Influence of Exocentric Avatars on the Sensation of Presence in Room-mounted Virtual Environments

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Abstract

The influence of avatars on the sensation of presence in room-mounted virtual environments is handled in this work. In room-mounted set-ups, users are located in the center of interaction and are surrounded by virtual stimuli while perceiving their real body. Several scenarios, like collision and occlusion during navigation and manipulation, demand for avatars that represent the user within the virtual world. Room-mounted set-ups allow for exocentric avatars only and therefore induce a mismatch during the process of identification of the body schema with the body representation. The study presented here clarifies the influence of exocentric avatars on the sensation of presence and evaluates different methods for simulation of kinematics. To do so, subjects were required to perform a sports task in a room-mounted virtual environment. The avatar and the simulation of kinematics were modulated. The results showed that subjective presence estimates are decreased during the display of an exocentric avatar. In conditions using an avatar, subjects clearly preferred avatars with synchronous kinematics over animated or rigid virtual humanoids. The paper discusses implications on the application of avatars in room-mounted virtual environments.

Keywords--- **avatars, kinematics, room-mounted virtual environments, presence, subjective and objective measures**

1. Introduction

Virtual environments are widely regarded as the future interaction medium for high complexity tasks that are seldom solved by present desktop systems. Virtual environments facilitate and enable, amongst other things, the exploration of large data sets difficult to understand in their complexity, the presentation and steering of complicated working procedures, or communication between distant parties. Notwithstanding numerous attempts to improve the available techniques, serious deficiencies still exist with regard to the interaction and acceptance of the content presented. Unresolved issues are found, among others, in the areas of simulation of assembly processes, manipulation of virtual objects, navigation in virtual worlds, or communication in distributed virtual environments. These application scenarios typically challenge current development in terms of the occlusion problem during manipulation, collision avoidance during navigation, or the general identification of the user with the virtual world. Methods and techniques for virtual environments thus continue to evolve. Virtual humanoids have been broadly discussed as a solution to the prevailing problems by creating a more natural and life-like working experience and a frame of identification for the user. However, the impact of virtual humanoids on users and their interrelations during interaction have not yet been clarified to a satisfying extent. In detail, the effects of avatars in room-mounted virtual environments on the sensation of presence have not been studied extensively to date.

The work presented here is focused on the user-acceptance of avatars with synchronous kinematics in room-mounted virtual environments. In this interrelation the simulation of kinematics of the avatar is regarded as the main factor. Besides performance metrics, the study used subjective and objective presence measures to estimate the user-preferences in the virtual environment. The room-mounted set-up implied that users perceived their own body and the body of the avatar at the same time (*cf.* Fig. 1). In this experiment, the subjects had to accomplish a sports task that required moving their entire body and stimulated their sense of vection and equilibrium. The kinematics of the avatar presented to the user were changed under three conditions and compared to a condition with no avatar. In view of the doubled body representation in room-mounted virtual environments it is of particular interest how the application of avatars influences the sensation of presence and the user-preferences. We hypothesize that during the application of an avatar presence will be lower due to additional mental processes involved in the dilemma of identification of the user's body schema with the two concurring body representations.

The remainder of the paper is structured as follows. Section 2 outlines the interrelations between avatars and presence and motivates the study undertaken that is described and discussed in section 3. The paper is closed with a conclusion and remarks on beneficial application scenarios for avatars in room-mounted virtual environments.

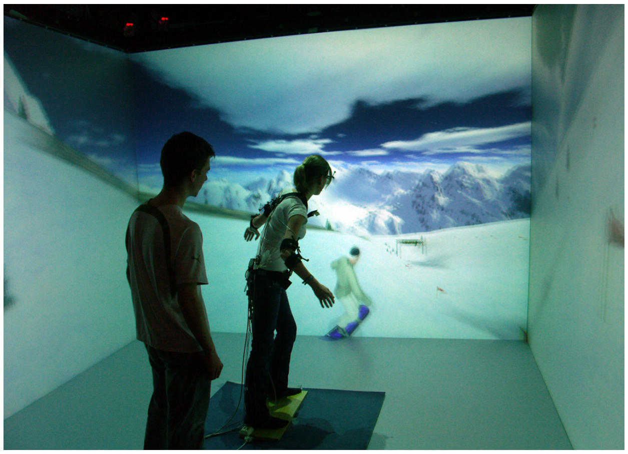

Figure 1: A subject in the room-mounted virtual environment and her avatar. An assistant is standing behind the subject in order to prevent the participant from making a false step or falling.

