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How Present am I

Three virtual reality facilities testing the fear of falling

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Virtual reality environments have long been used in studies related to architecture simulation. The main objective of this paper is to measure the sense of presence that different virtual reality devices provide to users so as to evaluate their effectiveness when used to simulate real environments and draw conclusions of people's behaviors when using them. The study also aims at investigating, in a quantitative way, the influence of architectural elements on the comfort of use of a built environment, namely considering the fear of falling reported by adults while using these architectural elements. Using a between-subjects design randomly distributed between two experimental conditions (safe and unsafe), a set of three studies were conducted in three different virtual reality environments using a 5-sided-CAVE, a Powerwall or a Head Mounted Display. The study shows that immersive virtual reality devices give users a higher sense of presence than semi-immersive ones. One of the conclusions of the study is that a higher sense of presence helps to enhance the building spaces perceived impacts on users (in this case the fear of falling).

Keywords: *Virtual Reality, Presence, Fear of falling, CAVE, HMD, Powerwall*

INTRODUCTION

Virtual reality environments are being used for more than 20 years in studies related to architecture. Besides studies focused on representation, visualization, digital heritage, building performance, education and design methods, Virtual reality (VR) is used to study users' responses to the built environment. VR is used to simulate reality and en-

ables researchers to extract conclusions about real life while subjecting participants to virtual reality simulations. When doing that, researchers aim at obtaining feedback about some sort of quality of space wherever it has to do with movement and wayfinding (Conroy-Dalton, 2001; Vilar and Rebelo, 2008; Tailade et al., 2013), emotions (Balakrishnan, Kalisperis and Sundar, 2006), engagement and attractiveness

(Boytscheff and Sfeir, 2007), or other responses. VR is also often used in architecture and real estate to engage people with the built spaces, namely architects, engineers, clients, users and others. The diversity of VR devices and the different ways a virtual environment, the virtual scene actually, is presented to experimental subjects may influence the perception. Therefore, assessing their efficiency in simulating a real environment is crucial to understand the results obtained by such studies.

The study presented here follows previous ones done by the ISTAR-IUL team. These studies of emotions induced by architectural spaces were conducted by sensing and statistically analysing the physiological signals of users experiencing the virtual environments (Dias, Eloy, Carreiro, Marques, et al., 2014; Dias, Eloy, Carreiro, Proença, et al., 2014; Ourique et al., 2017).

The objective of this study is to research and measure how technology-related factors, namely three different VR devices, influence presence. This enables us to evaluate effectiveness of VR technology when used to simulate real environments and draw conclusions of people's behaviours using it. For this, we used the same media content with different media forms variables. This study also aims at investigating, in a quantitative way, the influence of architectural elements (i.e., stairs and ramps, with and without handrails) on the comfort of use of a built environment, namely considering the fear of falling reported by adults while using these architectural elements. In previous studies (Dias, Eloy, Carreiro, Marques, et al., 2014), only an elderly group was tested for the same two conditions - safe and unsafe. The co-relation between the data from the self-reported sensations of fear of falling and the sense of presence enable us now to investigate what influence different VR facilities can have on the perceived sensations in a given virtual environment.

The main hypothesis considered to design this study was, that different VR devices would produce different senses of presence in users, namely that:

- Hypothesis 1 (H1): Immersive VR environ-

ments, namely a Head Mounted Display and a CAVE, create a stronger sense of presence than a semi-immersive VR environment, namely a Powerwall.

- Hypothesis 2 (H2): When the sense of presence is higher, people's perceived fear of falling is higher.
- Hypothesis 3 (H3): Fear of falling under unsafe conditions is being perceived in all three VR facilities.

Section "Related Work" of this paper gives an insight into related work on the topics of sense of presence and fear of falling. Subsequently, in the next section, the experiments to investigate the hypothesis of this study are described in more detail. Section "Results" describes and discusses the results obtained by these experiments. The paper ends with a section of conclusions and addresses future work.

RELATED WORK

Sense of Presence

The sense of presence has long been studied to assess the presence users feel when they are navigating in a virtual environment.

