Influence of Interactivity and Social Environments on User Experience and Social Acceptability in Virtual Reality

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Abstract

Nowadays, Virtual Reality (VR) technology can be potentially used everywhere through wearable head-mounted displays. Nevertheless, it is still uncommon to see VR devices used in public settings. In these contexts, unaware bystanders in the surroundings might influence the *User Experience* (UX) and create concerns about the *social acceptability* of this technology. The user acts in a *Social Environment* (SE), characterized by surrounding people's number, proximity, and behavior. Simultaneously, VR applications often require a different *degree of interactivity* concerning body movements and controllers interaction. In this paper, the influence of *Social Environments*, and *degree of interactivity* on *User Experience* and *social acceptability* is investigated. Four Social Environments were simulated employing 360° Videos, and two VR games developed with two levels of interactivity. Results showed a statistically significant influence of Social Environments on *Overall UX as well as Public VR, Interaction, Isolation, Privacy and Safety acceptability*, and of the degree of interactivity on *Presence, Valence, Arousal, Overall UX, UX Hedonic quality, and Safety acceptability*. Findings indicate that Social Environments and degree of interactivity should be taken into account while designing VR applications.

Keywords: Virtual Reality, Social Acceptability, User Experience, Social Environments, Interactivity, 360° Videos

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Virtual reality; Human-centered computing—Ubiquitous and mobile computing; Human-centered computing—Interaction design;

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(a) Transition Object (b) Transition Mechanism

Figure 1: Transition process, a) the transition object pops up in the VR Simulated Social Environment after some seconds from the beginning of the 360° Video, b) the user grabs the transition object using the dedicated grab buttons on the controllers, bringing it towards its head and releasing the button(s) to put it on virtually.

1 Introduction

In the last few years, we witnessed an increase in the popularity of Virtual Reality (VR) technology, particularly on wearable head-mounted headsets. This might be due to the advancement in the quality of the experience offered (e.g., more comfortable headsets and more engaging content) but also to different and affordable VR consumer products released on the market. The potential fields of application of this technology are considerably wide. Nevertheless, it is still very uncommon to see this kind of devices used in daily contexts other than home or industrial ones. As VR devices became all-in-one solutions (untethered VR), this technology can be potentially used everywhere. Notwithstanding, the presence of unaware observers in the surrounding area might have an influence on many aspects including: i) the User Experience (UX), which is the "user's perceptions and responses that result from the use and/or anticipated use of a system, product or service" [17] in terms of sense of Presence, Emotions, Pragmatics quality, Hedonics quality, general Usability; ii) the social acceptability of this technology, which is the phenomenon of judging a technology introduced in the future from comfort or discomfort of both the performer and the observers [1] [9].

It is important then to delve deeper into these phenomena and understand the drivers that guide the people to use and accept this technology in one situation or another. It is well-known that User Experience is one of the most important factors of any product's success. Nobody is prone to frequently use a product without a satisfying experience, especially when not strictly required in some scenarios. The social acceptability of VR technology is still a new topic of research. Some studies [1] [11] [23] [35], have only recently addressed some relevant research questions in this area, but a wide range of those remains incomplete or unexplored. In the case of VR usage in social settings, the user acts in the so-called *Social Environment* (SE), which can be defined as an environment characterized by the spatial layout and by the people being there (number of people, their proximity, their behavior). Moreover, depending on the VR experience played, the tasks might require a different *degree of interactivity* defined by the required range of body movements and level of interaction with the controllers. Given the attention already paid to those aspects in the aforementioned studies, researching how the scale of *Social Environments* (number of people and their proximity in the SE) and *degree of interactivity* are likely to produce informative and relevant results on User Experience and social acceptability of VR technology. By exploring these research variables as reported in this paper, it aims to enhance the understanding of where and how

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this technology can be successfully applied and accepted as well as gaining insights about the suitable degree of interactivity for certain situations towards better VR experiences.

2 Related Work

2.1 360° Videos in VR

Many of the last consumer VR devices on the market enabled the success of 360° Video technology in VR by supporting broad visual fields of view and including head orientation sensors. *360° Videos* are "immersive spherical videos, mapped into a 3D geometry, where the user can look around during playback using a VR head-mounted display (HMD). This gives the viewer a sense of depth in every direction" [15]. A public database of 360° Videos has been created, including Arousal and Valence, Emotions in VR ratings for each of them, showing that 360° Videos are useful means to evoke emotional responses in the participants [22]. It has also been successfully validated using 360° videos that it is possible to measure induced emotions with a continuous rating model in VR [43]. Despite some skepticism about the quality of the VR experience, it was shown that 360° videos could provide good perceptual quality scores and proper levels of Presence [40].

2.2 User Experience

User Experience (UX) has become a vast topic with new challenges that keep coming on specific areas of interest. When designing and studying UX for Virtual Reality, a more specific model encompassing a broader range of facets is necessary. Marc Hassenzahl, based on his previous studies [12] [13], presented the hedonic/pragmatic model of UX [14], which hypothesize that users' perceive interactive products along two different dimensions: i) *pragmatics* which "refers to the product's perceived ability to support the achievement of 'do-goals' (e.g., making a telephone call, finding a book in an online bookstore, setting-up a webpage)"; *hedonics*, which "refers to the product's perceived ability to support the achievement of 'be-goals' (e.g., being competent, being related to others, being special)". In 2018, Tcha-Tokey et al. proposed the User Experience in Immersive Virtual Environment Model (UXIVE model) [39], which shows the main components of UX in VR and their interactions with one another. Among such components, Presence, Immersion, and Emotion need a brief introduction, which makes these UX related constructs clearly defined in the study.

