The benchmark framework and exploratory study to investigate the feasibility of 360-degree video-based Virtual Reality to induce a full body illusion.

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Abstract

The feeling of ownership of a virtual body has been a topic of interest in recent years. In order to observe the mechanisms involved in the perception of the body illusion and its manipulation, the use of Virtual Reality (VR) has been essential. Various technical VR set-ups have been adopted by different authors to induce the sense of embodiment. Recently, 360-degree technology camera emerged as an innovative instrument to generate an immersive experience, with positive results in terms of involvement with the scenario. The current study aims to test the feasibility of 360-degree video-based VR to induce a full body illusion. To do this, we evaluated two different groups receiving different levels of immersion: a 3D immersive video and a 2D non-immersive video. Self-reported sense of embodiment and Heart Rate Variability (HRV) measures were analyzed. The results of the embodiment questionnaire showed that the immersive condition can trigger a full body illusion, with significant differences between the 3D and 2D conditions (ownership: *p*=.003, agency: *p*=.000, location: *p*=.013, haptic sensation: *p*=.027). No difference was found on the Root Mean Square of the

Successive Differences (RMSSD) index – the beat-to-beat variance of the heart rate - of the HRV measure (first 90_{sec}: p=.168, last 90_{sec}: p=.401). Based on these results, future studies are needed to investigate the 360-degree video-based VR technology as a medium to generate the sense of embodiment.

1. Introduction

In literature the concept of the Sense of Embodiment (SoE) embraces different scientific areas from cognitive neuroscience and psychology that consider the embodiment as the brain representation of the body and how this representation could be altered under certain circumstances (Lenggenhager et al 2006; Longo et al., 2008), to robotic perspective focused to generate a sensorimotor experience closer to what can be observed in real human interactions (Tidoni et al., 2016; Sergeeva et al., 2020). In the present article we used the concept of embodiment to refer to the ensemble of sensations that arise in conjunction with being inside, having, and controlling a body (Blanke et al., 2004; Kilteni et al., 2012), referring to the concepts of (1) *the sense of self-location* which refers to a certain space where people feel located with their body; (2) *the sense of agency* which refers to the sense of having conscious motor control of the body; and (3) *the sense of body ownership* which refers to one's self-attribution of the body (Longo et al., 2008).

Previous studies have investigated how to modulate the SoE under controlled experimental manipulation, especially through Virtual Reality (VR) applications (Haans and Ijsselsteijn, 2012; Matamala-Gomez et al., 2020, Pastel et al., 2020). The Rubber Hand Illusion (RHI) was the first method adopted to manipulate this sense. During the RHI a person watches a fake (rubber) hand while receiving synchronous tactile stimulations with his or her own real hand. After few minutes of the precise synchronous touch between the real and the fake hands, the participant might develop the vivid impression that the fake hand is his or her own (Botvinick and Cohen, 1998; Cebolla et al, 2016; Palomo et al., 2018). On the basis of this experiment and its results, researchers have hypothesized and confirmed the possibility of inducing the illusion of the entire body through the experimental manipulation of the visual perspective and sensory signals (Petkova and Ehrsson, 2008), which is referred to as Full Body Illusion (FBI). Through the FBI is possible to observe the entire fake body from a first-person perspective and place at the same spatial location as the real body is (Maselli and Slater, 2013; Petkova and Ehrsson, 2008). As for the RHI, the FBI can be achieved through visuo-tactile stimulation (Normand et al., 2011; Maselli et al., 2016), and visuo-motor correlations (Ponzo et al., 2018; Serino, et al, 2019). Another interesting manipulation of the embodiment is the Out of Body Experience (OBE) that mainly manipulated the sense of self-location of the embodiment. The OBE is defined as an experience in which a person seems to perceive the world from a location outside their physical body (Bourdin et al., 2017).

