Sense of Presence and Cybersickness While Cycling in Virtual Environments: Their Contribution to Subjective Experience

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Abstract. Head mounted displays (HMDs) are visualization devices that provide high levels of immersion in virtual environments (VEs), which have been recently used to enhance the experience of subjects performing a physical exercise. However, the use of these devices in rehabilitation is discussed as it could cause cybersickness and other physical drawbacks. In this context, we conducted a preliminary study investigating the experiences of navigating in the same VEs using a cycle-ergometer and either a projected screen (PS) or a HMD, considering whether the "the Sense of Presence" influenced the device's preference. Thirty-three healthy young adults were enrolled and randomized in four groups to counterbalance the two conditions and to investigate the effects of 5-days washout. Most of the subjects ($n = 26$) preferred the HMD with respect to PS; sense of presence was higher using HMD than using projector ($t = -11.47$, $p < 0.001$), but the difference between conditions was higher for those who preferred the HMD ($t = -14.64$, $p < 0.001$), compared to those who chose projector ($t = -2.70$, $p < 0.05$). The correlation of presence with cybersickness revealed that, despite higher levels of sickness, sense of presence probably counts more in choosing the HMD as the preferred device.

Keywords: Presence · Virtual reality · Immersive environments

1 Introduction

Virtual reality (VR) has recently been proposed as a means for the physical and cognitive rehabilitation of users with severe cognitive impairments, such as Alzheimer's Disease patients [1], and people affected by age-related decline [2]. Indeed, physical and cognitive exercise increases individual skills and well-being [3], limiting symptoms of decline and thus enhancing users' quality of life [4]. In this context, the use of VR has been proved to increase the motivation of the patients through the provision of physical and/or cognitive tasks in a controlled, safe and ecological

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environment, thus allowing the avoidance of real-life limitations and risks, and promoting the development of healthy habits [5].

However, to be engaging and to promote better performances, VR-based treatments must be able to induce in the users the sense of "being present" in the virtual world [6]. As a consequence, *presence* has become a more and more relevant concept. It should be always considered to evaluate, develop and improve Virtual Environments (VEs) and media systems [7], especially in a field – as physical and cognitive rehabilitation – in which users are requested to respond to virtual events and situations similarly to how they would act in a corresponding real environment [8].

In 2015, a research group developed Goji [9, 10], a preventive program based on the use of Virtual Reality and a cycle-ergometer aimed at preventing the occurrence of symptoms of dementia in elderlies with Minor Cognitive Impairment. The goal pursued with the project was trying of counteract the psycho-cognitive decline affecting these subjects [11, 12] by providing them with both a physical and a cognitive training. The intervention program was based on three different training scenarios dealing with activities of daily life: (1) riding a bike in a park, (2) crossing roads – avoiding cars – to reach a supermarket and, when arrived, (3) buy certain grocery items that are indicated on the shopping list.

For completing the former two scenarios, the users had to ride the cycle-ergometer and interact with the VEs – projected on a flat screen in front of them – using a PlayStation controller. Within these two scenarios, it has been hypothesized that the use of a Head Mounted Display (HMD) could enhance the navigational experience in the VEs, thanks to the increased sense of presence that the HMD can elicit [13]. In this way, in fact, it would be possible to increase the engagement of the patients leading them towards the achievement of better results during therapy [14].

However, it is also necessary to consider that VR and HMD in particular sometimes lead to the occurrence of physical malaise. The onset of cybersickness and other adverse events due to the disagreement between visual and vestibular feedback are not infrequent, though it may be somehow limited by taking into account some recommendations when designing the VE [15]. Thus, in order to promote a safe and engaging application of virtual reality in rehabilitation, sense of presence and cybersickness should be always taken in consideration: the positive effects of sense of presence and motivation must be not obscured by physical drawbacks [13, 16].

For these reasons, before taking advantage of this kind of immersive technologies in studies involving frail people, as elderlies with cognitive impairment, preliminary tests must be conducted on healthy subjects.

In this work, we report the results of a pilot study conducted on young adults with the aim of investigating how much sense of presence, considering the induced physical problems, counts in choosing the preferred device. Sense of presence and cybersickness were evaluated while cycling on a stationary bike in two different conditions, visualizing the VE using (1) a HMD or (2) a flat projected screen (PS).