According to Ijsselsteijn and Riva (2003) "as a user experience, the feeling of 'being there', or presence, is not intrinsically bound to any specific type of technology - it is a product of the mind". Following this approach Jurmet et al (2005) investigated on the human factors involved in the engagement of presence and the individual differences. Nevertheless the authors also agree, that the sense of presence a user experiences when using a VR devices is influenced by user characteristics/subjective (internal) and also by media characteristics/objective (external) (Slater, 1999; Ijsselsteijn and Riva, 2003). Characteristics of the medium can be subdivided into media form (e.g. immersion, interactivity) and media content variables (Ijsselsteijn and Riva, 2003).

For Ijsselsteijn and Riva (2003) presence in a mediated environment is influenced by the media form since it "will be enhanced when the environment is

immersive and perceptually salient, as well as when attentional selection processes are directed towards the mediated environment, thus allowing the formation of a consistent environmental representation". Banos et al. (2012) compared two different virtual environments, or media content, in order to assess if virtual environments would increase positive emotions and decrease negative ones while a high level of presence was being felt. Further work of this group investigates presence between virtual and imaginary environments (Baños et al., 2005). In this study, the authors concluded that participants in the virtual environment had a higher degree of presence than in the imaginary environment, and that VR helps users to stay in the virtual environment over time although the presence in the imaginary world is not of long duration.

Measuring presence subjectively is the most common approach taken and is usually questionnaire based (Ijsselstein and Riva, 2003). The two most used presence assessment methodologies are the ones of Witmer and Singer (1998) and of Slater, Usoh and Steed (1994). Witmer and Singer (1998) presence questionnaire consists of 32 questions each to be answered on a scale from 1 to 7. Slater, Usoh and Steed (1994) post-test subjective presence questionnaire is based on several questions all variations on one of three topics: "the sense of being in the virtual environment, the extent to which the virtual environment becomes the dominant reality, and the extent to which the virtual environment is remembered as a 'place'" (Usoh et al., 2000). All questions are also answered on a scale from 1 to 7 being a higher score an indication of a greater presence.

Fear of falling

Difficulties in accessing buildings are the main limitation that people with impairments face in daily life (Foster, Wenn and Harwin, 1998). People which experience movement incapacities report that they are afraid to be in public spaces because of disorientation and the possibility of getting lost. This phenomenon occurs frequently in elderly people (Fore-

man, 2005).

Falls are the most reported accident among the elderly and their impact can be very serious and cause severe disabilities. The loss of the muscular strength, of flexibility and body postures caused by getting older are reasons for the fear of falling, even among people never falling (Melo, 2011). Several authors have demonstrated that this perceived fear leads to a deterioration in the quality of life among older people (Campbell et al., 1997; Feder et al., 2000). The loss of independence and the attitude of avoiding some activities are consequences related to the fear of falling (Legters, 2002). The fear of falling is therefore a health problem that needs attention and can be as serious as the falls themselves. Therefore this fear needs to be assessed, understood and action must be taken accordingly (Lachman et al., 1998).

Some common architectonic elements as ramps and stairs are seen as physical barriers among the elderly population. Many of the falls reported in public areas occur on stairs (Tiedemann, Sherrington and Lord, 2007). It is reported that using stairs is one of the most challenging activity for people over 65 years of age (Startzell et al., 2000; Tiedemann, Sherrington and Lord, 2007) and that a large percentage of people is afraid of falling when facing stairs (Tiedemann, Sherrington and Lord, 2007). With regards to ramps, studies show that the average population walks different slants at different speeds, with decreasing speed when the angle is higher (Patla, 1986; Kawamura, Tokuhira and Tahechi, 1991). For elderly people, this effect becomes even more dominant. Sun et al. (1996) show that for this group the length of a step and the speed of walking is affected by the age, and that elderly people walk slower and have a shorter step width in more pronounced slants.