Recently, VR technologies made possible to study the RHI, the FBI, and the OBE (Figure 1), giving participants the "impression" of having another body (IJsselsteijn et al., 2006; Kilteni et al., 2012, Pavone et al., 2016; Riva et al., 2019). Different VR set-ups have been developed to manipulate the SoE. One of the first technical set-ups used was an ensemble of cameras connected to a Head Mounted Display (HMD) (Ehrsson, 2007). Specifically, two cameras are positioned on a mannequin, so that each recorded event from the position corresponded to one of the mannequin's eyes. The HMD is connected to the cameras and worn by the participants. It is connected in such a way that the images from the left and right video cameras are presented on the left and right eye displays, respectively, providing a true stereoscopic image (Ehrsson, 2007) (Figure 1A). This set-up is used to induce the sense of OBE by manipulating the visuo-tactile stimulation, principally focused to alter the sense of self-location (Lenggenhager et al., 2006). The second set-up to induce the body swap was utilized by Slater (2010) and it consisted of an Optitrack full body motion capture suit with a specific software to track user movements. At the same time, the user wore the HMD to become immersed in the environment (Banakou et al., 2016) (Figure 1B). Bailenson (2016) has adopted the optical sensors and inverse kinematics to track body movements and display them on an HMD to create these illusions (Figure 1C). Moreover, Bertrand group (Bertrand et al., 2018) designed a novel body swap set-up structured by a camera fixed to torso equipment and worn by the researcher during the experiment and connected to the HMD by software (Cebolla et al., 2019) (Figure 1D). The set-ups B, C, and D are adopted to induce the full body ownership illusion by which participants could see, through the HMD, the own virtual body from the first-person perspective and place at the same spatial location as the real body is (Slater et al., 2009; Maselli and Slater, 2013). The technical set-ups described were adopted for several studies that involved the body swap paradigm, addressing topics such as helping behaviour (Ahn et al., 2013), reducing implicit biases (Maister et al., 2013; Peck et al., 2013), reversing racial in-group bias (Hasler et al., 2017), enhancing financial planning (Sims et al., 2015), decreasing prejudice (Oh et al., 2016), and inducing compassion (Hamilton-Giachritsis et al., 2018), self-compassion (Cebolla et al., 2019), or empathy (Seinfeld et al., 2018; Ventura et al, 2020a). The critical point of these embodied technologies is their cost-efficacy gap because on one side these tools permit to participants to reach significant level of SoE, but on the other side these embodied technologies require expensive economic and human resources investments for the software development and the study design procedure. In contrast, immersive 360-degree video technology is increasingly affordable and available, and features continuously improved tech specs.

In the present work, we propose an innovative 360-degree video-based VR system to induce the SoE. Instead of a classical graphic-based VR scenario (Slater and Sanchez-Vives, 2016), we adopt the 360-degree video to record some body movements before playing them on the HMD. The 360-degree videos are video recordings shot using omnidirectional cameras or a collection of synchronized cameras with overlapped field of view. Furthermore, it is considered a subfield of VR due to its features to reproduce, in second time, the real environment and to generate the immersive experience to participants (Huang et al., 2017; Repetto et al., 2018). These videos recordings are usually mapped onto spherical projections that can be observed from a moving perspective, which is commonly defined by changing the orientation of a device equipped with an IMU, either using the hands, in the case of smartphones, or head rotations, in the case of VR headsets. However, the missing feature that prevents the 360-degree video to be a completely VR system is the interaction with the virtual environment, namely users are only passive observer of the virtual experience. The immersive set-up has been shown to have positive outcomes in term of involvement with the scenario (Schutte and Stilinović, 2017; Brivio et al., 2020), and recently it was also adopted for studies based on empathy research (Buchman et al., 2019; Hasson et al., 2019, Ventura et al., 2020b).

The aim of this study is to analyze the feasibility of the 360-degree video-based VR to generate the SoE. In particular, the objective is to investigate whether a pre-recorded video of some body movements could induce the body ownership illusion in participants that simply follow the recorded movements. The study compares two types of videos: a 3D recorded video display on the HMD (immersive condition) and a 2D recorded video display on a Computer Desktop (non-immersive condition), to analyze the influence of immersion on inducing the illusion. Two measures are analyzed: the subjective embodiment experience, and the Heart Rate Variability (HRV). Specifically, HRV represents the change in the time interval between successive heartbeats and provides an index of the parasympathetic nervous system (Berntson et al, 1997). The parasympathetic nervous system is associated with many aspects of psychophysiology, such as the self-regulation mechanism linked to cognitive, affective, social, and health phenomena (Laborde et al., 2017). Previous studies demonstrated that greater SoE grater heart variability due to the aversive stress perceived during the virtual experience (Slater et al., 2010; Maselli and Slater, 2013). In our study, we hypothesize that participants in the 360-degree video-based VR condition experience a higher SoE, and more heart variability compare to the non-immersive video condition.

PLEASE INSERT HERE FIGURE 1

2. Materials and methods

2.1. Participants

The study was approved by the Ethics Committee of the University of Valencia (Spain), with the registration number: H1547116450036. We recruited a total of 42 participants, randomly assigned to one of two groups: 21 in the 3D condition (immersive) and 21 in the 2D condition (non-immersive) to investigate the effect of the immersion variable on the SoE and HRV outcomes. The inclusion criteria were: (a) being 18 years older, (b) being a Spanish speaker, and (c) not having a severe physical disorder that interferes with free body movements.