2 Related Works

In recent years, technological developments eased the creation of VR indoor stationary exercise bike equipment [17] and many researches have designed and built VEs for stationary bicycles elderly rehabilitation and exercise in general [18].

Several studies showed in fact that physical exercises [19] and cognitive simulation [20] within VR could improve physical and cognitive control in the elderlies. Furthermore, older people seem to be open to use new technologies, provided there are not too many unnecessary learning processes [21]. For example, Brunn-Pedersen et al. [22] have proposed to the residents of a retirement home a cycling exercise enriched by an audio-visual virtual environment: the residents embraced the VE augmentation well, although they did not like the use of headphones for auditory inputs.

Another research [20] compared the cognitive and physical improvements of some elderly people who performed the training pedalling on a virtual reality-enhanced cyber-cycle, with age-matched controls training with the same effort on a traditional stationary bike. The first group showed greater improvements, especially in the cognitive domain, probably due also to the nature of the VE that was competitive. Authors reported that navigating in a 3D environment and competing with other people fortifies executive functions such as divided attention, focused attention and decision making.

The use of virtual reality to support physical exercise is particularly useful not only to tempt subjects to train in the short term, but also to modify the intrinsic motivation to perform the activity, thus promoting healthy behaviours that can prevent many diseases [23]. Data [22, 23] show, in fact, that virtual reality used during cycling on stationary bikes contributes to the desire to exercise longer, decreasing the fear of exercising and minimizing the focus on the exercise duration.

Bruun-Pedersen and colleagues observed the experience of some seniors while pedalling in an immersive environment using an HMD, in detail using an Oculus Rift [24]. In their experiment, the authors evaluated the system's usability and the intrinsic motivation during the exercise. Both qualitative comments and elderly behaviours during the exercise showed the positive effect of HMD on people's sense of presence; however, the authors did not quantitatively evaluate the sense of presence experienced and did not compare the use of the Oculus Rift with a non-immersive condition such as the use of a flat screen. The relationship between the subjective sense of presence and the system characteristics of immersion (in particular, the type of display) has been studied extensively over the last decades. As discussed by Slater et al. [25], there is a strong effect of immersion on presence.

All these results suggest that Virtual Reality and immersive VR in particular are able to provide very positive experiences for elderlies, though it is necessary to control the side effects that the immersive technologies may induce [13].

Finally, some theories assume that the time passing between two subsequent experiences in VR may affect subjective judgment about experience [26, 27], thus the differentiation in four groups – made to evaluate whether performing the task in two different days influences the results – have been performed.

3 Methods

3.1 Participants

Participants were enrolled among the employees of the Italian National Research Council; all the subjects gave informed written consent. Their characteristics are reported in Table 1.

Table 1. Sample characteristics. *= missing values.

Participants	N = 33
Age	31 ± 4.94
Sex (M/F)	23/10
Impaired vision:	
• Myopia, astigmatism	21
• No visual problems	9
Familiarity with VR (Y/N)*	6/26
Bike users*:	
• Yes	28
• No	4

No subjects had severe vision impairments. Participants with myopia and astigmatism were left free to wear their prescript glasses or to change the focal distance in the case of HMD. In both experimental conditions the pursued objective was making the subjects see the virtual environments as well as possible.

3.2 Study Design

A within-subjects repeated-measurements study in which participants performed the cycling tasks in two different experimental conditions was conducted. Both conditions used the same VEs and the same cycle-ergometer, but they differed in the devices allowing the visualization and interaction with the VEs (see in Sect. 3.3).

To control the order effects, subjects' exposure to each condition was counterbalanced; moreover, a balanced randomization scheme was used to study the effect of 5-days-washout period with respect to performing both conditions on the same day. This was made with the aim of investigating whether performing the same task after a certain time influenced the perception of sense of presence and the subjective judgement of experience in general. The final distribution of subjects in the study is shown in Table 2.

Table 2. Study randomization scheme.