EXPERIMENTAL DESIGN AND METHODOLOGY

A set of three studies was conducted using one virtual environment, the actual scene, and three different VR environments:

- Study 1 was conducted at the ISCTE - University Institute of Lisbon (ISCTE-IUL), ISTAR-IUL lab, Portugal, in a semi-immersive VR environment using a Powerwall;
- Study 2 was conducted at the High Performance Computing Center (HLRS) at Stuttgart University, Germany, in an immersive VR environment using a CAVE;
- Study 3 was also conducted at the ISCTE-IUL, ISTAR-IUL, in an immersive VR environment using a Head Mounted Display (HMD).

6. a ramp with the same dimension as the horizontal plane and with a slope of 40 % (Figure 1e, f, g and h)
7. a third neutral room (neutral room 3) with the same characteristics as neutral room 2

The studies used a between-subjects design randomly distributed between two experimental conditions for each participant in all three VR devices. Two test conditions were created from the same virtual environments - a safe and an unsafe condition. For the safe condition, a safety element (i.e. handrail) was added to the stairs and ramps presented in the virtual environment. For the unsafe conditions, the added safety elements were configured to be not visible to the participants. Between-subject analyses were conducted to evaluate differences between safe and unsafe conditions within the virtual environment (H2 and H3), and to evaluate the sense of presence reported by participants in each VR environment (H1). The dependent variable in these studies was the declared fear and anxiety.

Virtual environment

To test our research hypotheses a virtual building was designed to be used as a virtual surrounding for the various embedded experiments. The virtual environment consisted of:

1. a first room 30 m long and 5.5 m wide (neutral room 1)
2. two flights of stairs with 12 steps each (0.28 x 0.18 m) and 1.5 m wide (Figure 1a and b)
3. a second neutral room (neutral room 2) with the same characteristics as neutral room 1
4. two flights of ramps 10 m long and 1.5 m wide with a slope of 20 % (Figure 1c and d)
5. a horizontal plane 10 m long and 1.5 m wide

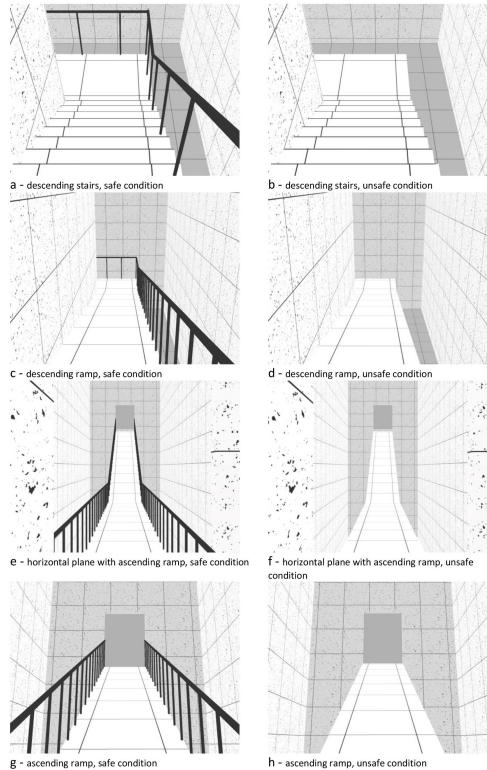


Figure 1
Virtual Environment, Left: safe condition, Right - unsafe condition

The neutral rooms were added to the virtual environment in order to act as a connection between the test spaces, where we claimed fear of falling could exist. The virtual environment was presented to participants in each of the three VR devices in the same way, the speed of movement was predefined and could not be changed by the participants. All rooms were equally textured. For the walls we used a concrete texture with a rectangular frame simulating the

concrete formwork and for the floor we used a grey colour with a square pattern simulating tiles. Lighting was constant for all environments.

Methodology

The study involved 75 people who experienced the virtual environment. The safe conditions, with handrails, were experienced by 39 people and the unsafe conditions, without handrails, were experienced by 36 people. The same virtual environment was presented to the participants in all three VR devices: Powerwall (used by 28 subjects), 5-sided-CAVE (used by 25 subjects), and HMD (used by 22 subjects). To answer our research hypotheses, after completion of the task, the subjects were asked to answer questionnaires about the perceived emotions they felt while walking through the virtual environment and about the sense of presence using questionnaires proposed by Slater et al. (1994) and Witmer and Singer (1998).