2.2.1 User Experience related constructs

Presence and Immersion: There are many theories regarding what it means to be present or immerse in the Virtual Environment. These two terms, *Presence* and *Immersion*, are often used interchangeably to describe Virtual Reality experiences. However, it is important for clarity of research and description to make a neat distinction between the two of them. According to Slater and Wilbur, *Presence*, is "a state of consciousness, the (psychological) sense of being in the virtual environment", whereas *Immersion* is "a description of a technology, and describes 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" [37]. In-depth research on the dimension of Presence is not the scope of this study; therefore, it is justified to adopt the reported definition to provide the basic concept as a standard reference. Nevertheless, the most recent and precise definition of Presence can be found in the literature [36]. **Emotion:** Measuring emotions in Virtual Reality is particularly challenging. A typical approach is using dimensional models, firstly introduced by Russel and Mehrabian [26] [31], which identify emotions using two or three continuous independent dimensions: *Valence* (pleasure and displeasure), *Arousal* (excitation level), *Dominance* (level of control in a situation).

2.3 Interactivity in VR

Interactivity in VR "is not merely the ability to navigate the virtual world; it is the power of the user to modify this environment. Moving the sensors and enjoying the freedom of movement do not themselves ensure an interactive relation between a user and an environment: the user could derive his entire satisfaction from the exploration of the surrounding domain. He would be actively involved in the virtual world, but his actions would bear no lasting consequences" [32]. Steuer [38] identifies three main factors that influence the degree of interactivity in VR: speed, range and mapping. Moreover, in the literature [5] [24], there are some studies on Interaction Fidelity (IF) and its impact on UX, arguing that the success of VR applications depends on the high-fidelity sensory stimuli. Rogers et al. showed that different levels of IF should be chosen according to the kind of interaction task [30]. A high IF has the advantage of being perceived as more natural, but a low IF benefits from the similarities with commonly used computer interfaces [25].

2.4 Social Acceptability

For any new technology, investigating acceptability in general, and social acceptability, in particular, is crucial to assess its future success and adoption rate. *Social acceptability* refers to a prospective judgment toward a technology or measures to be introduced in the future [9]. Performer and observers act in the so-called *Social Environment* (SE), an environment characterized by a specific spatial layout and the people's number, proximity, and behavior.

2.4.1 Social Environments - Personal Space

Previous studies on Social Environments and VR tackled research topics from users' perspectives of such an environment. This showed relevant findings by investigating the concept of Personal Space (PS), which could be identified "as a flexible maintained around oneself in real-life situation" [4]. Bönsch et al. showed how PS was affected by Virtual Agents' (VAs) emotions (happy or angry) and number (one or three VAs) through a within-subject user study in a CAVE, finding that angry VAs leads to larger distances compared to happy ones and that single VAs are allowed closer compared to the group of three [4]. Pohl and Achtelik [27] investigated PS and proposed some multilevel options for a detailed selection of which objects or avatars to include. This was done by registering users' PS preferences for avatars or objects displayed through 3D rendering or 360° video.

2.4.2 Social acceptability of wearables

In the literature, there are many studies on the acceptability of wearable devices and gestures. All of those analyze observers and/or the performer's different feelings when using wearable devices in public contexts rather than private ones. The main results of those show high variability in the rate given from one participant to another when having to judge social acceptability. The situation in which the device is used but also the device's physical appearance (visibility) is relevant [35] [28]. Besides, an interesting finding is that performers' level of acceptability is more favorable than the spectators; this is because spectators are often not familiar with the technology used [20]. Culture and gender have also been shown to influence the spectators' perspective on the acceptability of a device [29]. Furthermore, past research on Virtual and Augmented Reality wearable applications for fragile users (e.g., Hololearn [2] for the elderly or SMUP [44] for young adults with cognitive impairments) have considered situations in which such systems are used in a Social Environment in which peers in the surrounding physical space share the performer's view of the virtual environment on an external display. These studies suggest that this setting promotes verbal communication between observers and performers and increases engagement and motivation for both, also contributing to improving social acceptability. A significant problem in the research conducted on the topic is the lack of focus on tools to measure and quantify social acceptability [11]. The

WEAR scale presented by Kelly is one of the best attempts to create a structured set of quantifiable social acceptability questions [19].

2.4.3 Social acceptability of input modalities and gestures

The low visibility of input modalities and gestures have been discovered to be more socially accepted than extravagant and noticeable movements [1]. That is very true, especially if there is no acquaintance between performers and spectators. Besides, the safety of input modalities and gestures in public places constitutes a significant concern [35]. A relevant study in the field is the one on the social acceptability of AR gestures published by Hsieh et al. [16]. The study confirms that the location of use and strangers' presence play a crucial role in AR technology adoption. A related study that aimed to identify desired attributes for 3D hand interaction design and rank hand-interaction techniques is the one from Kang et al. [18], which explored MR three hand-interaction techniques, such as gaze and pinch, touch and grab, and worlds-in-miniature interaction, for selecting and moving virtual furniture in a 3D scene. Besides, hands-free interaction modalities typical of MR has been recently implemented for VR devices (e.g., Oculus Quest) thanks to on-camera hand-tracking and gesture control. Voigt-Antons et al. [42] in their research investigated using the Oculus Quest VR headset, effects on User Experience when varying interaction modality (controller vs. hand tracking) in two different tasks.

