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Afforded Actions as a Behavioral Assessment of Physical Presence

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Abstract

A particular afforded action was used as a behavioral assessment of physical presence in a virtual environment. The subject's task was to walk through a virtual aperture of variable width. In the case of presence, the subject's body orientation, while walking, was expected to be adapted to the width of the aperture. Most, but not all, subjects adapted their behavior to respect to both their body architecture and the virtual width constraints. These subjects rotated their trunk in yaw while walking through the virtual aperture. This behavioral adjustment, which typically represents an afforded action, is assumed to be an objective indication of presence. Beyond these results, the present study advocates for all afforded actions as potential behavioral assessment of presence.

Keywords--- **Presence, Behavior, Affordance, Virtual Reality**

1. Introduction

The notion of presence in a virtual world is central to virtual reality research [1, 2]. Because this notion is highly interdisciplinary, its use has long been marked by a rich and burgeoning polysemy. In an attempt to share a common vocabulary, the presence community research has proposed the following definition : "Presence is a psychological state or subjective perception in which even though part or all of an individual's current experience is generated by and/or filtered through human-made technology, part or all of the individual's perception fails to accurately acknowledge the role of the technology in the experience." [3]. This definition has two main interests. First, it stresses the fundamental illusory aspect of presence. It is close to the conception according to which presence would be basically "a perceptual illusion of non-mediation'' [4]. Additionally, this definition contains a criterion of falsifiability [5]. According to this criterion, depending on whether or not "part or all of the individual fails to accurately acknowledge the role of the technology in the experience", it can be concluded that such an experience involves (or not) presence.

Beyond this minimally agreed-upon definition, what psychological processes underlie presence remains an open question. One possible way to progress on this question would be, not to consider presence as a whole, but rather to differentiate between different types of presence. As a multi-dimensional concept, it has generally been proposed that three main categories of dimensions could be taken into account: the dimensions "that involve perceptions of physical environments, those that involve perceptions of social interaction, and those that involve both of these" [3]. For example, IJsselsteijn, de Ridder, Freeman, Avons. distinguished between *social presence* (the feeling of being together and communicating with others) and *physical presence* (the feeling of being physically located in a place) [6]. The present work is focused on physical presence.

Considering that presence was a key aspect of virtual reality, ultimately linked to its effectiveness, researchers went on to measure it. There are multiples ways of assessing presence [7]. However, three main evaluation approaches (with rich interactions) can be distinguished. Historically, questionnaires have been first developed and are still being used and improved [e.g., 8]. Next to this, physiological indicators involving the autonomous nervous system activity, such as skin conductance or cardiac rhythm are used, considered as more objective than answers to questionnaires [e.g., 9]. Finally, overt behavioral observations which are thought not to be under conscious control, such us a startle reflex or postural sway has also been used to assess presence [e.g., 10]. Moreover, physiological and behavioral evaluations can be conducted during VR exposure, whereas questionnaires are post-exposure measurements of presence For both physiological indicators and overt behaviors, the basic assumption is that the more a subject feels present in a Virtual Environment (VE), the more similar his/her responses will be to those s/he would exhibit in a similar real environment [11]. This work is focused on a particular type of overt behavior as a tool to objectify physical presence.

In the present experiment, in order to assess presence in VE, we investigated spatio-temporal aspects of adaptive behavior, governed by volition and selection. In everyday life, there are well known robust adaptive behaviors, which imply both an intention to act and a selection among variations of the same act. This selection may be constrained by the relationships between the body architecture and action capacities and the environment. As such, evaluating presence in a VE may be approached using the concept of affordances [12].

Gibson assumed that we perceive in order to act in the environment. Perception is thus designed for action and determined by action capacities. These perceivable possibilities for action were named affordances (e.g. the same obstacle affords jumping over for a horse and going around for a human). The main hypothesis of our study is that the degree of presence in a VE can be evaluated by its actual affordances for action, which can be experimentally tested. For example, a subject may have to lengthen the step while stepping over a street gutter or to rotate the body while walking through a narrow aperture [13]. These adaptive behaviors pertain to body-scaled motor adjustments. For a street gutter of constant width indeed, the tendency to lengthen the step is more pronounced if the legs are short. Similarly, for an aperture of constant width, the tendency to rotate the body is more marked for larger shoulder widths. These body-scaled behaviors present a twofold interest. First, they can be potentially elicited within virtual environments. In addition, they are objectively and continuously measurable. As such, they can provide a behavioral evaluation of presence.

