https://doi.org/10.2352/ISSN.2470-1173.2018.03.ERVR-433

Presence in Virtual Reality: insights from fundamental and applied research

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Abstract

The concepts of immersion and presence are complementary in the field of Virtual Reality research. Immersion is indeed a necessary and non-sufficient condition for the sensation of presence, this latter being also linked to psychological and contextual factors. In our experimental approach, we focus mainly on spatial presence (the sensation of being "there" in the virtual environment). Spatial presence is dependent on cognitive and sensorimotor aspects of navigation and manipulation within virtual environments. More precisely, we focus on behavioral presence, the fact that participants in virtual reality experiences behave in a manner similar to their behavior in a real environment. In this sense, presence appears as a relevant concept, to evaluate the psychological and behavioral validity of human behavior within virtual environments, with respect to reality. Through different experimental studies dealing with human spatial behavior and using different VR setups, our behavioral approach to presence is presented and discussed. An application case will be also presented, suggesting that presence is also related to visuo-proprioceptive coherency.

Introduction

Immersion refers to the sensorimotor coupling between a participant and a virtual environment, including sensorial vividness and real-time interaction capacities of the Virtual Reality (VR) setup. Immersion is thus described as the quantifiable, physical, aspects of the simulation, and can be qualified as the potentialities of the VR setup to isolate the participant from the real world. A large number of studies have investigated immersive determinants of performance (e.g. latency of the real-time loop, display resolution, field of view...). The general hypothesis is that immersive properties of the virtual environment (VE), by isolating the participant from stimulation emanating from the real environment, and by replacing them with stimulations from the virtual environment, will promote optimal behavioral control and performance within the virtual environment.

However, if immersive properties of a VR setup are a necessary condition for behavioral performance in a virtual environment, it is not a sufficient condition for the expression of a behavior that is representative of the actual behavior in real conditions [1]. Contextual, narrative, psychological and maybe also personality and emotional factors come into play. These factors remain to be more deeply investigated [2,3]. The feeling of presence (inside the virtual environment) was thus proposed to bridge the gap between immersive properties and representative (of the real world's) behavior. Presence aims to address the question of the "ecological validity" of behaviors observed in VR setups. In other words, presence is related to the fact that the participant feels "concerned" by what is happening in the virtual scenario [4].

Presence thus refers to a psychological, attentional and cognitive state, in which the participant, immersed within a virtual environment, behaves in accordance with the affordances provided by this environment, as if what is happening in the virtual environment was real. Presence is being addressed using multiple tools, from post-hoc questionnaire to physiological on-line measures [1]. In our approach, we mainly focus on behavioral presence.

Experiment 1: Walking through a narrow aperture

In a first experiment, we investigated spatio-temporal aspects of a basic adaptive behavior [5]. For example, walking from one place to another can be performed using different paths, depending on the relationships between environmental constraints and behavioral capabilities (including body size). As a consequence, evaluating presence in a virtual environment may be approached using the concept of affordances [6]. Affordances are precisely action possibilities in a given environment. As such, it is a relativistic concept that was already being presented as a way to evaluate the reality of experience in a virtual environment [7].

The main hypothesis of this study was thus that the degree of presence in a VE can be evaluated by its actual affordances for action, which can be experimentally tested. We started from a classical study by Warren & Whang [5], in which they studied body rotation while walking through a narrow aperture. Figure 1 exemplifies the transition from frontal walking for a wide aperture to shoulder rotation to pass through (real) narrow apertures. The question was: can this adaptive behavior be observed with virtual apertures?

Figure 1. For a large aperture, frontal walking is observed, while a narrow aperture (smaller that the subject's shoulder width) mechanically triggers shoulder rotation.

Following Warren & Whang's original protocol, we designed an experimental study, in which subjects had to walk naturally through a virtual aperture, whose width was manipulated. Continuous monitoring of the position of their shoulders with respect to the sides of the aperture enabled us to evaluate the adequacy of their body adjustments to the size of the aperture (i.e. avoiding colliding the door's sides). This experiment was conducted in a CAVE setup (figure 2). The floor was a 3x3 m square, enabling natural locomotion.