Experimental settings

For study 1, a Powerwall was used as a semi-immersive setup. The Powerwall displays stereoscopically projected images on a 4 m x 3 m screen, while the participants have to wear active 3D-glasses. The observation distance (the distance between the observers' eyes and the screen) was 3.50 m. The virtual camera had a horizontal field of view (FOV) of 45° and a vertical FOV of 33°, approximately. Participants could navigate through the virtual environment using a joystick (Logitech Extreme 3D Pro) with a constant speed of movement of 0.82 m/s = 3Km/h (Patel et al., 2006). The virtual camera was linked to a pre-defined path, and the participants only had the possibility to move forward or backward and to stop. The camera was also animated to simulate natural head movement, (Dias, Eloy, Carreiro, Vilar, et al., 2014). The Powerwall was driven by the CAVE Hollowspace software system (Soares et al., 2010), which is fully developed and maintained by ISTAR-IUL.

For study 2, a 5-sided-CAVE was used as an immersive setup. The virtual environment was stereoscopically projected on five surfaces, which are ar-

ranged as a cube with an edge length of 2.7 m surrounding the participant. The participant has to wear active 3D- glasses, which are continuously being tracked by an optical tracking system to calculate the stereoscopic images for all 5-projection screen according to the participant's position and orientation. As a result, the participant had the possibility to look around the scene freely. The observation distance was approximately 2.0 m. The CAVE is driven by the software COVISE/OpenCOVER, which is developed and maintained by HLRS.

For study 3, a virtual reality headset, the Oculus Rift consumer version, was used. The Oculus Rift has a FOV of 110° and head tracking. In this experiment participants navigated through the virtual environment using a keyboard. To equalize the three experiments, we decided for a controlled navigation in which all participants followed the same path, on which they could nevertheless look around in the scene.

Participants

A total of 75 subjects participated in this study. A different group of participants was used for each experiment. For study 1 using the Powerwall, 28 people between 19 and 32 years old (mean age = 22.7; SD = 3.44) participated. 11 navigated the VE with handrails and 12 navigated the VE without handrails. For study 2 using the CAVE, 25 people between 26 and 58 years old (mean age = 39.0; SD = 9.8) participated. 13 navigated the VE with handrails and 14 navigated the VE without handrails. For study 3 using the Oculus Rift, 22 people between 20 and 64 years old (mean age = 36.1; SD = 15.7) participated. 12 navigated the VE with handrails and 10 navigated the VE without handrails.

Participants of the three experiments were randomly assigned to the two experimental conditions. In study 1 and 3 participants were recruited from ISCTE-IUL staff, students and visitors. In study 2 participants were recruited from HLRS staff, researchers, interns and staff. All participants were selected considering the following admission criteria: having nor-

mal sight or using corrective lenses, do not suffer from claustrophobia, do not suffer from dizziness. Before the experimental test, all participants were asked to sign a term of consent.

Experimental protocol

The same experimental protocol was used in all three studies. The study objectives were only partially communicated to the participants, so that there was no influence on the data collected related to the issues we wanted to study (namely fear of falling and sense of presence). At the beginning of the experiment, participants were told that the main objective was to get to know their opinion about a new designed building. After signing the term of consent, each participant was asked to complete a demographic questionnaire. In study 1 and 2, participants completed the questionnaire in a separate room and were then taken to the Powerwall (study 1) or the CAVE (study 2) by one of the researchers. In study 3 both parts were performed in the same room.

For the experiments, participants were signed to one of the two experimental conditions (safe and unsafe). Participants were instructed to navigate through the building until reaching the end. And by the fact that it was a controlled navigation, all participants followed the same path. Participants were told that the simulation would stop automatically when it was finished. There was no time limit for the participant's interaction with the virtual building, but the researcher could abort the simulation if it lasted longer than five minutes. After completing the virtual reality experience, the participants were taken to another room (study 1 and 2) or stayed in the same room (study 3) in which s/he was asked to answer the post-hoc questionnaire. First, a retrospective was made showing images (screenshots of the virtual environment) and for each image a question was asked about their feelings of safety, pleasure and fear. Afterwards, the presence questionnaire was completed.