Surprisingly, there is very few research in which afforded actions were used to assess presence in VE. Gibson's ecological framework has already been theoretically suggested as a promising functional approach for defining the reality of experience in relation to the problem of designing VE [14]. In addition, objectifying presence via body scaled motor adjustment while walking through an aperture has already been attempted [15]. However, this study failed to demonstrate that virtual and real apertures were experienced in the same way. In particular, in the VE, there was no evidence that the subjects could relate the size of the aperture to their own shoulder width. Instead, body rotation was observed for every aperture size, even when no body rotation was required to pass through the aperture [15]. This initial failure may explain why affordances has been so poorly investigated in physical presence research [1, 2].

Stappers, Flach, Voorhorst's negative results might also be due to the use of helmet-mounted displays, suffering from a reduced field of vision and the residual presence of a head-fixed visual frame [15]. Thus, we undertook a similar study with a CAVE®-like system, enabling us to stimulate the subject's entire visual field. We designed an experimental study, in which subjects had to walk through a virtual aperture whose width was manipulated. Continuous monitoring of their movements while walking forward through the virtual aperture was achieved, in order to evaluate the adequacy of their body adjustments to the size of the aperture. In other terms, we tried to measure whether their eventual shoulder rotation was adapted to the width of the virtual aperture. Additionally, we examined whether their eventual shoulder rotation was related to the ratio between the width of the aperture and their shoulder width, a phenomenon already reported in the literature, in real conditions [13, 16]. We assumed that such an adaptive behavior would be a significant behavioral indicator of presence.

2. Method

2.1. Subjects

Nineteen male subjects participated in the experiment, ranging in age from 18 to 30 years (mean = 21.6; sd = 3.1). They had normal or corrected to normal vision. They were free from any known locomotor disorder. They were naïve as to the purpose of the experiment and voluntarily participated. They were not a priori selected regarding their stature. Their standing height ranged from 159 to 194 cm (mean = 178.4; sd = 8.9). Their shoulder width ranged from 40 to 55 cm (mean = 45.6; sd = 3.1). Their inter-pupillary distance ranged from 57 to 69.5 mm (mean = 63.6; sd = 3.2). Their stereoscopic acuity ranged from 20 to 140 seconds of arc (median = 20; upper and lower quartiles were 50 and 20; interquartile range = 30).

2.2. Apparatus

The experiment was conducted inside a CAVE ®-like virtual reality system (Figure 1). The hardware consisted of four projection surfaces: the front, left and right vertical walls and the horizontal floor. The 3 walls (3 meters wide and 4 meters high) were back-projected acrylic screens. The floor (a square with a side of 3 meters) was directly projected from above. The height of the display (4 meters) was defined in order to avoid the need for a ceiling projection surface, while optimizing visual immersion. Only the top and the rear faces of the Cube were not projection surfaces.

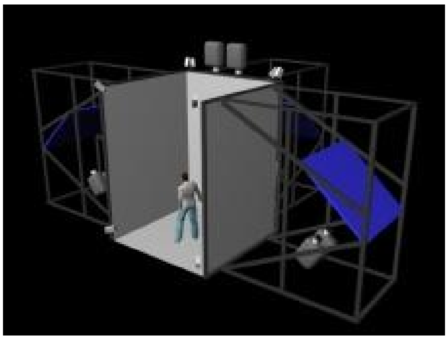


Figure 1 Schematic representation of the VR system

Each projection surface received images with 1400 × 1050 pixels resolution. The screens were seamlessly joined to provide a visually continuous projection surface. Stereoscopic projection of virtual environments was achieved by two DLP ® (Digital Light Processing) projectors attached to each projection surface. Each projector addressed one eye. Stereoscopic separation between left and right eye images was ensured by colorimetric separation (Infitec ® technological solution). Infitec ® filters were installed in the projectors, while the subject was wearing glasses with the same filters. This guaranteed perfect separation of images between the two eyes. Finally, a head tracking system (ArtTrack ®), using infrared recognition of passive markers placed on the subject's glasses, was used to record the subject's head position and orientation and to update in real time (60 Hz frame rate) the stereoscopic images relative to the subject's point of view (Figure 3). Additionnally, passive markers were symmetrically placed over the shoulders. The whole projection system was controlled by a cluster of 5 PCs (1 master + 4 slaves). Each slave PC was attached to a couple of projectors devoted to a projection surface. Surrounding spatialized sound stimulation was achieved by means of a 7.1 sound system. We used Virtools ® solution to build and control virtual scenarios, for experimental control and data recording.