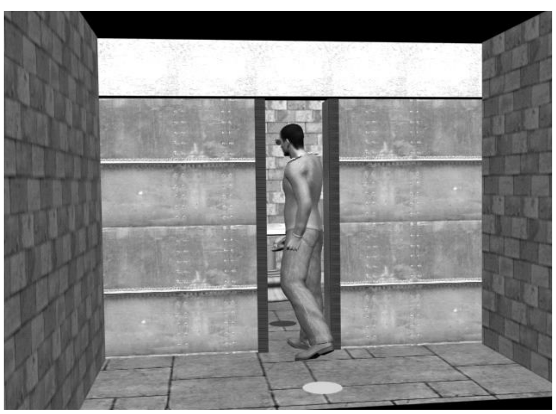

Figure 2. The participant, inside a 4-sided cave system, was simply asked to walk from one starting point to a target. S/he had to walk through an aperture of variable width (sliding door). Appropriate shoulders' rotation when passing the "door" was measured as an indicator of presence.

The results of this first study [8] indicate that the behavioural pattern of subjects having to walk through a virtual aperture strongly resemble those of subjects who have to walk through a real aperture. For most subjects, a behavioral transition from frontal walking to shoulders' rotation is observed as the ratio between the size of the virtual aperture and individual shoulder's width becomes inferior to about 1.3 (similar to what was observed in real conditions). A "safety" margin (around 10 cm) was observed between one's shoulder and the door.

From these observations, we concluded that the subjects' adaptive behaviour was a valid indicator of (behavioural) presence in this task. We will not discuss further the fact that a few subjects did not respond to our experimental setup. They systematically adopted frontal walking while they walked through the aperture, whatever its size. We consider the hypothesis that subjects' cognitive and personality characteristics, such as field-dependency [9, 10] come into play. Ongoing, large scale studies will try to investigate this point, suggesting again the presence is not simply a consequence of immersion. Nevertheless, we will pursue here our approach to the relationships between immersion and behavioural presence.

Experiment 2: Passing door with an HMD

In a second experiment, we wanted to compare subjects' behavior in a CAVE (see above) and while wearing a Head-Mounted Display (HMD). We used the same basic task (walking through an aperture of variable width).

In a CAVE, the subject sees his/her own body. This is no longer the case when s/he wears a head mounted display (HMD). This raises the question of the role of the perception of one's own body (a virtual self) during behavioral adjustments to environmental properties (here the virtual door's variable width). Our general hypothesis was that, when the subject wears an HMD, the presence of a (visual, co-localized)) virtual self will favor the perceptual calibration of the body/environment relationships (and the processing of body-scaled information [8]).

Another reason to test the subject's behavior while wearing a HMD is that we previously observed [11] that, when the subject's body approaches a virtual object (or worse passes through that object), this latter has a tendency to become transparent (eventually destroying the feeling of presence, as was observed for a few subjects in the first experiment in the CAVE). This, of course, is no longer the case with an HMD (and a virtual body representation). Furthermore, in line with recent studies, we proposed that a vibrotactile feedback (signaling, in our study, that one's shoulder was approaching the virtual door) might also contribute to an optimal behavioral calibration. The lack of haptic feedback in most VR setups results in incomplete sensorial feedback, as soon as the subjects interacts with virtual objects. For example, collisions of the body with virtual objects do not typically result in proprioceptive and haptic feedback: nothing is actually there to stop the subject's movement. This deficiency might lead to a lack of user's presence in VE, and be one reason for inappropriate behavior, with respect to reality.

We thus started investigating the effect of vibrotactile stimulation while interacting with virtual objects and asked whether vibrotactile stimulation might act as a substitute for haptic stimulation (see also [12]). The general hypothesis is that vibrotactile feedback (signaling approach to- or contact with a physical surface) enhances collision awareness, and spatial perception in general.