The final sample was composed of 27 females (64.3%) and 15 males (35.7%), aged from 19 to 36 years old (M = 24.88, SD = 4.09). The level of education was undergraduate *n* = 8 (19%), bachelor's degree *n* = 15 (35.7%), and master's degree *n* = 19 (45.3%). None of participants declared having any body illness. All the participants were volunteers and signed the informed consent document before starting the experiment, in accordance with the Declaration of Helsinki.

2.2. Implementation and Apparatus

The 2D and 3D scenes were recorded with the LG360-105 camera and the LG360 viewer software. The 3D video was recorded through the 360-degree option (double eyes), and the 2D video was recorded through the 180-degree option (one eye) from the same LG camera. To record the videos, both female and male performers (both researchers in the Lab) sat on a chair and wore the camera on their heads, using a head strap. Figure 2 shows the camera perspective.

Two videos were recorded, one with female and one with male performer, later display in two format, immersive or non-immersive, depending on the participant's condition. During the video recording, the performers (the female and male characters of the videos) made a set of slowly movements: they had to move their hands, the legs up and down, caress their limbs, and rotate their hands with the goal to test the sense of ownership, and the sense of agency of the participants. These movements are later imitated by the participants during the experimental session. Furthermore, both videos were recorded in a different room from where the experiment took part with the goal to detect the sense of self-location of the participant. At the end of the video, a yellow ball was suddenly thrown to the performer's right hand. This "disturbing event" was chosen because we looked for an event that could explicitly break the "experimental harmony", in order to evaluate how the virtual scenario and real tactile perception could interact each other. Both videos last 3 minutes and are composed of four parts: hands (from 0" to 1'30"), legs (from 1'31" to 2'00"), and arms (from 2'01" to 2'49") to analyze the difference between conditions for each limb, and the "disturbing events" of the yellow ball (from 2'50 to 3'00") to analyze the haptic sensation. The baseline and post-events are the screenshot of the video, and they last 6 seconds each, according to the HRV literature for baseline measures (Malik et al., 1996; Laborde et al., 2017; Shaffer and Ginsberg, 2017).

The video was edited and synchronized with the HRV system Polar H10 (Polar Electro, Kempele, Finlandia) using the development platform Unity 3D (Unity Technologies ApS, San Francisco, CA, USA). The 3D video is played on the Oculus Rift connected to the Computer

Alienware 15, and the 2D video is displayed on the Desktop of the Alienware (15.6 inch - UHD display).

PLEASE INSERT HERE FIGURE 2

2.3. Measures

2.3.1. Embodiment Questionnaire

It is an adaptation of the original questionnaire to assess the Rubber Hand Illusion experience developed by Longo et al. (2008). It is composed of 10 items rated on a Likert-type scale ranging from 1 (strongly disagree) to 7 (strongly agree). The original scale contains 3 subscales: 5 items assess body-ownership, 3 items assess the self-location, 2 items assess agency. At the present, we added 2 items that assess the haptic sensation of the ball at the end of the videos, for a total of 4 subscales (Table 1). The scale was translated from English to Spanish by a bilingual professional to correct conceptual discrepancies.

PLEASE INSERT HERE TABLE 1

2.3.2. Heart rate variability (HRV)

The HRV was directly estimated and provided by the Polar H10 chest strap (Polar Electro, Kempele, Finland), which provides high quality HR and HRV measurements. Although the device does not provide the ECG raw data, it has been repeatedly used as a reference for wearable HR measurement systems (Plews et al., 2017; Gilgen-Ammann et al., 2019).

2.4. Experimental Procedure

The experiment took place at the Faculty of Psychology at the University of Valencia. After giving their consent, participants were invited to wear, in a separate room for privacy, the Polar H10 on their chest, and they were instructed to sit comfortably on a chair with their legs resting on a footstool and their arms resting on their legs. Before starting the video, the researcher gave them the instruction to follow and synchronize with the performer body movements watched in the video as much as possible during the entire experiment. Specifically, the participants are invited to imitate the movements of the video previous recorded. Depending on the gender and the condition assigned, each participant was exposed to one of the videos. As Figure 3 shows, participants in the experimental condition (3D - immersive) were exposed to the scene through the HMD (Figure 3A), whereas participants in the control condition (2D - non-immersive) were exposed through the Computer Desktop (Figure 3B). In both conditions, participants never saw the performer’s face, only his or her body. After the experimental session, participants were invited to fill out the embodiment questionnaire and take off the Polar H10.