	5-days-washout	Same day
HMD then PS	Group 1 (n = 10)	Group 3 (n = 6)
PS then HMD	Group 2 (n = 10)	Group 4 (n = 7)

3.3 Equipment

The two VEs – the park and the road-crossing – were developed using Unity 3D. The former (Fig. 1) represented a trail in the park that flows according to the pedals' velocity; an empirical estimation to identify the conversion factor between the cycle-ergometer velocity data – acquired in Round Per Minute (RPM) – and the flowing velocity of the visual representation had been made before this study. If the rider stops pedalling the environment continues to slide, as it would happen in reality, as the cycle-ergometer wheel continues rotating because of its inertia.

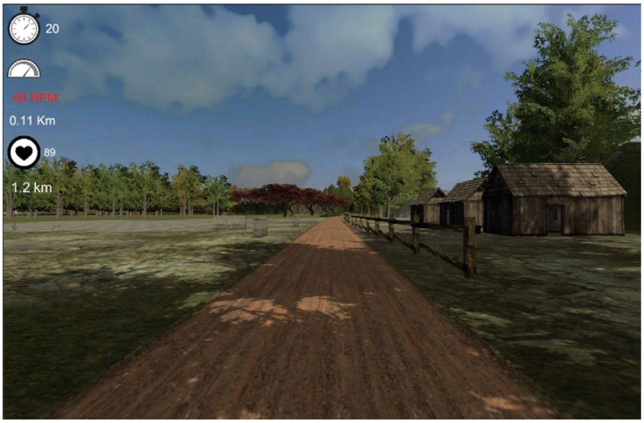

Fig. 1. A screenshot of the park scenario.

The aim of this VE was increasing engagement of the users and providing them with the information needed to control the exercise, such as RPM and remaining time, which are displayed as on-screen text.

The user travelled the path in first person following a predefined route, which included only slight bends to try to avoid the occurrence of cybersickness due to the expectation of lateral accelerations [13]; no interaction to deviate from the itinerary were allowed. In details, the path was created through the placement of subsequent nodes on the route, whose interpolation occurs in real-time using quaternion spherical linear interpolation (slerp). To increase the realism of the scene, trees' leaves and grass moved as the wind was blowing and, sometimes, wild animals appeared in the sky or on the trail sides. Moreover, realistic 3D sounds were implemented in the scene.

The latter VE (Fig. 2) represented an urban route in which the subjects had to face the crossing of five traffic-congested and non-regulated crosswalks. The aim of this VE was to train cognitive impaired patients' visuospatial abilities while performing a frequent and thus familiar activity. The subjects, in fact, were requested to reach the supermarket (at the end of street) crossing the road without being hit by any moving vehicles. They had to cycle to reach the sidewalk edge, brake, look around to check if the way is free and proceed only if it safe.

Fig. 2. A screenshot of the urban scenario.

Cars were randomly generated and had different velocities. Collisions with moving cars were signaled to the user via 3D sounds of car horns, braking and glass breaking. If an accident occurs, the user is brought in a safe-position and could restart to pedal as the cars disappeared from that cross in a few seconds.

The hardware equipment is composed by the cycle-ergometer, an upright stationary bike (Cosmed Eurobike 320), a Samsung GearVR HMD equipped with a Samsung S6 smartphone, a projector (EB-1430WI, Epson) and a computer handling the data exchange, as shown in Fig. 3.

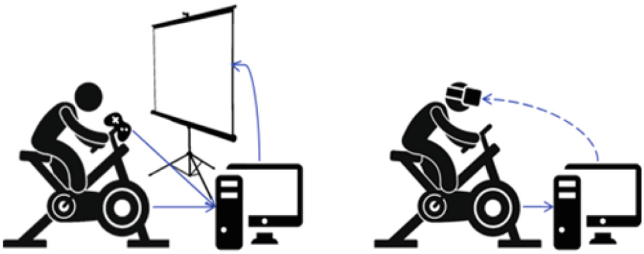

Fig. 3. A schematic representation of the setup used in the PS condition (on the left) and in the HMD condition (on the right). Continuous lines represent cabled connection; the dotted line represent the client-server connection used to synchronize the visual flow with the user's velocity in the HMD condition.

The dimensions of the projected screen (1.30 × 2.35 m) were kept constant for all the trials, as well as the distance of the cycle-ergometer from the projected screen. The cycle-ergometer was connected to the PC using a serial port; thanks to its Software Development Kit (SDK) and a communication protocol developed ad-hoc, it was possible to get the users' cycling velocity as input, so that the visual flow in the VEs could be synchronized. For the HMD condition only, a client-server connection was set up to allow the PC to send the velocity data to the application running on the smartphone (Fig. 3).