2.4.4 Social acceptability of VR Technology

There is still little research on the social acceptability of VR technologies. However, there has been an increasing interest in the topic as the following very recent (2018-2019) studies show:

Schwind et al. [35] showed that social acceptability from the spectator perspective is highly dependant on the situation and environment. In settings like bedroom, metro, or train, the use of VR seems to be acceptable. In contrast, in settings where it is expected to have a social interaction like living rooms or public cafe, the acceptability is highly reduced. This study set the basis for future investigations but still keeps the limitations of an online study where participants are not experiencing a face to face interaction with the technology they are judging. Furthermore, the validity of results from the performer's perspective remains unexplored. In a study performed by Alallah et al. [1], on the social acceptability of input modalities for HMD display, it is argued that from the performer's perspective considering a social context appropriate to the use of the technology is mostly related to their mental construct about accepting or rejecting a specific gesture in that setting. In particular, the visibility of a gesture is the crucial variable that influences both performer and spectators' acceptance. This constitutes an interesting result, which it would be important to verify also in a pure VR study. Allalah et al. only focused on AR technology that is not affected by significant issues like safety related to the impairment of the external world vision typical of VR HMD. Mai et al. investigated the influence of spatial layout on users' VR experience [23], testing and comparing it while being surrounded by other people with and without any physical barrier and while being in an empty room. Their study shows that people tended to be comfortable using the VR in all three settings. The cognitive threats due to the spectators in the public condition were reported to affect the User Experience only in the first minutes. There were no meaningful changes between the public conditions with and without barriers. The users reported that the sense of safety is related to a positive attitude towards others and familiarity with the surroundings. This study has been focused on the spatial layout of the physical environment more than on spatial position. Moreover, the UX assessment leaves out hedonic and pragmatic qualities of the experience and does not take into consideration different degrees of interactivity of the tasks performed by the user. Understanding and identifying the factors influencing the performer experience and the spectators have been pursued by Eghbali et al. [11]. Their findings showed that in a university's public context, the use of a VR headset does not annoy or make the spectators uncomfortable . Besides, from the performer's perspective, a sense of Presence can be experienced even while surrounded by people. Being isolated is interpreted positively by the user but negatively from the spectators' point of view, which would have liked to understand what was going on during the experience. One of the users' major concerns was related to safety issues like fearing of bumping into objects or people, which are implications of VR headsets' full immersion. A first attempt to face this challenge can be found in the research performed by Valentini et al. [41] on tools for 3D scene reconstruction in VR environments to improve obstacle awareness and enhance interaction. Furthermore, as in other studies, there is no control and variation on spatial position and setting. Thus, there is a need to check whether UX's resulting factors still apply to different environments.

2.5 Objectives

This work aims to contribute to the advancement of knowledge and understanding of the factors that influence VR technology adoption in social settings. The objective is to overcome limitations and filling some gaps identified in previous research [1] [11] [23] [35] as described in 2.4.4. To that end, it is studied how the scale of Social Environments (number of people and their proximity in the SE), in which a VR experience is performed and the interactivity of the tasks to be done influence the User Experience and the social acceptability of VR. Some research questions of interest have been designed to explore and fill some of the spotted research gaps.

1. How does the scale of Social Environments influence User Experience and/or social acceptability of VR?

2. How does the degree of interactivity influence User Experience and/or social acceptability of VR?

3. How does the combination of the scale of Social Environments and degree of interactivity influence User Experience and/or social acceptability of VR?

3 METHODS

This study was designed following an inductive approach since it allows exploring and conducting freer research on the topic and only at the end, discover and building a theory based on the results [33]. As an experimental setting, a controlled laboratory was chosen to have more control of the experimental environment and conditions. Due to the emergency generated by the spread of the virus COVID-19 in the first half of 2020, this choice was also the most reasonable option. In fact, it would have been risky and unethical to conduct the study in real social environments, where the power of the stimuli and, consequently, their impact on results would have been higher. The alternative setting designed, which uses Simulated Social Environments in VR (SSE-VR) through 360° videos, provides already sufficient reliability to identify initial variable trends, leaving testing and additional validation in real social environments to future works. The adopted approach to collect answers/data is a mixed approach with a higher loading on quantitative than qualitative research. A tendency to perform quantitative research is motivated by the need to measure and analyze causal relationships between variables, which is crucial to find correctly structured answers [8]. Given the high number of experimental conditions (N = 8) and a target sample of more than 25 participants, a within-subject design with randomization of conditions has been selected. Lastly, to gather and analyze the resulting data from the study, web-based questionnaires composed of multiple-choice scales and open-ended questions have been utilized. All the quantitative data has been classified and analyzed using the

(a) One Distant Person (b) Few Distant Persons (c) Few Close Persons (d) Many Close Persons

Figure 2: Example of Simulated Social Environments in VR (SSE-VR): for including the SSE-VR, some 360° Videos made available on Youtube by Sygic Travel, including a different number of people or level of proximity, have been selected: a) One Distant Person - Dubai, Safa Park, b) Few Distant Persons - Milan, Arch of Peace, c) Few Close Persons - Paris, Arch of Defense, d) Many Close Persons - Vienna, Christmas Markets.

statistical software IBM SPSS [1] to run descriptive and inferential statistical analysis. A two-way repeated-measures Analysis of Variance (ANOVA) was identified as the appropriate statistical test to run. ANOVA has higher statistical power compared to non-parametric tests, and it is also quite robust to violation of normality [3]. It allows comparing the mean differences between groups that have been split on independent variables (Social Environments and degree of interactivity). Hence, giving information on their effect on some dependent variables (Presence, Emotions, User Experience, Social acceptability).