PLEASE INSERT HERE FIGURE 3

2.5. Data analysis

For the analysis of the questionnaire responses, we performed descriptive statistics and MANOVAs (ownership, location, agency, and haptic sensation), all with two-way interactions (2D and 3D). Post-hoc analyses using Bonferroni corrections were carried out when significant effects were found. For the HRV, the recordings were visually inspected for motion artifacts. In case a time slot was found to be affected, it was discarded from analysis. We analysed the RMSSD index, which is the HRV time domain index, primarily connected to vagally-mediated change and relatively free of respiratory influence (Shaffer and Ginsberg, 2017). HRV analyses were performed through BioSignalsPlux propriety software OpenSignals with the respective HRV analysis pack, following established guidelines (Shaffer and Ginsberg, 2017). We analyzed the HRV of the limb movements, respectively the hands, legs, and arms, and the HRV of the video time slot. Giving that both videos, 2D and 3D, last approximately 3 minutes, we analyzed the first and last 90 seconds of both conditions. We choose the 90 seconds time slot because, according to the literature (Malik et al., 1996), 1 minute is the minimum time to obtain a reliable assessment of RMSSD and evaluate its change. Considering the RMSSD index as the dependent variable with a group factor (experimental and control), we performed the following analysis: i) an independent t-test to analyse the difference between conditions (2D and 3D) and the video recorded time (first 90 seconds and last 90 seconds); ii) an independent t-test to analyse the difference between conditions (2D and 3D) and the limb section (hands, legs, and arms); iii) a mixed 2 × 2 ANOVA to analyse the difference between conditions (2D and 3D) and the video recorded time (first 90 seconds as T1 and last 90 seconds as T2), in order to analyse the differences in the RMSSD index due to embodiment induction. All the statistical analyses were performed with SPSS for Windows v.24 (SPSS Inc., Chicago, USA).

3. Results

3.1. Embodiment questionnaire

Results revealed significant differences between conditions and the subscales of the embodiment questionnaire, confirmed by the post-hoc Bonferroni analyses: ownership p = .003; 95% CI (.45, 2.04); agency, p = .000; 95% CI (.94, 2.90); location, p = .013; 95% CI (.25, 2.03). Moreover, the factor haptic sensation was significant p = .027; 95% CI (.15, 2.26). Means, and standard deviations are presented in Table 2.

PLEASE INSERT HERE TABLE 2

3.2. Heart Rate Variability

HRV analysis revealed 10 drop-out because they exceed the admissible range for the RMSSD value (19-75) (Shaffer and Gisberg, 2017), with the final sample of 32 (*n*= 17 in 3D condition, and *n*= 15 in 2D condition). Regarding the effects of the conditions on the limb movements, there were no significant differences in HRV on the RMSSD index: hands, $F(1, 30) = 1.967$, $p = .171$, 95% CI (-14.982, 2.783); legs, $F(1, 30) = .382$, $p = .541$, 95% CI (-11.639, 6.233); and arms, $F(1, 30) = 1.193$, $p = .284$, 95% CI (-12.095, 3.667). Moreover, no significant interaction effect was found between the conditions (3D and 2D) and the time slot of the video (first 90 seconds and last 90 seconds): $F(1, 30) = 1.782$, $p = .192$, 95% CI (-13.625, 2.853).

PLEASE INSERT HERE AND FIGURE 4

4. Discussion

This study aimed to explore the feasibility of the 360-degree camera technology to induce the sense of body illusion. We expected that by synchronizing one's own body movements with a pre-recorded performer's movements in an immersive set-up, the body illusion would occur. To do so, we compared two groups: 3D immersive and 2D non-immersive set-ups, and we hypothesized difference between conditions in the self-reported sense of embodiment and physiological measures (HRV).

Regarding the results, significant differences emerged between conditions on the embodiment questionnaire. All the subscales - agency, location, ownership - have higher scores in the immersive condition than in the non-immersive one; results showed significant differences even for the haptic sensation; namely, participants in the immersive condition could feel the ball (event that occurs at the end of the video) hit their hands. This result is in line with a previous study (Slater et al., 2010) in which an avatar that slaps the female virtual body induces the participants to feel the slap, even on their faces.