More in detail, a standalone program – the server, running on the PC established a connection on demand and exchanged data over the network, thus allowing the client component in the VE to remotely access the devices via a wireless network. The two applications (the client on Android smartphone and the server on a Windows PC) communicate via a proper protocol, based on a TCP client-server connection. No issues due to end-to-end latency of the system were perceivable by human users.

The interactions with the VEs were implemented in two different ways. In PS condition, the PlayStation controller, connected to the PC via USB, regulated the interaction between the users and the VE: the joystick was used to look around, while X button simulated the brake. In HMD condition, the gyroscope integrated in the Samsung GearVR handled the rotation of the point of view; participants were able to freely look around with their head in the virtual environment, not to define their steering direction. The braking function was implemented as a result of the touching of the device touchpad.

The brake could be implemented only in the virtual world because, due to physical structure of the ergometer, it was impossible to access the wheel compartment and create a physical brake, able to stop the inertial wheel rotation. The complete stop of the visual flow was thus obtained in both cases decreasing linearly the velocity (i.e. the last value measured when the button/the touchpad was pressed). In both cases, the braking interactions were not handled in the most realistic way as possible, thus introducing in both of them a potentially distractive element for sense of presence.

In both conditions, to proceed forward after a stop, the user had to restart pedaling: the voluntary restarting of the cycling reset the system to the normal acquisition of data.

3.4 Study Protocol

All the enrolled subjects were instructed at the beginning of the test session about the scenario they would be presented and how to handle the interactions (rotating the point of view and braking). All of them were asked to perform the test navigating in the two VEs using both visualization devices, whose order was defined according to Table 2 (Sect. 3.2). For all groups, the presentation order of the VEs was kept unvaried. The first part of the test consisted of 5 min of cycling in a virtual park. Subjects were instructed to pay attention at maintaining the pedals' cadence between 50 and 70 RPM, since that was the pedal cadence used in our previous study [9], with the aim of inducing a training effect in the elderly patients. Within that setup, the workload was in fact adjusted according to the subject's heart rate; in this study, the workload was set to 0 to avoid inducing fatigue in the users, especially in the case in which the two conditions were performed in the same day.

After this task, the environment turned automatically into the urban route and the subject was asked to cross the road, avoiding accidents with moving cars. In this second scenario, participants thus performed different visuospatial and attentional tasks:

(1) pedalling to reach the border of the sidewalk, (2) brake when being near it, (3) check on both sides if there are cars moving closer and, if not, (4) restart pedalling to reach the following cross.

3.5 Measures

The subjective experience was assessed as a whole; therefore both scenarios together were assessed through questionnaires.

The sense of presence (SoP) was evaluated using the Igroup Presence Questionnaire (IPQ) [28] immediately after the administration of each condition.

Data on cyber sickness were also collected using the Simulator Sickness questionnaire (SSQ) [29].

Furthermore, after the completion of both conditions, participants were asked which device they preferred.

Participants' comments during and after the test were collected and analyzed, as they could be useful in providing qualitative information usually not detected through questionnaires [27]. Comments that were judged relevant to Sense of Presence were examined through thematic analysis [30].

3.6 Statistical Analysis

IBM SPSS was used to perform all the statistical analyses. Paired t-tests were run to compare the Sense of Presence in the two conditions. Unpaired t-tests were also used to compare SoP in sub-groups defined according to: (a) device's preference, (b) belonging to a specific Group (Table 2), (c) personal characteristics (Table 1).

A 2×4 mixed ANOVA was performed to evaluate the effects of the interaction [condition * group] and the two main effects of Condition and Group.

Cybersickness was compared between the two conditions in each group using Wilcoxon signed rank tests.

The effect size was measured too. Cohen's d was calculated when the two groups had similar standard deviations and were of similar size; Hedges' g was used where there were different sample sizes. Effect size for Wilcoxon signed rank tests was calculated following Pallant's indication [31].

Correlations of SoP with the cybersickness were evaluated using both Pearson's index correlation and partial correlations. Partial correlation was applied with the aim of examining the relationship between the two variables without the effect of the others. Since SSQ total scores have non-normal distributions [29], a square root transformation was performed before running this statistic.