RESULTS

Presence

The results on the participants' sense of presence were obtained by applying specific items from two known presence questionnaires developed by Witmer and Singer (1998) (WS) (Table 1 and Figure 2) as well as by Slater, Usoh and Steed (1994) (SUS) (Table 2 and Figure 3).

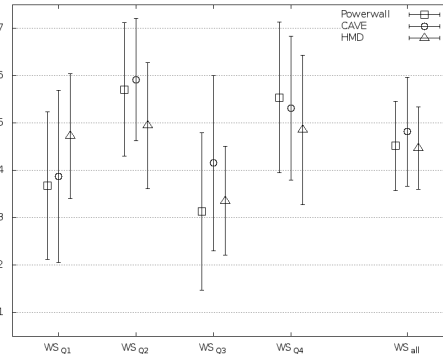


Figure 2 Results of the application of specific items of the WS questionnaire to participants in the three experimental settings

Experiment	WS_Q1	WS_Q2	WS_Q3	WS_Q4	WS
Study 1 - Powerwall	3.68 (SD=1.56)	5.71 (SD=1.41)	3.14 (SD=1.66)	5.54 (SD=1.59)	4.52 (SD=0.94)
Study 1 - CAVE	3.88 (SD=1.82)	5.92 (SD=1.29)	4.16 (SD=1.85)	5.32 (SD=1.52)	4.82 (SD=1.15)
Study 3 - HMD	4.73 (SD=1.32)	4.95 (SD=1.33)	3.36 (SD=1.15)	4.86 (SD=1.58)	4.48 (SD=0.87)

Table 1 Results of the application of specific items of the WS questionnaire to participants in the three experimental settings

The following questions were asked from the WS questionnaire:

1. How natural was the mechanism which controlled movement through the environment? (where 1 = very little and 7 = very much)
2. How quickly did you adjust to the virtual environment experience? (where 1 = very slow and 7 = very fast)
3. How aware were you of your display and control devices? (where 1 = very much and 7 = very little)
4. How distracting was the control mechanism? (where 1 = very much and 7 = very little)

Higher results WS questions indicate a higher level of presence.

The WS questionnaire shows that the higher sense of presence was perceived in the CAVE. For question 4, the Powerwall performed better than the other two devices. The participants reported that the available control mechanisms used in the Powerwall were the less distracting. The VR devices, in which participants were more aware of display and control devices, and therefore sensed less presence, was the Powerwall, followed by the HMD and the CAVE at the end. The participants chose the HMD as the most natural control mechanism, followed by the CAVE. The most impressive single result was how quickly the participants got used to the virtual environment using the CAVE. An overall analysis of the results of the SW questionnaire shows that the CAVE, study 1, was the VR device that achieved a higher level of presence according to WS questionnaire.

Figure 3 Results of the application of specific items of the SUS questionnaire to participants in the three experimental settings

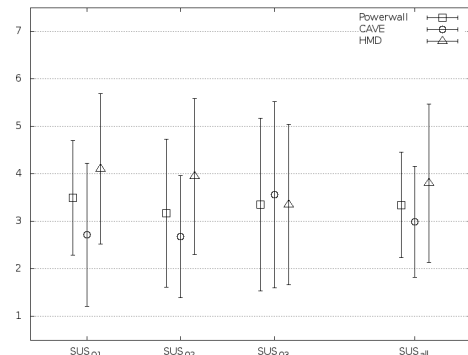


Table 2 Results of the application of specific items of the SUS questionnaire to participants in the three experimental settings

Experiment	SUS_Q1	SUS_Q2	SUS_Q3	SUS
Study 1 - Powerwall	3.50 (SD=1.21)	3.18 (SD=1.56)	3.36 (SD=1.82)	3.35 (SD=1.11)
Study 2 - CAVE	2.72 (SD=1.51)	2.68 (SD=1.29)	3.56 (SD=1.96)	2.99 (SD=1.17)
Study 3 -HMD	4.11 (SD=1.59)	3.95 (SD=1.64)	3.36 (SD=1.69)	3.81 (SD=1.67)

The following questions were asked from the SUS questionnaire:

1. In the computer-generated world I had a sense of "being there". (1 = not at all, 7 = very much)
2. There were times during the experience when

the computer-generated world became more real or present for me compared to the "real world"... (1 = at no time, 7 = almost all the time)

3. The computer-generated world seems to me to be more like? (1 = something that I saw, 7 = somewhere that I visited)

Higher results in SUS questions indicate a higher level of presence.