3.1 Test setup

The study was conducted in a lab room equipped with a head-mounted display (HMD) - Oculus Quest. It enables users to get six degrees of freedom in movements. The developed Unity application includes different environments categorized in Simulated Social Environments (SSE-VR) and VR game environments. In the SSE-VR, some 360° Videos made available on Youtube by Sygic Travel [2] [3] , fitting specific design requirements, have been selected. Specifically, all the videos selected needed to have been shot from a static point of view with an unobstructed view and have a different number of people visible to the camera with different levels of proximity. Suitable locations of four different cities are shown in the selected videos (Fig. 2). Each of them provides different settings in terms of the number of people and the proximity required: one distant person, a few distant persons, few close persons, many close persons. From the SSE-VR, there is the need to have a transition mechanism to the VR game environment. The designed transition mechanism (see Fig. 1) requires a transition object (3D model of a Headset), which pops up in the SSE-VR after some seconds from the beginning of the 360° Video. The user can grab it using the dedicated grab buttons (Hand Trigger buttons) on the controllers, bringing it towards its head and releasing the button(s) to put it on virtually. The change of scene and the appearance of a game loading window gives visual feedback that the transition is happening. After the transition, the user finds herself/himself in one of two possible game environments: static game or dynamic game.

The static game (see Fig. 3) aims to be playable with a low level of interactivity. It only requires head movements for looking around, one hand movements for pointing around by using a controller, and a finger pressing a button to select. The game objective is to select numbers in the correct order from 1 to 50 in the shortest time possible.

[1]https://www.ibm.com/analytics/spss-statistics-software

[2]https://www.youtube.com/channel/UCN027-rS7Z7QmmR336HJA1Q

[3]https://www.sygic.com/it/travel

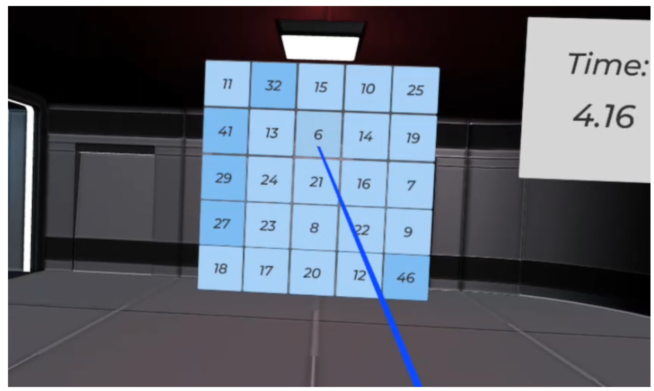
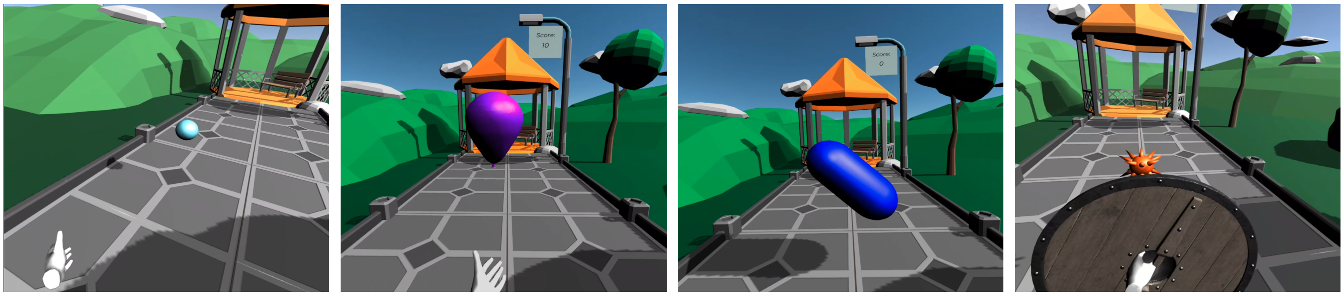


Figure 3: Static game UI, which is composed of 25 cells containing numbers. The 1-25 numbers are distinguished from the 26-50 using a different shade of light blue (contrast ratio higher than 7:1 for an easier VR readability [21]). If a number in the range 1-25 is correctly selected, it disappears, leaving space for a random number from 26-50; otherwise, the cell becomes red-colored, and the number cannot be selected anymore.

The dynamic game (see Fig. 4) aims to be playable with a high level of interactivity. The inside-out tracking functionality and the two hand-held controllers enable complex forms of interaction in the virtual environment. This game objective is to perform four different kinds of tasks:

- Lateral Grabbing: grab light blue spheres that first approach the user from a random transversal position (Fig. 4a). This interaction is meant for the user to position and grab using the preferred controller and require lateral body movements to intercept the object trajectory.
- Forward Grabbing: grab a purple balloon that free falls from above (Fig. 4b). This interaction is meant for the user to do longitudinal movements and grab. Besides, it might also require forward movements to be able to intercept the purple balloon free-fall trajectory.
- Dodging: dodge a dark blue obstacle that front approaches the user from a random transversal position (Fig. 4c). This interaction is meant for the user to perform high-range lateral movements to dodge the dark blue obstacle.



(a) Lateral Grabbing (b) Forward Grabbing (c) Dodging (d) Shielding

Figure 4: Dynamic game UI, examples of the four different kinds of tasks: a) Lateral Grabbing, b) Forward Grabbing, c) Dodging, d) Shielding. The inside-out tracking headset functionality and the two hand-held controllers empower to obtain 6 degrees of freedom in head and body movements. These features enable complex forms of interaction all over the Virtual Environment. The shown objects randomly spawn and go towards the user one by one.