Chi-squared test was run to establish whether the difference in device preference was generalizable. For this test, VR frequent users were excluded to avoid any bias of the sample.

4 Results

The results of three subjects were excluded: one did not perform the second condition for reasons independent from the study (Group 2), one did not express a preference between devices (Group 2) and the last was considered an outlier since she reported too high scores in SSQ in both conditions (Group 1).

4.1 Sense of Presence

Scores in IPQ ranges from 13 (minimum SoP) to 91 (maximum SoP). In both conditions, scores of SoP were verified to be distributed according to a normal distribution.

In condition PS, subjects got variable scores from 19 to 50(36.5 ± 8.32); with HMD, instead, scores were significantly higher with a minimum of 35 out of 91 (56.8 ± 10.39) (Table 3).

Table 3. Groups' differences in sense of presence measured using IPQ.

		SoP	p-value	Effect size
Group 1	PS	37.00 ± 9.17	$p < 0.05$	Cohen's $d = 1.9$
	HMD	55.89 ± 10.68		
Group 2	PS	33.00 ± 6.16	$p < 0.05$	Cohen's $d = 1.98$
	HMD	52.00 ± 12.10		
Group 3	PS	42.29 ± 7.63	$p < 0.001$	Cohen's $d = 2.16$
	HMD	60.86 ± 9.48		
Group 4	PS	24.43 ± 8.10	$p < 0.05$	Cohen's $d = 3.97$
	HMD	57.86 ± 8.71		

Considering separately those who preferred the projector or the HMD, the difference in sense of presence in the two conditions was statistically significant for both groups: $t = -2.70$, $p < 0.05$ and Cohen's $d = 1.337$ for the former and $t = -14.64$, $p < 0.001$, Cohen's $d = 0.239$ for the latter. The sense of presence of those who chose the projector as preferred device was 42.33 ± 6.563 using this device and 53.33 ± 9.61 using HMD; those who preferred the Samsung GearVR obtained 35.04 ± 8.17 in PS condition and 57.67 ± 10.59 in HMD condition.

Observing the four groups, no difference in IPQ's scores was found: all subjects experienced greater sense of presence in the HMD condition, regardless of the group they belonged to (Table 3).

The 2 × 4 mixed-ANOVA was performed (Condition: [PS, HMD; within] x Group [group 1, group 2, group 3, group 4; between]). The main effect of condition was statistically significant ($F(1, 26) = 134.19$, $p < 0.001$ and $\eta 2 = 0.59$), whereas nor the main effect Group ($F(3, 26) = 1.97$, $p > 0.05$ and $\eta 2 = 0.14$), neither the interaction between the two variables ($F(3, 26) = 0.297$, $p > 0.05$ and $\eta 2 = 0.009$ were.

No effect of personal characteristics was found in SoP scores between the two conditions (Fig. 4). All subjects experienced more presence with HMD regardless of sex (t = 0.93, p > 0.05 and Edges' g = 0.41 for PS condition; t = 1.29, p > 0.05 and Edges' g = 0,05 for HMD condition); visual problems (t = −0.88, p > 0.05 and Edges' g = 0,034 with projector screen, t = −1.934, p > 0.05 and Edges' g = 0,46 with HMD); bicycle's use (t = −0.34, p > 0.05, Edges' g = 0.02 using PS, t = 1.06, p > 0.05 and Edges' g = 0.48 using HMD) and past experience with virtual reality (t = −0.59, p > 0.05 and Edges' g = 0.38 with PS; t = −1.49, p > 0.05 and Edges' g = 0.001 with HMD).

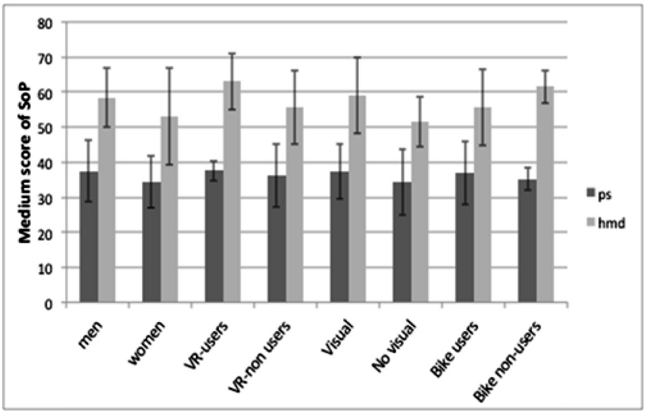

Fig. 4. Sense of Presence, measured with IPQ, according to personal characteristics. No significant difference was found between subgroups.