2.3. The virtual environment

The VE was designed using 3D modelling software (3DSmax). It was then imported into Virtools ® for building and running the experimental scenario. The VE was composed of two adjoining rooms connected via a sliding door (Figure 2). The first room was empty and was marked with a starting point (green disk displayed on the floor). The second room was furnished (in order to provide static and dynamic depth cues) and was marked with an arrival point (blue disk). The sliding door consisted of two mobile surfaces (height = 204 cm, thickness = 25 cm) that could be closed or opened by lateral translation. The opening and the closing of the door were accompanied with different rattle sounds. The sliding door formed an aperture whose width was variable and ranged from 40 to 80 cm, by 5 cm steps. The nine possible aperture widths were 40, 45, 50, 55, 60, 65, 70, 75 and 80 cm. The starting point, the center of the door and the arrival point were aligned. The distance from the starting point to the door, and from the door to the arrival point were 110 cm and 90 cm respectively. The center of the door was located at the center of the Cube (along front-back and left-right axes).

Figure 2 The virtual rooms and the sliding door

2.4. Procedure

Each subject was prepared in an independent room adjoining the room containing the Cube. Several anthropometric and perceptual measures were performed in that room. The standing height was canonically measured using a stadiometer. Shoulder width, the widest frontal body dimension, was measured with an anthropometer from the tip of the left humerus (humeral greater tubercle) to the tip of the right humerus with the shoulders relaxed, in a standing subject. The inter-pupillary distance was measured with a corneal reflection pupillometer. This measure was taken into account in order to generate body-scaled stereoscopic images and hence individually optimize spatial perception from binocular vision. The stereoscopic acuity was measured using the Randot ® Graded Circles test (Stereo Optical Company Inc, Chicago, Illinois). This multiple-choice series tests fine depth discrimination. Within each of ten targets are three circles. Only one of these circles has crossed disparity, which, when seen binocularly, should appear to stand forward from the other two. The test is hold upright before the subject at 40 cm (16 inches) reading distance. Polarizing viewers must always be worn –over prescription glasses, if used. The 10 targets test stereo-acuity of 400, 200, 140, 100, 70, 50, 40, 30, 25 and 20 seconds of arc (at 40 cm) respectively. Starting with the largest disparity in a descending scale, the subject was asked to verbally identify the circle (left, middle or right) at each level that appeared to be floating in front of the page or jumping out of the page. The last level for which the subject answered correctly was considered to be the level of stereoacuity. Once the subject's level of stereoacuity was determined, the examiner went back three levels and repeated the test. The final threshold was the mean of these two results.

The subject was equipped with INFITEC ® stereo glasses and with reflective markers on the glasses and on both shoulders (Figure 3). The shoulder markers were symmetrically placed over the trapezius muscles (between the neck and the shoulder) and not on the heads of the right and left humeri. This particular placement was designed to avoid subjective widening of the shoulders [17, 18]. These equipments allowed 3D tracking of the subject's cyclopean point of gaze (for real-time updating of the visual scene) and of shoulders' positions (for offline analysis of the subject's posture) by the ART ® system.

Figure 3 Representation of the subject's equipment, with markers attached to stereo glasses and a set of markers on each shoulder

Figure 4 Schematic representation of a subject walking through the virtual aperture

Once equipped, the subject was conducted from the welcome room into the Cube. In order to optimize immersion into the VE, the eyes-closed subjects were guided (by the experimenter) into the VE and required to open their eyes only when facing the front wall from the starting point, while the VE was displayed. In this way, they could see the VE only throughout the experimental session.