This experiment was conducted in the same physical environment as before (CAVE). The task was the same as before. However, instead of projecting the VE on the CAVE screens, subjects were equipped with an Oculus Rift DK2 device. We studied the effects of two independent crossed variables. The first one was the type of feedback. It could be only visual or augmented with vibrotactile stimulation. Vibrotactile feedback operated as a radar (similar to those in cars). All collisions and distances to the doorpost were recorded during the experimentation (using the same motion capture system -ART- as before, with markers on the subject's shoulders). The second condition was the presence (or not) of a virtual body (co-localized with the subject's body, see figure 3).

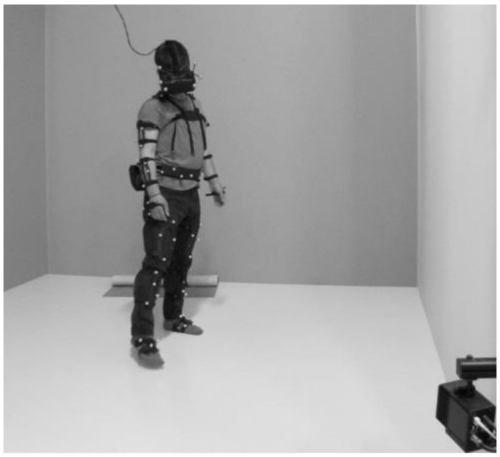

Figure 3. A subject in the experimental setup. He wears the HMD, equipped with an ART target for the tracking of the head's translational movements. He also wears an ART all-body capture set.

Overall, subjects rotated their shoulders while passing through narrow apertures [13]. This shows the immersive properties of an HMD, favoring behavioral presence.

However, concerning the use of body-scaled information [8], a main difference with previous results in the CAVE was observed (see figure 4), when we analyzed the collisions of the subject's shoulders with the door sides.

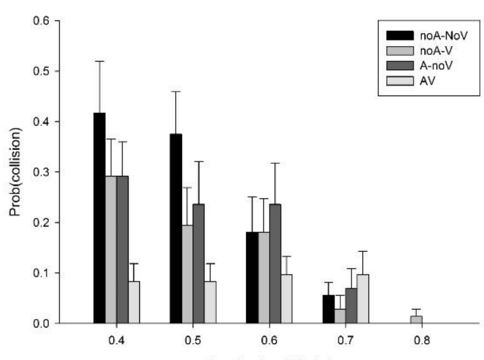

Figure 4. In the absence of a self-avatar (A) and of vibrotactile feedback (V), for small apertures (inferior to .5 meters) collisions occur in almost 50% of trials (noA-noV). In the presence of an avatar OR vibrotactile feedback (A-noV or noA-V) collision rates decrease, but remain high. An avatar AND vibrotactile feedback (A-V) seriously reduces collision for small apertures (10%).

In summary, optimal performance was only observed when both the avatar and vibrotactile feedback were present. This last result requires further investigation, since it can be related to different hypotheses.

It might be that the avatar helps the subjects feel present in the virtual environment and consequently improves distance perception [13]. Subjects using an HMD without any self-representation often complain of a feeling of "floatation" (you do not see your feet, so do not know where you are as compared to the ground surface). However, such body-appropriation might not be sufficient to get rid of the depth-compression effect in VEs, such that vibrotactile feedback would be necessary to further calibrate body-scaled spatial perception. It might also be that the "quality" of the avatar was not sufficient in our conditions to be fully effective and/or that the co-localization between the real and virtual body was imperfect (spatially and temporally), resulting in distorted spatial perception.

Experiment 3: Reaching for objects in a cluttered environment

So far, we noticed the benefits of using an HMD, to the expense of the necessary presentation of a virtual self-located avatar of the self. We also observed that vibrotactile feedback (signaling approach or contact with a virtual object) significantly improves behavior, in terms of distance perception.

In the last experiment, we used these results to investigate an applied case [14]. In industrial settings, the operators' behavior in future facilities has to be studied, to guarantee their viability, in terms of accessibility and maintenance. The operator must often work in a confined environment and has to pay attention to the position of his/her whole body, relative to the position of various elements of the environment. In this context, VR plays a significant role in trying to behaviorally validate future installations.

We designed an experimental study, exploring the contribution of multi-localized vibrators to visuo-proprioceptive consistency, during goal-directed movements in a cluttered virtual environment (figure 5). We use the term visuo-proprioceptive consistency to refer to the spatio-temporal correspondence between the operator's proprioceptive inputs (aided via vibrotactile feedback) and his/her avatar's kinematics (as visually perceived in the HMD).