The higher overall result for the HMD was mainly caused by questions 1 and 2, and only in question 3 the CAVE was considered a higher presence than the Powerwall.

Combining the two presence questionnaires, WS and SUS, the overall experiment allows the conclusion that in comparison, the HMD enables a higher level of presence (4.19 in a scale of 1 to 7) than the CAVE (4.03) and the Powerwall at the end (4.02). In summary, hypothesis 1 was confirmed very weakly by WS and SUS questionnaire showing that participants reported a higher level of presence in immersive virtual reality (CAVE and HMD).

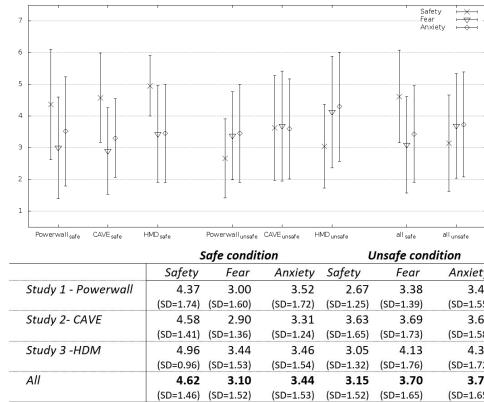
Fear of falling

Participants' perception of fear of falling was answered in the questionnaire by means of screenshots of the virtual environment in selected points (i.e. top of the stairs - Figure 1a/b, top of the ramp - Figure 1c/d, beginning of the plane - Figure 1e/f, and middle of the ascending ramp - Figure 1g/h). A Likert-type scale with seven points (1 = nothing; 7 = very much) was used to evaluate the user's perceptions of fear of falling. For each safe and unsafe conditions, participants were asked about their fear, safety and anxiety.

Results in Figure 4 and Table 3 show that the perceived fear is lower in the safe condition than the one in the unsafe condition. In the safe condition, safety is perceived higher than in the unsafe condition. Anxiety, also as expected, is higher in the unsafe condition. All these results are the same for all three VR facilities, except for anxiety measured in the Powerwall.

The highest value for fear appears in study 3 (HMD), which was also the study where people's sense of presence was the highest. This confirms Hy-

pothesis 2. Results also show that the generally perceived fear of falling in unsafe conditions is verified for all three VR facilities, which confirms Hypothesis 3.



CONCLUSION AND FUTURE WORK

The aim of the study was to test the influence of using different VR devices to simulate real environments and to draw conclusions on people's behaviours.

The study shows that immersive VR devices give the users a higher sense of presence than semi-immersive devices. Another conclusion of the study is that a higher sense of presence helps to enhance the perceived impact of building spaces on users (in this case the fear of falling). Although there were differences between the three VR devices, which allow only a moderate distinction, the study shows that all the three facilities can simulate a virtual environment by giving users the feeling of being present in that VE. At the same time, all three devices can generate the same perception of space on users.

By contributing to the assessment of VR devices in terms of enabling the sense of presence and the perceived impact of building spaces on users, this study also contributes to the debate on using VR to simulate reality. One aspect that is relevant in this discussion is the level of realism needed to simulate real-

ity in order to study space perception. Although realism may be important in some cases, which certainly needs further investigation, this study shows that a basic level of realism is sufficient to measure the fear of falling. In fact, the VE was based on a well-defined spatial geometry, treated only with grey colour and a simple concrete texture to convey the sense of depth. No lights, shadows or any other elements have been added to the VE.

Limitations of the study

Although the sample used for each study was random, there are specificities in each group that might create some bias. One of these is the fact that the HLRS sample was mainly constituted by the staff of the institute, who are very familiar with VR technology and may have a lower inclination to consider such a simple virtual environment as immersive. In fact, user characteristics (e.g. needs, preferences, past experience, age, gender) addressed by Ijsselsteijn & Riva (2003) were not taken into account in this study, so no conclusions can be drawn on this subject.