The initial scene (Figure 2) showed the sliding doors wide open (aperture = 250 cm). Then the doors were closed, leaving an aperture whose width was one of the nine predetermined values. This closing was accompanied by a spatialized rattling sound located at the doors location. Facing the front wall, the subject stood on the starting point. He was prevented from walking forward since he was restrained by the shoulders by the experimenter located behind him. The subject was required to walk straight from the starting point to the arrival point and to stop at this point (Figure 4). This neutral directive aimed to avoid any behavior induction by instructional semantic effects. To allow him to do so, the experimenter liberated the subject from any physical constraints. The unconstrained walking speed should be normal and comfortable. Once at the arrival point, the subject was required to stand still, facing the front wall and not to make a U-turn. The subject was informed that the sliding door behind him would open wide. This opening was accompanied by a spatialized rattling sound located behind the subject. When the sliding door was opened, the subject walked backwards from the arrival point to the starting point. The experimenter held the subject by the shoulders in order to guide him during this backward walk. This backward walk with the doors wide opened was designed to avoid possible cognitive conflict that may have arisen if the subject could pass through or hit the virtual walls that delimited the door. Once at the starting point, the subject was required to precisely face the front wall. The doors were then closed, leaving an aperture whose width was one of nine predetermined values. A new trial could then begin.

During an experimental session, subjects run a series of trials, with the following logic. The aperture could be one of 9 widths: 40, 45, 50, 55, 60, 65, 70, 75, 80 cm. A block of trials involved 9 trials (one trial per width). Each subject performed 3 blocks (27 trials). For each block, the order of presentation of the 9 widths was randomized.

2.5. Dependent variable

For each trial, the maximal absolute shoulder rotation was calculated from the recorded successive positions of the shoulder markers, while the subjects walked through the virtual aperture.

3. Results

3.1. Individual results

The mean absolute maximum angle of shoulder rotation is plotted as a function of aperture width (Figures 5).

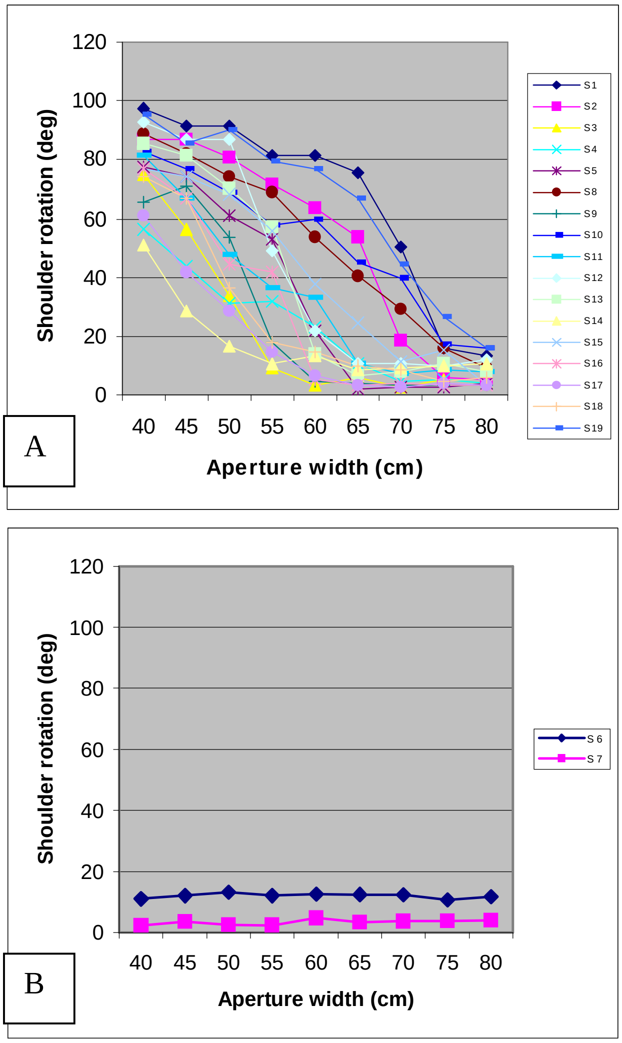


Figure 5 Individual mean absolute max angle of shoulder rotation as a function of aperture width. Seventeen subjects adapted their body orientation to the aperture width (5A). Two subjects exhibited frontal walking whatever the aperture width (5B).

From the data, the population was divided into two subsets. On one hand, two subjects did not rotate the shoulders at all while walking through the virtual aperture. During each trial, they systematically exhibited frontal walking whatever the aperture width (Figure 5 B). On the other hand, 17 subjects adapted their body orientation to the aperture width (Figure 5 A). The following analyses were conducted on behavioral data from these 17 subjects only.

An ANOVA (Blocks x Apertures) was conducted on these 17 subjects. This ANOVA revealed a main effect of aperture width ($F_{8, 128} = 89.62$, $p < 0.001$) and a main effect of blocks ($F_{2, 32} = 4.03$, $p < 0.03$) without interactions. The main result here is that that the magnitude of body rotation significantly increases as the aperture width decreases.