- Shielding: use a shield to protect from a red spiked ball front approaching the user from a random transversal position (Fig. 4d). This interaction is meant for the user to vary the controller usage by keeping pressed different buttons to activate the shield.

While being in either game environment, the user can still hear the audio coming from the previous 360° video played in the SSE-VR. This aims at making the user feel that he is still acting in the Social Environment even when he does not see it anymore.

Category	Statement
Public VR	1. It felt appropriate to use the VR headset in a public place.
	2. It felt rude to use the VR headset in a public place.
	3. I felt uncomfortable being watched by others while using the VR headset a public place.
User	4. The VR device in public space made me look cool.
Public Communication	5. It would be useful for me if the people around me could communicate with me.
VR Interaction	6. It felt awkward doing head movements while using VR in public.
	7. It felt awkward performing body movements and hand gestures while using VR in public.
Isolation	8. I did not like the fact that I was isolated from the rest of the people in a public space.
	9. It would be interesting if the other people could see what I was doing and seeing in the VR.
Privacy	10. I was concerned that people would record me while using the VR in public.
Safety	11. I was concerned about bumping to objects and people while using the VR in public.

Figure 5: Social Acceptability Questionnaire (SAQ) used in [10], with statements grouped by category.

3.2 Procedure

Participants were invited to a lab room, each at a different separated time slot to take part in the experiment alone. In the beginning, the participant was welcomed by a moderator and presented with an introduction of the study. After signing a consent, a participant was given a pre-questionnaire asking about demographic information and their previous virtual reality experience. Additionally, participants were asked to fill in the Affinity for Technology Interaction (ATI) Scale questionnaire to find out their tendency to engage in intensive technology interaction actively. The next step was to give participants an introduction to the Oculus Quest VR headset, controllers, and interactions needed for the experiment.

After this introductory part, the participant could start the condition communicated by the moderator. In total, there were eight experimental conditions given by all combinations between one of four Social Environments (one distant person, few distant persons, few close persons, many close persons) and one of two degrees of interactivity (static, dynamic). After each condition, the participant was asked to answer web-based questionnaires encompassing igroup Presence Questionnaire (IPQ) general item, Self-Assessment Manikin (SAM), Social Acceptability (SAQ), and Short User Experience (UEQ-S) Questionnaires:

- igroup Presence Questionnaire (IPQ): it is a scale for measuring the sense of Presence experienced in a Virtual Environment. The general item of IPQ measures the "sense of being there" [37].

- Short User Experience Questionnaire (UEQ-S): It is a questionnaire to measure users' subjective impressions towards products' user experience [34]. It contains two sub-scales, which measure the pragmatic and hedonic quality of the experience. It provides a total score value reflecting the overall User Experience.

- Self-Assessment Manikin (SAM): It is an emotion assessment tool that uses graphic scales, depicting cartoon characters expressing three emotional elements: pleasure, arousal, and dominance [6].

- Social Acceptability Questionnaire (SAQ): this non-standard questionnaire is built on top of the one used in [10] for rating social acceptability from the performer's perspective. It includes 11 questions that were rated using a 7-point Likert scale, the level of agreement with statements on Public VR, User, Public Communication, Interaction, Isolation, Privacy, and Safety (see Fig. 5) [10].

While the participant answers the mentioned questionnaires, the moderator sets the following condition on the headset according to the randomized order of conditions assigned to that participant. After all the conditions have been played and rated, the participant was asked to rate the VR application usability with the System Usability Scale (SUS) [7]. Finally, the participant was asked to answer some multiple-choice and open-ended questions in a final qualitative questionnaire, which included aspects such as graphical quality (e.g., 360° videos), appropriateness of social environments and VR games, use of VR in real social settings, and future applications of VR technology in those contexts.

3.3 Participants

A total of 28 people participated (N = 28, 21 male, 7 female). The average age was 24.64 years (SD = 2.6 years, min. 21 years, max. 31 years). Out of them, nine participants had no prior experience with VR. Moreover, five described themselves as not at all familiar, four as low familiar, 14 as averagely familiar, four as very familiar, and one as extremely familiar with VR technology. The average Affinity for Technology Interaction of the participants was 4.55 (SD = 0.69).

4 RESULTS

A repeated measure Analysis of Variance (ANOVA) was performed to determine statistically significant differences. An overview of all significant effects that will be explained in the following sections is given with Table 1.

Table 1: Two-way repeated-measures ANOVA statistically significant results show effects of Social Environments (Environment) and degree of interactivity (Interactivity) on UEQ-S Overall and Hedonic quality scores (UEQ-S_Overall, UEQ-S_Hedonic), Social Acceptability Questionnaire scores (SAQ_Public_VR, SAQ_Interaction, SAQ_Isolation, SAQ_Privacy, SAQ_Safety), IPQ general dimension (IPQ_G1) and SAM dimensions of valence and arousal (SAM_V, SAM_A).