The second limitation is that presence was measured subjectively using the most common approach by questionnaire. A complementary objective measurement of behaviours and psychophysiological responses could ideally be used in combination to overcome the limitations of each approach (Ijsselsteijn and Riva, 2003).

Future work

Regarding the sense of presence Ijsselsteijn and Riva (2003) observe that "although the experience of presence becomes more convincing as media becomes more interactive, immersive, and perceptually realistic", users also "can feel present in environments which will not be mistaken for reality". Following these considerations, further investigation is needed to assess where and when realism is of advantage for architecture design and research in which the sense of presence and the level of immersion may or may not be required. It is our understanding that for a large part of the architectural design process the im-

Figure 4
Average results from WS and SUS in the two conditions and the three experimental settings.

Table 3
Average results from WS and SUS in the two conditions and the three experimental settings.

mersive and perceptually realistic characteristics of the VE and VR devices may not be relevant.

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REFERENCES

- Balakrishnan, B, Kalisperis, LN and Sundar, S 2006 'Capturing Affect in Architectural Visualization – A Case for integrating 3-dimensional visualization and psychophysiology', *24th Conference Education and Research in Computer Aided Design in Europe (eCAADe)*, pp. 664-669
- Banos, RM, Botella, C, Guerrero, B, Liano, V, Alcaniz, M and Rey, B 2005, 'The third pole of the sense of presence: Comparing virtual and imagery spaces', *Psychology Journal*, 3(1), pp. 90-100
- Banos, RM, Etchemendy, E, Castilla, D, Garcia-Palacios, A, Quero, S and Botella, C 2012, 'Positive mood induction procedures for virtual environments designed for elderly people', *Interacting with Computers*, 24(3), pp. 131-138
- Boytscsheff, C and Sfeir, MK 2007 'Experimental Results in immersive Virtual Reality (IVR): Searching Critical Design Factors within IVR to Increase Architectural Space Qualities', *eCAADe*, pp. pp. 91-98
- Campbell, A, Robertson, M, Gardner, M, Norton, R and Tilyard, M 1997, 'Randomized Controlled Trial of a General Practice Programme of Home Based Exercise to Prevent Falls in Elderly Women', *British Medical Journal*, 315, pp. 1065-1069
- Conroy-Dalton, R 2001, *Spatial Navigation in Immersive Virtual Environments*, Ph.D. Thesis, University cCollege London
- Dias, MS, Eloy, S, Carreiro, M, Marques, S, Moural, A, Cruz, J, Carvalho, N, Pedro, T and Language, M 2014 'Space Perception in Virtual Environments. On how biometric sensing in virtual environments may give architects user's feedback', *Fusion - Proceedings of the 32nd eCAADe Conference*, pp. 1-10
- Dias, MS, Eloy, S, Carreiro, M, Proença, P, Moural, A, Pedro, T, Freitas, J, Vilar, E and Azevedo, AS 2014 'Designing better spaces for people: Virtual reality and biometric sensing as tools to evaluate space use', *Rethinking Comprehensive Design: Speculative Counterculture, Proceedings of the 19th International Conference on Computer-Aided Architectural Design Research in Asia (CAADRIA 2014)*, pp. 739-748
- Dias, MS, Eloy, S, Carreiro, M, Vilar, E, Marques, S, Moural, A, Proença, P, Cruz, J, Carvalho, N, Azevedo, AS and Pedro, T 2014 'Space Perception in Virtual Environments: on how biometric sensing in virtual environments may give architects', *Fusion - Proceedings of the 32nd eCAADe Conference*, pp. 271-280
- Feder, G, Cryer, C, Donovan, S and Carter, Y 2000, 'Guidelines for Prevention of Falls in People over 65', *British Medical Journal*, 321, pp. 1007-1011
- Foreman, N, Stanton-Fraser, D, Wilson, P, Duffy, H and Parnell, R 2005, 'Transfer of Spatial Knowledge to a Two-Level Shopping Mall in Older People, Following Virtual Exploration', *Environment and Behavior*, 37, pp. 275-292
- Ijsselsteijn, W and Riva, G 2003, 'Being There: The experience of presence in mediated environments', in Riva, G, Davide, F and Ijsselsteijn, W (eds) 2003, *Being There: Concepts, effects and measurement of user presence in synthetic environments*, los Press
- Jurnet, IA, Beciu, CC and Maldonado, JG 2005 'Individual Differences in the Sense of Presence', *8th Annual International Workshop on Presence*, London
- Kawamura, K, Tokuhiko, A and Tahechi, H 1991, 'Gait analysis of slope walking: a study of step length, stride width, time factors and deviation in the centre of pressure', *Acta Medica Okayama*, 45, pp. 179-184
- Lachman, M, Howland, J, Tennstedt, S, Jette, A, Assmann, S and Peterson, W 1998, 'Fear of Falling and Activity Restriction: The Survey of Activities and Fear of Falling in the Elderly (SAFE)', *Journal of Gerontology and Psychology Science*, 53(B(3)), pp. 43-50
- Legters, K 2002, 'Fear of falling', *Physical Therapy Science*, 82, pp. 264-272
- Melo, C 2011, 'Adaptação cultural e validação ao da escala "Falls Efficacy Scale" de Tinetti', *Ifisionline*, 1(2), pp. 33-43
- Ourique, L, Eloy, S, Resende, R, Dias, MS, Pedro, T, Miguel, R and Marques, S 2017 'Spatial perception of landmarks assessed by objective tracking of people and