3.2. Critical aperture widths and "Aperture/Shoulder" ratios

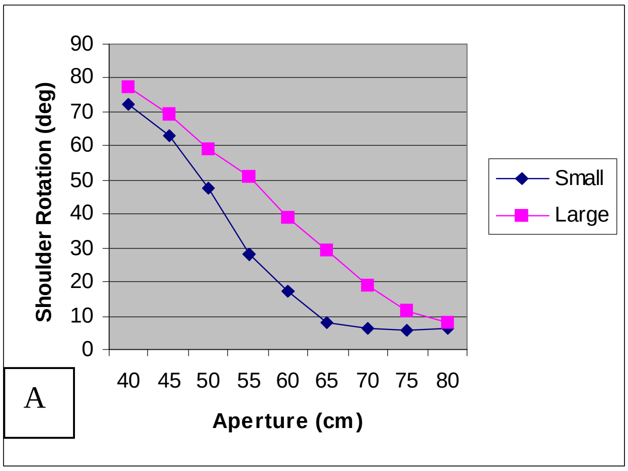
After having demonstrated that shoulder rotation was systematically related to the width of the virtual aperture for 17 subjects, this new analysis examined whether shoulder rotation was conjointly determined by both the aperture width and the shoulder width.

To this aim, the population of 17 subjects was then divided into three groups (small, medium and large) based on their shoulder width. The shoulder width ranged from 40 to 45 cm for the small group (n = 6 subjects), and from 46 to 55 cm for the large group (n = 6 subjects). The shoulder width was above 45 cm and below 46 cm for the medium group (n = 5 subjects). Hereafter, we focused on the comparison between small and large subjects.

As expected, the large subjects have greater ($F(1,10) = 6.03$, $p = 0.034$) angles of shoulder rotation than the small subjects (Figure 6 A) for intermediate apertures (55, 60, 65, 70, 75 cm). On the contrary, there was no effect of shoulder width neither when the subjects walked through narrow (40, 45, 50 cm) apertures ($F(1,10) = 0.55$, $p = 0.47$) nor when they walked through the broadest (80 cm) aperture ($F(1,10) = 0.59$, $p = 0.45$).

Interestingly, the differences between groups tended to diminish when the same shoulder rotation data were replotted against the "Aperture width / Shoulder width" (body-scaled) ratio (Figure 6 B). Thus, rescaling of the virtual aperture as a function of a relevant body characteristic eliminates group differences, suggesting that small and large subjects behave similarly relative to their own body size.

In order to test this hypothesis, we computed the Critical Aperture Width and Critical A/S Ratio from which subjects exhibit a behavioral transition from frontal walking to body rotation while walking through the aperture. This was done under the following assumptions. Each subject was considered to use "frontal walking" while walking through the largest aperture (80 cm). The eventual body rotation exhibited at each narrower aperture (75, 70, 65, 60, 55, 50, 45, 40 cm) was statistically assessed by comparison with frontal walking through the largest aperture. For each subject, following descendant width values, the first aperture giving rise to a significant difference with frontal walking (as assessed using paired t-tests) defined the critical aperture width or the critical A/S ratio.



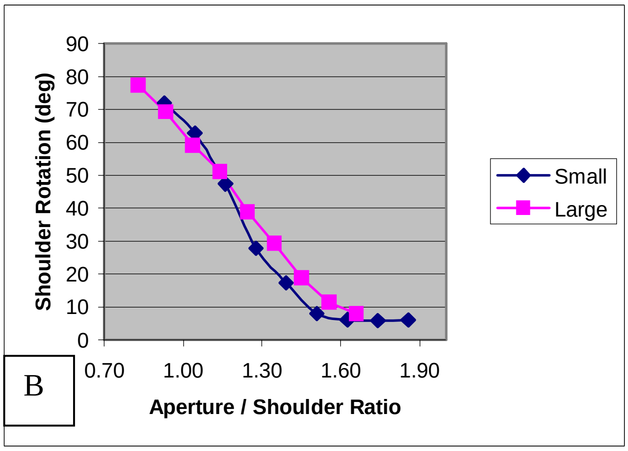


Figure 6 Average max angle of shoulder rotation, for large and small subjects, as a function of aperture width (6A) and as a function of the body-scaled ratio of aperture width divided by shoulder width (6B).