Parameter	Effect	df_n	df_d	F	p	η^2_G
Environment	UEQ-S_Overall	3	81	2.785	.046	.093
Environment	SAQ_Public_VR	1	27	14.317	.001	.347
Environment	SAQ_Interaction	1	27	8.647	.007	.243
Environment	SAQ_Isolation	3	81	2.829	.044	.095
Environment	SAQ_Privacy	1	27	6.533	.017	.195
Environment	SAQ_Safety	1	27	11.913	.002	.306
Interactivity	IPQ_G1	1	27	10.075	.004	.272
Interactivity	SAM_V	1	27	15.707	$<.001$	.368
Interactivity	SAM_A	1	27	13.106	.001	.327
Interactivity	UEQ-S_Overall	1	27	6.754	.015	.200
Interactivity	UEQ-S_Hedonic	1	27	6.869	.014	.203
Interactivity	SAQ_Safety	1	27	7.717	.010	.222
Environment&Interactivity	SAM_A	3	81	2.948	.038	.098

4.1 Social Environments

The independent variable Social Environments has a statistically significant effect on the dependent variables of User Experience and social acceptability. Results (see Fig. 6) have shown that participants have reported significantly better UEQ-S_Overall score for the Social Environment with one distant person (M=1.424, SE=0.135) compared to the few close persons one (M=1.205, SE=0.161). The main effect of Social Environments found on average Public VR acceptability has shown that it is more acceptable to use VR in the public condition one distant person (M=5.929, SE=0.268), compared to the many close persons one (M=4.321, SE=0.412). When it comes to VR Interaction acceptability, participants have reported significantly higher acceptability of interactions for the Social Environment with one distant person (M=5.571, SE=0.288), compared to the many close persons one (M=4.482, SE=0.329). Furthermore, results have shown VR Isolation is significantly more accepted for the Social Environment with one distant person (M=5.482, SE=0.198) compared to the many close persons one (M=4.946, SE=0.247). For what concerns, VR Privacy acceptability for the Social Environment, it has been found that the privacy concerns are higher for the condition with one distant person (M=5.571, SE=0.307) compared to the many close persons one (M=4.554, SE=0.367). When rating VR Safety acceptability, participants reported to feel safer for the Social Environment with one distant person (M=4.893, SE=0.365) than the many close persons one (M=3.125, SE=0.386).

4.2 Degree of Interactivity

The independent variable degree of Interactivity has a statistically significant effect on the dependent variables of User Experience and social acceptability. Results (see Fig. 7) have shown that participants have reported significantly lower average General Presence value for static interaction (M=4.134, SE=0.130) compared to the dynamic one (M=4.446, SE=0.102). The main effect of the degree of Interactivity found on SAM Valence have shown valence to be less pleasant for static interaction (M=4.027, SE=0.124) compared to the dynamic one (M=4.420, SE=0.104). When it comes to SAM Arousal value, participants have reported arousal to be less intense for static interaction (M=3.438, SE=0.152) compared to the dynamic one (M=3.911, SE=0.163). Furthermore, results have shown that participants have reported significantly worse UEQ-S_Overall score for static interaction (M=1.175, SE=0.148) compared to the dynamic one (M=1.417, SE=0.152). In particular, the UEQ-S_Hedonic component showed a notable difference between the static interaction (M=0.603, SE=0.237) and the dynamic one (M=1.016, SE=0.223). Results on VR Safety have shown that participants have reported to feel safer for static interaction (M=4.321, SE=0.306) compared to the dynamic one (M=3.982, SE=0.295).

4.3 Interaction of Social Environments and Interactivity

Results have shown a significant combined interaction between the independent variables Social Environments and degree Interactivity on the dependent variable SAM Arousal. As shown in Fig. 8, opposite profile trends (increasing-decreasing) resulted between the static and dynamic conditions. In the static case, Arousal increases with a higher number of people in the Social Environment. For the condition dynamic, the arousal value decreases for a higher number of people in the Social Environment.

4.4 System Usability Scale

From the analysis of the SUS [7] results, the developed VR experience was rated with a score of 85.98 (SD = 10.91). The score indicates that the application usability is above average (>68), indicating a good usability level.

5 DISCUSSION

5.1 Social Environments

Four different scales of Simulated Social Environments in VR (One Distant Person, Few Distant Persons, Few Close Persons, Many Close Persons) were simulated through 360° Videos to determine the influence of Social Environments on UX. It has been found that the UEQ-S overall score was the only User Experience variable influenced by the differences in the scale of each setting. Therefore, the number of people and their proximity, were an overall concern for the users playing the VR games. The decreasing trend of UEQ-S overall score average with the increase of the scale of Social Environments is probably related to the more noise made by people chattering in the environment, which acted as a distractor and the perceived freedom of interaction. This idea is supported by the results of Eghbali et al. [10], which report noise and freedom of interaction as contributing to the autonomy in choosing the intended actions to perform without being affected by outside influence. The fact of not having found any statistically significant influence for the scale of Social Environments on Presence, Valence, Arousal, Dominance and the specific Hedonic and Pragmatic quality of the experience might depend on the 360° Videos in VR psychological cues not have been powerful enough to replace an on-field experience. Therefore, not raising significant variations on those dimensions.

Another aspect that has been investigated was the influence of Social Environments on social acceptability. As presented, four different scales of Simulated Social Environments in VR were simulated through 360° Videos, and questions about social acceptability dimensions were answered. It is evident how the scale of Social Environments has had a significant influence mainly on social acceptability dimensions. This seems to conclude that people are strongly affected by social acceptability issues that each Social Environment