4.2 Cybersickness

SSQ-TS total scores as measured in the four Groups are reported in Table 4. All groups experienced greater discomfort using HMD.

Table 4. SSQ raw scores and Z-tests. Values are reported as median (minimum – maximum) values.

		SSQ-TS	Z-test	Effect size
Group 1	PS	1 (0–8)	−2,53 p > 0.05	r = 0.59
	HMD	8 (1–20)		
Group 2	PS	0.5 (0–6)	−2,53 p > 0.05	r = 0.63
	HMD	9 (1–26)		
Group 3	PS	4.5 (0–9)	−2,21 p > 0.05	r = 0.64
	HMD	9.5 (4–16)		
Group 4	PS	0 (0–7)	−2,37 p > 0.05	r = 0.63
	HMD	10 (4–50)		

4.3 Correlation Between SoP and Cybersickness

Using the HMD, cybersickness and sense of presence were correlated, but only when the simple correlation is run ($r = -0.39$, $p < 0.05$). The correlation disappears when the partial correlation test is performed, indicating that probably sense of presence is more strictly related with other feelings that may arise during the experience of the navigation in the VE. In the PS condition, there is no correlation between the two variables in any case (Fig. 5).

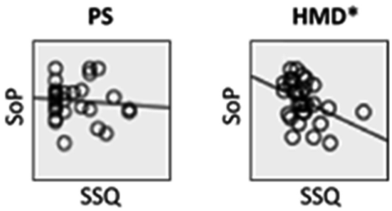

Fig. 5. Correlation between Sense of Presence, measured using IPQ, and cybersickness, measured with SSQ. Cyber-sickness and sense of presence were significantly correlated only in the HMD condition.

4.4 Device Preference

Data showed a significant difference in the device's preference between those who chose HMD ($N = 24$) and PS ($N = 6$): chi-square = 10.8, $p < 0.001$, even when considering only subjects who did not regularly use virtual reality systems ($N = 25$) to avoid any potential bias (chi-square = 6.76, $p < 0.01$).

4.5 Participants Comments and Free Notes

The participants' comments about the sense of presence experienced during the exercise were identified and separated from the others. To perform the thematic analysis, four different main areas related to SoP were identified: *realness*, *interaction*, *engagement* and *physical drawbacks*.

Comments labelled as *realness* dealt about the naturalness of the virtual environment and of the exercise, namely how similar the reality was perceived to the virtual experience. According to many of these comments, the lack of realism led to distraction from the experience in both conditions (e.g. "The change in bike's direction is not so natural", "I believe there are missing elements which can make the environment more realistic: walking people, animals"), thus reducing the SoP. Some criticisms were made on the poor fluidity of VE, pale images, too slow cars ("The environment is not very detailed", "The movement of cars is unrealistic", "The city is aseptic and fake") and, especially, on the static nature of cycle-ergometer in the bends ("The change in bike's direction is not so natural", "During the test, I felt detached from the ground"). Most of the participants complained that the braking was too unrealistic and immediate in both conditions and that the change of the point-of-view with PS was too sharp because of the joystick sensitivity.

Besides these comments relating to *realism*, which were the most numerous, others were related to self-efficacy and active control of the VE. Within these comments, classified under the label *interaction*, many subjects suggested an increase in the interaction with the virtual environment, even by adding mini-games in the first scenario ("I would have liked to be able to choose the path to follow", "I could not interact with the environment", "It would be nice if something happens at your passage: for example something that rolls and should be avoided"). In the PS condition, subjects reported issues in the interactions with the second VE, as "The change of the visual perspective with the joystick is too quick and unnatural", "The commands to change the point of view are unrealistic and increase the difficulty of the task". In the HMD condition, one subject complained that braking was unrealistic ("Braking is not so natural and distracts from the experience"); two subjects made clear comments on the increase engagement induced by the use of HMD ("The possibility to look around freely increases the level of realism of the experience and makes it more enjoyable and less static", "Exercising with HMD is more realistic and immersive: the environment surrounds the person and thus its visual exploration is more immediate").

