order to enhance their experience, or to push them to perform a purchase a virtual asset. Also, virtual agents can be used to direct consumer behavior in future IVR retail stores (e.g., Papagiannidis, Pantano, See-To, Dennis & Bourlakis, 2017). Another way that conformity with VHs can be useful is in the context of clinical interviews. Studies (e.g., Lucas et al., 2014) showed that VH-interviewers can increase willingness to disclose and elicit more honest responses. In these applications, other virtual patients can be used, and, in a group interview, to influence the real patient to become more revealing and honest, through social conformity.

7.4 Limitations and Future Work

In this section the limitations of this study are discussed along with further research directions that have emerged. This work provided empirical evidence that a group of VHs can influence the user's decision making within IVEs through conformity. However, the level of normative conformity is evidently lower than the level of conformity reported in studies using human majorities (Asch, 1951). Further research needs to be done in order to compare conformity with VHs in IVR, and conformity with real humans in the physical world. Also, the results of this study showed that the level of agency (the extent to which the user believes that the VHs are controlled by other users rather than a computer) does not affect the level of normative conformity or the users' sense of social presence. However, we did not test the impact of agency on informational conformity. Further research must be conducted in order to investigate the impact of agency on informational conformity with VHs in IVEs.

Also, in this study, we used a simple and objective perceptual task. The impact of the VHs' opinion on more social-objective tasks, or in real-life scenarios, is also an interesting avenue to explore in a future study. Additionally, as already mentioned, informational conformity can affect not only the behavior of the individual but also more internal and mental changes may occur because of it (Midden et al., 2015). For that reason, the possibility of more permanent effects of conformity with VHs within IVEs is important to be investigated.

In experiment 3, we observed a relationship between the participants' Self-Esteem on their gaze behavior in the High Behavioral Realism condition. This is an interesting result that can be further investigated in a future study. The gaze behavior data collected in this study was not very accurate, since the gaze direction of the participants was estimated using the head orientation of the HMD. Eye tracking HMD devices that provide accurate gaze behavior data are available and can be used for deeper investigation of the participant' gaze behavior in future studies using VHs in IVEs.

Finally, an additional aspect that would be interesting to be studied, is the impact of the users' embodiment on conformity with VHs. The sense of embodiment is the perception of the virtual body by the participant as his biological body (Kilteni et al., 2012). This could be achieved by using real-time full-body motion tracking technology and by mapping the participant's movements to those of their virtual avatar. We assume that strengthening this illusion will eliminate the distinction between the self and the avatar, making the participant a direct recipient of social pressure and thus affecting the rate of conformity. Additionally, studies (Slater & Sanchez-Vives, 2014) showed that people tend to alter their attitudes and behaviors to match the expectations that are implied by the attributes of their virtual body. Future studies should be conducted to investigate the impact of the user's body characteristics on conformity with VHs.

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