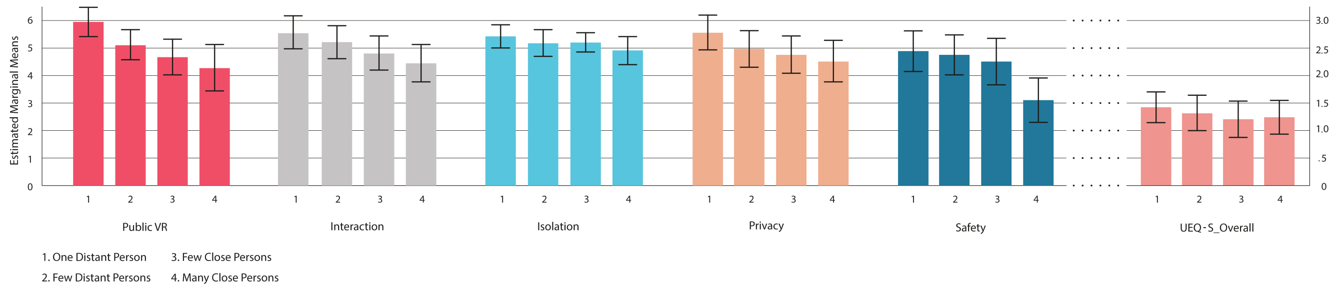


Figure 6: Estimated marginal mean values (95% CI) of social acceptability of Public VR, VR Interaction, VR Isolation, VR Privacy, VR Safety (1...7), and of UEQ-S Overall (-3...3), for Social Environments.

brings with it. The trend resulting from the social acceptability Public VR dimension shows that the acceptability of using VR in public drastically reduces already when shifting from a higher level of seclusion (One distant person) to a slight increase in the number of people (Few Distant Persons). As shown, it keeps going down as the scale of the environment increases. Most likely, people still feel ashamed and are concerned about using such technology in front of many people.

Notwithstanding, 32.1% of participants openly stated that they would use it due to the new opportunities this technology opens. The decreasing trend observed in the social acceptability Interaction dimension showed a more considerable difference between the Few Close and Many Close Person conditions. As revealed by the final questionnaire qualitative results, this might mean that the awkwardness of making body and head movements is connected to the fear of hurting people as they are closer to the user. Moreover, this result can also be related to the ones from Alallah et al. study [1], which pointed out people's concerns about their movements' visibility. The social acceptability Isolation dimension was also significantly affected by the scale of Social Environments. The variability in the average rating of Isolation is low among the conditions. However, it can still be noticed how Isolation acceptability reduces with the increase in people's numbers. Most of the participants commented that they would use VR if the situation were appropriate. However, it seems like isolating themselves using VR with some people around is not fully considered as such.

Furthermore, when it comes to Privacy, they are still quite concerned about spectators recording them. These concerns are reasonably much deeper (hence less acceptable) in conditions with a high number of people. This result is not matching with the one from Eghbali et al. study [10], probably because the university setting in which their experiment was performed was creating some reason why using VR. The lowest social acceptability ratings for each condition are registered from the Safety social acceptability dimension. The scale of Social Environments strongly affects Safety, which is considered the most limiting aspect of the adoption of VR in Social Environments. The results show how this dimension's acceptability largely drops when comparing Distant Persons conditions with Close Persons ones. In this case, it is logically a matter of risking to hurt people and themselves due to the proximity more than the number. It can be undoubtedly said that Safety is a recurrent concern for people using VR in Social Environments. Eghbali et al. [10], and final questionnaire results confirmed that people prefer environments without obstacles, with fewer people and enough space to move safely.

5.2 Degree of Interactivity

Aiming to investigate the influence of the degree of interactivity on UX, two different VR games requiring a low and high interactivity level were developed, and questions about UX dimensions were answered. It is interesting to notice how, contrary to Social Environments, the degree of interactivity has been found mainly to influence UX dimensions. The effect on General Presence shows that higher interactivity (dynamic condition) provides a higher sense of being in the Virtual Environment. A higher level of interactivity reasonably brings the user to be more focused and engaged by the task, making him less conscious of the real environment. Similar results also emerged from the effect on the Valence and Arousal dimension. Having a higher interactivity increase people's pleasure in playing VR experiences but also their excitement level. A low level of interactivity might make the people feel somehow limited, and the experience repetitive, boring with lower levels of happiness and excitement as a consequence. The UEQ-S has been found scores indicating a better and more enjoyable UX with higher interactivity, with an additional measured influence on the Hedonic aspect. In particular, the huge gap of the Hedonic quality rating between the static and dynamic conditions might imply that a VR experience is highly perceived as suitable and with a reason to be when the required interactions to perform are the "special" ones this technology uniquely enables (i.e., grabbing and moving). The mere use of a headset and a controller to visualize and interact with 2D UI elements (static condition) might not be enough reason to use VR.

Another aspect that has been investigated was the influence of the degree of interactivity on social acceptability. As presented, two different VR games requiring a low and high level of interactivity were developed, and questions about social acceptability dimensions were answered. The degree of interactivity has been found to influence the Safety component of social acceptability. Results show higher acceptability for the static conditions where the movement range is limited than on the dynamic one. This result is confirmed by the final questionnaire insights that highly relate social acceptability to safety concerns for the performer and the surrounding people.

5.3 Interaction of Social Environments and Interactivity

A statistically significant interaction between the Social Environments and degree of interactivity was reported to affect the SAM Arousal dimension from the results. This is probably to be attributed to the opposite trend patterns as the scale of the Social Environments increases between static and dynamic conditions, or the interaction could be an outside influence, and the sources of a more specific reason for that outcome need to be investigated in further research. What can be argued is that the study on the simple main effects showed an overall trend that confirms the effect of the degree of interactivity on arousal being significant.