Some subjects said that the experiment was, especially with the projected virtual environment, quite monotonous ("I found the exercise boring and therefore not very engaging"). Nevertheless, the same subjects reported also a contrast of emotions, reporting involvement with the Head Mounted Display ("It is to be improved, but I found the experience very fun", "The experience with HMD was engaging") and amusement at some points in the pathway. All these comments were grouped under the category *involvement*.

Finally, some subjects' comments related to the physical discomfort experienced during exercise. This category was named *physical drawbacks*. Mostly, people reported general discomfort and vision problems during the HMD condition "I had nausea and dizziness", "I had a slight sense of nausea", "The background was somewhat blurry and it caused a slight annoyance", "I did not feel comfortable, maybe because I did not see well"). While the latter were felt throughout the exercise, the former appeared mainly during bends ("During the curves, the trajectory was fragmented and this caused malaise" "I felt good on the straight path, but not in the curves"), in the first scenario, and after braking, in the second ("I felt pushed out of my body"). In two cases, malaises were reported also in the PS condition ("I had headache", "I felt a little dizzy").

5 Discussion

Results of this study, which compared Sense of Presence and other different aspects related to the visualization of virtual environments, showed that the preferred visualization device in a sample of healthy young adults was largely the HMD. It has to be highlighted that both those who preferred the projector and those who preferred the HMD experienced a greater sense of presence with Samsung GearVR; however, the difference between the two conditions was greater for those who preferred HMD. Thus, although there could be physical side-effects [13, 32], positive feelings induced by higher SoP seemed to have weighted more in the subjects' choice of the preferred device. In addition, the results of this experiment indicate that exposure mode to both devices does not affect the sense of presence experienced, but they are in contrast with previous studies [33].

Our study did not show any differences in the sense of presence depending on some user's characteristics. These data confirm some studies' conclusions about the differences for males and females for sense of presence [34], but are in contrast to the experiments that reported that virtual reality frequent users experience a higher sense of presence [35]. This may be due to the different way in which questions related to past experience with VR have been posed.

The obtained results also indicate that the physical discomfort (cybersickness) affects sense of presence, but only while wearing the HMD; since no difference in SSQ was found in the two conditions, however it may be possible that cybersickness participates indirectly in SoP determination, by weighing on other variables. This findings are in agreement with what Witmer and Singer's [36] reported in their study, i.e. the physical drawbacks turns the focus away from the virtual environment, decreasing involvement and, consequently, reducing the sense of presence.

Examining the participants' verbal productions, we found four categories of comments about sense of presence: realness, interaction, involvement and physical effects.

These categories correspond to the latent factors already identified in specific questionnaires created to investigate the sense of presence. First, the comments labelled "Realness" are completely comparable to those found in other studies; for example, in the IGroup Presence Questionnaire [28] authors talk of "Experienced Realism", while Witmer and Singer [36] named it "Interface quality". Our second category, namely "Interaction", is perceived as a part of the widest "Space Presence" category for Schubert, and Witmer and Singer insert it in the PQ's first cluster: "Involve/Control". Unlike in Witmer's PQ, that include involvement comments in the first subspace in addition to the VE's sense of control, we have separated these phrases in a single category ("Involvement"); in the Igroup Presence Questionnaire [28] this aspect is present in the first subs-scale, called by the authors "Spatial Presence".

What is interesting is that only one person explicitly reported the feeling of being present in the virtual environment ("I had the feeling of being in the park") but all comments in the "interaction" category contained the implicit reference to the interruption of the sense of presence ("I could not turn the handlebars and this distanced me from the virtual environment"). These outcomes have a twofold importance. On the one hand, they support Schubert and colleagues' proposal [28], which combine interaction and general sense of feeling present in the wider category "Spatial presence"; on the other hand, they suggest the possibility of assessing the sense of presence by alternative methods. In this context, Slater and Steed [37] conducted an experiment in which they asked the subjects to report how many times they were aware of the environment in which they were physically present in. Authors reported a significant correlation between the number of times that subjects reported a conscious transition between the virtual world and the real world, and the sense of presence evaluated through a questionnaire. The comments of subjects enrolled in this study confirmed that often the sense of presence is detected through an interruption.