Regarding the HRV results, no significant differences emerged between the conditions on the RMSSD index for limb movements or video time, so the hypothesis that higher HRV higher SoE was rejected perhaps because the duration of the video, approximately 3 minutes, was not long enough to detect the change in HRV (Shaffer and Ginsberg, 2017). Future studies could increase the video time to see if any differences in the HRV index occur. Even if the change in HRV did not match the study hypothesis, according to the embodiment questionnaire response, the video time was long enough to induce the illusion in the participants. A longer video could have caused high level of sickness (Petri et al., 2020) proper of the 360-degree video (Jung et al., 2017) with the risk to break the illusion.

It is also important to highlight that some results confirm that the 360-degree video could be used to produce the body swap, and this could occur for two main reasons: first, the synchronized movements performed with the recorded video allows participants to identify with the video performer. Second, as in other VR systems, the recorded video allows participants to feel like they are in the place depicted by the system. In our case, the video was recorded in a different room where the experiment took part with the aim to permit to participants to feel located in a different place. When the virtual body is perceived to be in the same place where the real body should be, this provides very strong evidence the brain can use to generate the illusion that the virtual body is one's own (Slater et al., 2010). Our findings are analogous with what has been established for the RHI: first, the hand needs to pass a fitness test in terms of anatomical, volumetric, and postural constraints (Tsakiris, 2010). Once the fitness test has been passed, other features enhancing the realism of the object can be incorporated, e.g., the skin texture, to modulate the intensity of the illusion (IJsselsteijn et al., 2006).

The fundamental advance made in this study is the demonstration that the 360-degree camera could be an efficacious tool to induce the body illusion. What does the current system add to the previous one? The 360-degree camera is a small, low-cost, and user-friendly system for research purposes. Compared to other tools, the camera is accessible to a wide range of users, and specific technical skills are not required to operate it. Moreover, the video content could be reproduced by a smartphone through an appropriate App (both for iOS and Android), such as VRPlayer or VR360 (from App Store), or the video could be uploaded to YouTube and played. Then, the VR headset allows the immersive experience, and so it is effortless to move the VR content outside the laboratory setting.

The current study presents some limitations. The first is the small sample size because 42 participants are the minimum number to reach the power effect. Using G*power v. 3.1.9.7 (Faul et al., 2007) we calculated the power analysis to detect effects greater than or equal to d=.40, the standard value of psychological studies (Brysbaert, 2019). Moreover, the sample was homogeneous in term of demographic characteristics. In the 2D condition the female participants were 16, compared to 5 males (in the 3D condition we had 11 women, and 10 men). Furthermore, we evaluated a sample with an average of 24 years old and the older participant was 36, so the elderly population is not included in the study. Future studies should overcome this point. Second, the baseline time interval used in this study could be considered limited by some authors, even though artifacts were removed from the HRV recordings (Shaffer and Ginsberg; 2017). Third, both conditions are synchronous, and we do not know what happen if we compare with the asynchronous condition. Moreover, in both conditions, participants are asked to follow the pre-recorded movements, and maybe this task could generate some milliseconds delay between what participants see in the video, and the time needed to program the limbs movements. Futures studies are planned to clarify these research points.

5. Conclusion

According to previous studies, VR set-ups have achieved important results in inducing the SoE (Kilteni et al., 2012; Ahn et al, 2013; Slater et al., 2010). However, the VR systems adopted so far are expensive in terms of the economic investment and human resources employed. To overcome these limitations, the 360-degree video-based VR could be an efficacious technological alternative to induce the SoE, although more studies are needed. Future study is oriented also to test the difference between the VR artificial environment (the 3D VR) and the VR natural environment (360-degree video) to investigate the significance of the 360-degree video to compete with the others immersive technologies on the marketplace.

The present finding could have practical implications, for example the studies that use the 360-degree video-based VR for the paradigm of changing participants perspective such as from male to female perspective, could include a short immersive video of embodiment induction before play the entire virtual environment. We believe that this procedure could help the participants to perceive themselves with another body for the entire experiment.

Abbreviations

Virtual Reality (VR); Head Mounted Display (HMD); Heart Rate Variability (HRV); normal-to-normal R-R intervals (RMSSD).

Author Contributions Statement

SV and AC made substantial contributions to the conceptualization, formal analyses, data collection, and drafting of the manuscript. JT and RL made substantial contributions to the development of the Unity environment and the HRV analysis. TE made substantial contributions to the collection of the data, and RB made a substantial contribution by revising the manuscript critically for important intellectual content. All authors provided final approval of the version to be published and agreed to be accountable for all aspects of the work by ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as potential conflicts of interest.

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