6 CONCLUSION

In this paper, the influence of Social Environments and the degree of interactivity of VR applications on User Experience and social

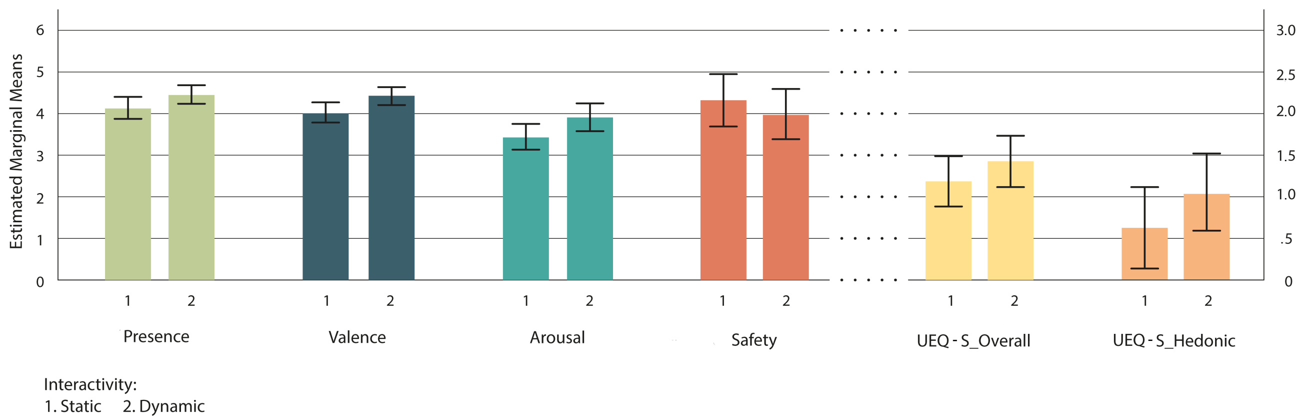


Figure 7: Estimated marginal mean values (95% CI) of General Presence, Valence, Arousal(1...5), social acceptability of VR Safety (1...7), UEQ-S_Overall, UEQ-S_Hedonic quality (-3...3), for degree of interactivity.

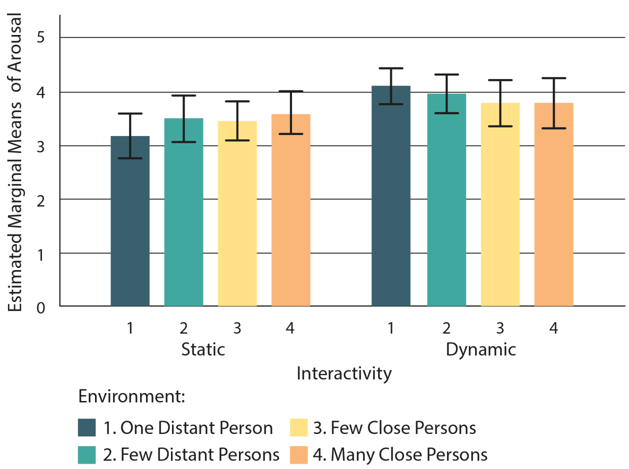


Figure 8: Estimated marginal mean values (95% CI) of Arousal(1...5), for the combined affect of the degree of interactivity and Social Environments.

acceptability have been investigated, aiming to contribute to the advancement of knowledge and understanding of factors that influence VR technology adoption in social settings. This has been done by simulating four different scales of Social Environments (One Distant Person, Few Distant Persons, Few Close Persons, Many Close Persons) varying the number of people, their proximity, employing 360° Videos in VR, and by the development of two different VR games with a low (static) and high (dynamic) level of interactivity required. Combining these created eight different conditions (Social Environment-degree of interactivity) that the participants (N = 28) had to rate by answering post-task questionnaires and final post-test questionnaires in a within-subject repeated measures user study.

A two-way repeated-measures Analysis of Variance (ANOVA) has been performed on the questionnaires' results to get information on the effect of Social Environments and interactivity on UX and social acceptability. The scale of Social Environments has been shown to affect User Experience and mostly social acceptability dimensions. The dimensions affected were *Overall UX, Public VR acceptability, Interaction acceptability, Isolation acceptability, Privacy acceptability, and Safety acceptability*. As the scale increases, it causes distractions, inappropriateness, limitation of movements, shame, besides raising concerns about privacy and safety (RQ1).

The degree of interactivity has been shown to affect mostly User Experience dimensions but also social acceptability. The dimensions affected were *Presence, Valence, Arousal, Overall UX, UX Hedonic quality, and Safety acceptability*. Higher interactivity levels increase presence, focus, engagement, pleasure, and excitement levels and give a reason to use VR. Nevertheless, the safety of interactions remains a concern (RQ2).

The combination of the scale of Social Environments with the degree of interactivity did not reveal significant findings to discuss for the scope of this study, but suggests further research might be needed (RQ3).

The answers found to the research questions contribute by creating new knowledge and insights for researchers and practitioners in the VR application design domain, showing how different design aspects affect the UX and the acceptability at the individual and social level. This study suggests that Social Environments and degree of interactivity are critical dimensions that should be considered while designing VR applications. By doing that, VR acceptability and a good VR UX in daily contexts would be more successfully achieved.

6.1 Limitations and Future Work

While thanks to this study, some answers to the initial research questions have been found, the findings are limited by the simulative nature of the Social Environment, therefore not completely ecologically valid. This research's natural extension is to repeat the experiment in similar Social Environments in the real world to enhance the results' external validity.

This research focused on the influence of the degree of interactivity and Social Environments on UX and social acceptability. Many other dimensions, such as VR content, performance parameters, body movement patterns, and many more, would still need to be explored further to widen the body of knowledge on the topic.

Moreover, more comprehensive recruitment of participants could also be performed to explore the opinions of other age ranges rather than the single age range of 21-31 years that were investigated.

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