2. Avatars and Presence

In the original concept, presence is viewed as a state of consciousness and part of the attribution of sensation to some distal stimulus, possibly generated by a mediated environment. Current definitions of presence, e. g., [12, 21, 24, 27, 33], relate the topic to the experience of users in virtual environments. Sheridan defines the term “virtual presence” as a subjective experience or the illusion to be located in a virtual place [24]. Witmer and Singer use a corresponding definition: “[Presence is] the subjective experience of being in one place when one is physically situated in another” [33]. Accordingly, most definitions of presence are abbreviated to the term “sense of being there” in a mediated environment. Steuer [28] cites an unpublished manuscript by Reeves [18] where the “sense of being there” is discussed in connection with consumption of TV media. Heeter uses also this term but does not explicitly connect it to presence [9]. The work by Slater *et al.* [26], IJsselsteijn and colleagues [10], and the book [19] edited by Riva *et al.* use the term more frequently and relate it explicitly to presence. Schuemie *et al.* mention the term “being there” in connection with measurement of presence [23]. All previous definitions focus on the fact that a user is situated in an environment interacting with it and perceiving it with his senses. Presence is understood as a subjective acceptance of the environment as the current location. Presence in a real environment is therefore defined, as well, and should be at its peak for healthy human beings. The concept becomes more exciting if the considered environment is generated through media and therefore variations of presence are to be expected. Another widely spread circumscription of presence is that of “suspension of disbelief”, which is a formulation from the reverse perspective. It is equivalent to the previously mentioned definitions; however, it emphasizes the fact that inconsistencies in the perceived environment create a sensation of disbelief towards the environment. Presence is reciprocally identified with this sensation. Similarly, this disbelief should be low in reality and starts to vary in mediated environments. Even though most authors agree that presence is a subjective sensation of a user experiencing media there is no unique, generally accepted definition of presence.

The topic discussed here aims at answering the question whether avatars have the capability to influence presence and general interaction metrics (*cf.* [3, Chapter 11]), in particular, task performance and user preference. Avatars and self-embodiment are discussed by several researchers as one factor that increases presence, thought to be the result of a strong perceptual link between the mental representation of one’s own body and the perceived virtual body [2, 25]. In more detail, Biocca postulates three body representations: the natural (objective) body, the virtual body represented through an avatar, and the body schema, also referred to as body image [8], which is the user’s mental concept of his body. This mental representation is not stable and can be altered in a mediated environment. In particular, the body schema is oscillating between the natural and the virtual body. Biocca emphasizes that avatars in immersive virtual environments can significantly bind to the body schema and have the potential to replace the natural body in the mental representation, resulting in an increased sensation of presence [2]. This effect is observed in even comparatively primitive media systems. In the majority of studies avatars and presence are mainly discussed in combination with head-mounted displays (HMDs) or desktop-based virtual environments. Furthermore, mostly hand-avatars are applied in order to study basic interaction tasks like manipulation, reach-to-grasp, and docking, as well as to evaluate sensory feedback interrelations. Although the hardware applied and the techniques for graphical representation have been somewhat limited in past studies, avatars are generally considered as a factor capable of strongly increasing presence.