Actors	**Critical Aperture Width (cm)**		**Critical A/S ratio**	
	Mean	**SD**	**Mean**	**SD**
Small (n = 6)	52.5	4.18	1.22	0.14
Large (n = 6)	62.5	8.22	1.29	0.15

Table 1 Means and standard deviations of Critical Aperture Widths and Critical A/S Ratios in small and large subjects.

Mean critical aperture widths and critical A/S ratios are given in Table 1. The difference between the critical widths for the small group (52.5 cm) and large group (62.5 cm) was statistically significant, as assessed by Student t-test ($t(10) = -2.65$, $p < 0.02$). However, when these values were expressed intrinsically, the A/S ratios are quite similar: 1.22 for the small group and 1.29 for the large group, and not statistically different ($t(10) = -0.83$, ns). These results lend strong support to the view according to which, in real environment [13] as well as in VE, small and large subjects behave similarly relative to their own body size.

Conclusions

The results of this study indicate that the locomotor postural patterns of subjects having to walk through a virtual aperture strongly resemble those of subjects who have to walk through a real aperture [13, 16]. For most subjects indeed, a behavioral transition from frontal walking to body rotation was observed as a function of the virtual aperture width. Additionally, subjects with wider shoulder were observed to rotate their body more than subjects with small shoulder widths. Finally, the differences between “small” and “large” subjects tended to vanish when body rotation was considered with respect to a body-scaled dimensionless ratio (aperture width/shoulder width). We suggest that these facts constitute a strong behavioral indicator of spatial presence.

Furthermore, the present results show that, out of 19 naïve subjects, 17 always systematically responded to the experimental setup (rotating their body to pass through the aperture without hitting the sides), while being only asked to step forward. This positive result demonstrates the immersive characteristics of the VR setup, including real-time interaction between the subject's movement and sensorial updating of the VE, 3D cues (stereoscopic vision, motion parallax), surrounding visual and auditory stimulation. Future research will investigate deeper the role of these different factors. From the literature, it can be suggested that self-generated motion cues associated with large field stimulation [19], as well as converging multi-sensorial stimulation (here sound and vision) [11] contribute to the sensation of presence.

However, it remains that 2 subjects never responded to our experimental setup (they walked straight through the aperture whatever its size). Here, we can refer to Slater and Steed approach, considering that, after all, subjects are facing a real and a virtual environment [20]. In this sense, presence can be considered as a bi-stable phenomenon and/or an illusory percept. The fact that 17 of our subjects behave in coherence with the VE can then be considered as evidence that our experimental setup was efficient (immersive) in making the subjects believe that they were actually facing a real door, necessitating shoulder rotation to pass through. In short, most subjects behave as if they believed in the tangibility of the visual world. What happened with the 2 subjects disregarding the "illusory" door?

Here a couple of (non exclusive) hypotheses can be evoked, which will certainly require further studies. We tried our best to optimize immersion, including having subjects blindfolded until they were "inside" the VE and never letting them look backwards. Doing that, we tried to minimize "real world" stimulation. However, it might be that some uncontrolled variables (e.g., the unavoidable junction between screen surfaces) and/or subject behavior (looking up momentarily to the ceiling) has destroyed the sensation of presence inside the VE. This hypothesis points toward limitations of the immersive setup (one subject told us that he did not see the reason why he would react to immaterial, transparent surfaces). In addition, we might also consider the hypothesis that subjects' cognitive and personality characteristics, such as field-dependency [21, 22] come into play, when it comes to the subjective and integrative balance between different sensorial streams.

To sum up, in the present study, presence was assessed by a particular motor adjustment which links the size of a body feature (shoulder width) to the size of some characteristics in the environment (width of the door). This kind of adjustment pertains to body-scaled motor adjustment. In other words, these motor adjustments constitute some “realized affordances”. According to Gibson, an affordance is an action possibility which is provided to an organism depending both on the organism properties and environment properties [12]. In short, the present study suggests that eliciting “acted affordances” in virtual reality research could contribute to behaviorally assess presence in virtual environments. Since any “acted affordance” implies measurable variations (e.g. magnitude of body rotation) of a given action (e.g. walking through an aperture) and that these variations depend on both some body characteristics (e.g. the shoulder width) and some VE feature (e.g. the width of the aperture), we propose that any “acted affordance” can provide a sensori-motor evaluation of presence.

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