- space syntax techniques', *Proceedings of the 11th Space Syntax Symposium*
- Patla, A 1986, 'Effects of walking on various inclines on EMG patterns of lower limb muscles in humans', *Human Movement Science*, 5, pp. 345-357
- Slater, M 1999, 'Measuring Presence: A Response to the Witmer and Singer Presence Questionnaire', *Teleoperators and Virtual Environments*, 8, pp. 560-565
- Slater, M, Usoh, M and Steed, A 1994, 'Depth of Presence in Immersive Virtual Environments', *Presence: Teleoperators and Virtual Environments*, 3(2), pp. 130-144
- Soares, LP, Pires, F, Varela, R, Bastos, R, Carvalho, N, Gaspar, F and Dias, MS 2010, 'Designing a highly immersive interactive environment: The virtual mine', *Computer Graphics Forum*, 29(6), pp. 1756-1769
- Startzell, J, Owens, D, Mulfinger, L and Cavanagh, P 2000, 'Stair negotiation in older people: a review', *Journal of the American Geriatrics Society*, 48, pp. 567-580
- Sun, J, Walters, M, Svensson, N and Lloyd, D 1996, 'The influence of surface slope on human gait characteristics: a study of urban pedestrians walking on a inclined surface', *Ergonomics*, 39(4), pp. 677-692
- Taillade, M, Sauzéon, H, Déjos, M, Arvind Pala, P, Larrue, F, Wallet, G, Gross, C and N'Kaoua, B 2013, 'Executive and memory correlates of age-related differences in wayfinding performances using a virtual reality application', *Aging, Neuropsychology and Cognition*, 20(3), pp. 298-319
- Tiedemann, A, Sherrington, C and Lord, S 2007, 'Physical and Psychological Factors Associated With Stair Negotiation Performance in Older People', *Journal of Gerontology: Medical Sciences*, 62 A(11), pp. 1259-1265
- Usoh, M, Catena, E, Arman, S and Slater, M 2000, 'Using presence questionnaires in reality', *Presence: Teleoperators and Virtual Environments*, 9(5), pp. 1-16
- Vilar, E and Rebelo, F 2008 'Virtual Reality in Wayfinding Studies', *2nd International Conference on Applied Human Factors and Ergonomics jointly with 12th International Conference on Human Aspects of Advanced Manufacturing (HAAMAH)*, pp. 14-17
- Witmer, BG and Singer, MJ 1998, 'Measuring Presence in Virtual Environments: A Presence Questionnaire', *Presence: Teleoperators and Virtual Environments*, 7(3), pp. 225-240