At last, our "Physical Drawbacks" category is presented only in [7] (with the label "Negative Effects"); in this case, it has to be underlined that most of the physical reactions due to immersion into a virtual environment are evaluated with other specific questionnaires, such as the Simulator Sickness Questionnaire [29].

Many phrases of the subjects referred to the need for motivation in order to have fun and to feel more involved in the virtual environment. Although motivation was a variable we investigated separately, it is interesting how people have spontaneously linked it to the sense of presence. This can be explained by the influence that motivation has on involvement and, consequently, on the sense of presence. Other studies confirmed the strong correlation between motivation and sense of presence [38].

Dealing with the presented system, specific comments have been very helpful for future improvements of the tool. It appeared that cycling in both environments had been enjoyable, but bends and hard braking were judged too sharp and were identified as the main cause of malaise. This could be expected since during brakes and bends, the human body – and its vestibular system in particular – expects to perceive respectively frontal and lateral accelerations. These situations induce a strong conflict between visual and vestibular signals that increased physical discomfort [13, 39]. A correct design of the virtual environment, that has to be developed excluding all the elements that provoke symptoms in susceptible individuals, is indeed a recommendation that has to be pursued [32, 39]. Moreover, it seems plausible that adding some interactions with the environment, as suggested by this study participants, can be useful to increase future users' engagement, but also to reduce motion sickness as suggested in [32, 39, 40].

User comments have highlighted how the sense of presence is important. Though the sample may be biased with respect to the target population (i.e. young adults have more familiarity with VR) who did not complain about graphical features [9], their suggestions to improve the graphic and the technical features of the instrument, and adding sounds, highlighted how the realism of the scenarios is strongly linked to provision of a better experience.

6 Conclusion

In this study, the results of a preliminary test comparing the visualization of two VEs using a projector and a HMD while riding a cycle-ergometer are reported. In particular, the role of sense of presence has been investigated and discussed. The influence of cybersickness was also investigated and reported. It has been noticed that, despite HMD often caused higher discomfort, it was the preferred device for the majority of the subjects and obtained results indicate that this is due to the increased sense of presence that HMD elicited; this underlines the importance of designing engaging systems and exercises with clear and motivating goals. Moreover, the IP Questionnaire's scores obtained in this pilot study were not related to those of cybersickness, contrary to what studies on the antecedents of the sense of presence have reported [7], but this is probably due to the small sample.

Although in this experiment we have evaluated only two variables, it is evident that many others have to be studied when considering the sense of users' presence. It would be interesting to integrate future analyses with other variables: various researches revealed relationships between usability and sense of presence [41], between sense of presence and attention [36] or between usability and memory [27], without considering the role of perceived motivation. Other studies reported that user characteristics, such as cognitive abilities and the willingness to suspend disbelief can be important in influencing presence [36].

Further tests should also be conducted to consider the effect of time and of the habituation on the tolerability of the instrument [42] and the possibility of including objective measures, such as heart rate, skin conductance and/or postural instability. Other experiments, in fact, reported an association between sense of presence and these physiological parameters [43, 44].

Finally, since the study highlighted that the system can be improved to better respond to users' needs, some modifications will be implemented in order to engage more future users. First, since sharp bends and brakes were the main causes of malaise for most of the subjects, they will be improved with the aim of reducing motion sickness. The trajectory of the bike in the park, which resulted sometimes fragmentary, will be modified to create a smoother path, which should not induce in the user the expectations of centripetal accelerations. Moreover, the sensitivity of the braking device, especially in the case of the HMD, will be decreased, recreating the situation in which the velocity slowly decreases until the complete stop. The use of different HMDs, like Oculus Rift or HTC Vive, whose have higher performance than Samsung GearVR, and thus may induce less discomfort [45], will also be considered in future developments. The employment of these devices, in fact, will allow increasing the details of the VEs and the vertices of the objects displayed in the scene, thus leading to a plausible increased realism.

When the navigation and the interaction will be comfortably tolerated by a population of young adults, first tests on frail people and elderly – the target population of the designed physical and cognitive intervention – will be conducted taking into account the proper safety equipment (e.g. harness) and recommendations [32].

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