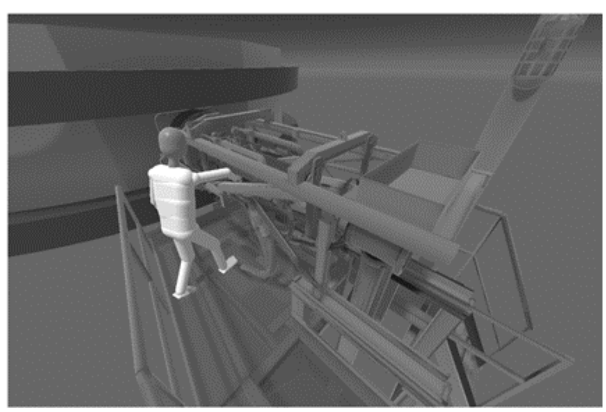

Figure 5. Third-person view of the experimental task. The participant, wearing an HMD, saw a self-colocalized avatar, while reaching for targets in a cluttered virtual environment.

We investigated several conditions of vibrotactile feedback during goal-directed movements in a cluttered environment, while our subjects wore an HMD. Compared to pure visual feedback of a co-localized arm avatar, this feedback was meant to enhance the detection of collisions (as was seen before). Specifically, we compared spatialized vibrotactile feedback with ten vibrators along the upper limb, one non-spatialized vibrotactile feedback with a single vibrator on the hand and a condition without any vibrotactile feedback (visual condition). Participants had to reach targets with their right hand in a cluttered virtual environment (figure 5).

Overall, we found that participants made less and shorter contacts with environmental objects in the presence of a spatialized vibrotactile feedback, as compared to a pure visual feedback. In other words, adding proprioceptive information (through tactile feedback) helped the subjects navigate though the cluttered environment and correctly use visual information available though the vision of their avatar. In this sense, we suggest that visuo-proprioceptive consistency improves spatial awareness, helping subjects to maintain the spatio-temporal co-localization between their real arm and the virtual arm.

Here, we tested a situation where the subjects used an HMD. As a consequence, they did not see their real arm. This is certainly why vibrotactile information played such a significant role in perceiving (or not) the distance between the real and virtual arm. This situation is certainly different from an augmented reality situation, in which the operator can see his/her own arm, adding a visuo-visual factor (between the real and virtual arms) to visuo-proprioceptive consistency. It would be interesting to test our experimental setup in a CAVE system for instance, where the subject has direct vision of his/her real arm (we have ongoing work in that direction). However, the "CAVE" setup poses serious problems such as the fact that objects become transparent when your real arm penetrates them, jeopardizing presence. Comparing CAVE and HMD setups remains a topic of interest for future work. Especially for having a better understanding of the role of vibrotactile feedback, considered as pseudo-haptic feedback, to optimal performance.

Conclusion

In this quick survey, we presented a behavioral approach to presence, as a function of immersive and informational aspects of different VR setups. We compared CAVE and HMD setups, using simple spatial tasks.

In summary, in a CAVE setup, participants naturally see their own body, enabling them to calibrate the relationships between the self and environmental objects. For simple tasks, such as passing through a narrow aperture, the CAVE thus appears as superior to an HMD. This seems to be related to the fact that, with an HMD, subjects do not see their own body, compromising body-scaled visual information. Furthermore, adding a co-localized self-avatar in an HMD does not seem to be enough to optimize behavioral presence and we found that a spatialized vibrotactile feedback, enhancing visuo-proprioceptive consistency, favored greatly body-scaled perception.

Furthermore, when subjects have to interact with close environmental objects, as in the last experiment, a CAVE setup has a detrimental effect, tending to make objects appear as inconsistent when the subject's body parts approach them. The HMD appears there as superior, to the expense that a self-avatar is then necessary.

To conclude at this point, it is difficult to decide which device is optimal, since it depends obviously on the task. However, one outcome of this work is that behavioral presence is dependent on visuo-proprioceptive consistency.

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