In order to identify interesting factors influencing presence one has to analyze the user-avatar interaction and the related loop of perception and action. The human body can be described as an “array of sensors propelled through space to scan, rub, and grab the environment” [2]. The user perceives the virtual or real environment and creates a mental world representation mainly provided by exteroceptors. Based on this information and the desired goal, a motor plan is generated and transformed into movements. This action is controlled on-line by sensory feedback and the motor plan is corrected if necessary. The consistency of data from different modalities affects the acceptance of the perceived environment. Mismatch between sensory information may even lead to symptoms similar or equal to simulator sickness. In the particular question of avatars and presence, the acceptance of the virtual body, i. e., the identification of the body schema with the virtual body depends likewise on the correlation of the perceived sensual data. In general the user changes parameters of the avatar in a direct, synchronous way and perceives the virtual body representation through his senses. Beside the common human *external senses* of sight, hearing, touch, and in virtual environments more theoretically regarded senses of taste and smell, an *internal sense*—the proprioception—has a large impact. Proprioception delivers data about the body posture and motion and is therefore essential in the projection of the body schema. The correlation between the external senses and proprioception is substantial for the acceptance of the virtual body. While the believability of the avatar is judged based on stimuli registered by exteroceptors the effect of the motor plan and the consistency evaluation of proprioception are directly related on the simulation of kinematics in the virtual humanoid. As a result of these considerations the kinematic link between the user and the avatar has to be further analyzed as one aspect of the simulation of avatars and their influence on the sensation of presence. Kinematics is an essential factor because it expresses the results of the motor plan and is involved in the integration of proprioceptive data. Kinematics in virtual environments is researched by several groups. Kuhlen and colleagues compare reach-to-grasp movements with real and virtual objects [11]. This study has not involved virtual humanoids but has contributed to the clarification of the cerebral organization and control of movements. Several researchers have examined the particular influence of modalities and their variations on presence and performance [6, 13]. Mason and MacKenzie suggest that for highly complex tasks, avatars with sophisticated kinematics could minimize task complexity [13]. Kinematics plays a central role for the overall acceptance of the virtual body, i. e., the avatar as a representation of oneself. Several related studies deal with perception of kinematics, e. g., [5], observation of kinematics of virtual arms [17], and the perception of (partially rigid) avatars, e. g., [4, 20, 32]. A recent study by Farrer *et al.* involves the rotation of a virtual hand derived from deviations of a joystick [7]. This study aims at identification of actions caused by oneself, i. e., the experience of agency. The aforementioned studies indicate the importance of simultaneous kinematics for presence.

Another important issue in the evaluation of the influence of avatars on users is imposed by the virtual environment technology itself. It seems that an avatar is preferably accepted as a representation of the own body if located in the same spatial position as the own body and if perceived from the natural *egocentric* view, i. e., the first person perspective. Such a scenario can be generated with HMDs where the vision of the real world is completely replaced by virtual stimuli. However, current virtual environments are room-mounted installations where a user perceives him surrounded by the virtual world. In such a scenario a matching of the avatar to the location of the user makes no sense because it creates a perturbing interference between the real and virtual stimuli. Hence, an

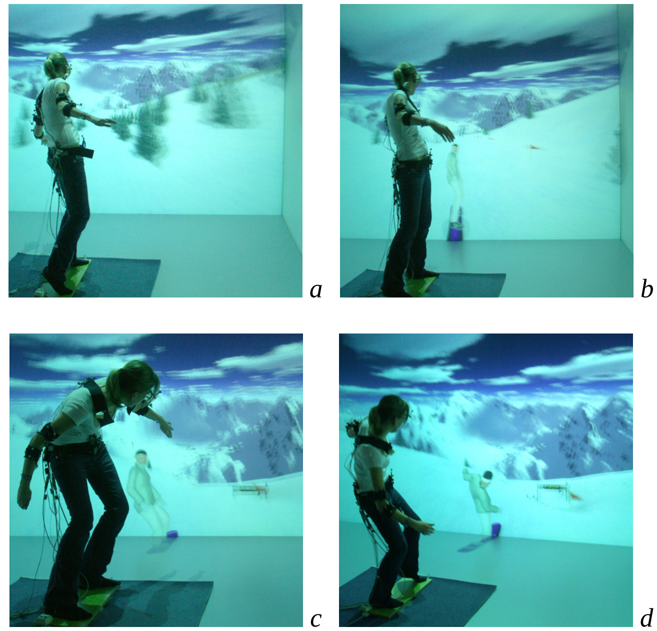

Figure 2: Experimental conditions in the study: (*a*) no avatar N–, (*b*) rigid avatar N+, (*c*) an animated avatar A+, and (*d*) a fully tracked avatar T+.

exocentric, i. e., a third person perspective has to be used instead. David and colleagues have reported results indicating that variations of perspective lead to a decreasing quality of agency, a sense to be in charge of action [4]. By contrast, Taylor points out that third person perspective in 3D games can contribute to the involvement in the mediated environment because the avatar seen from a third person perspective offers an identification possibility within the context of the virtual world [29]. Given the fact that most studies dealing with avatars and presence have been carried out in egocentric scenarios, and given the conditions of current room-mounted virtual environments requiring an exocentric view on avatars, it is of interest to further examine the capabilities of avatars in room-mounted set-ups.

Despite the extensive discussions in literature on the overall influence of avatars on presence two open questions remain: first, how is this interrelation expressed in current, sophisticated virtual environments? And, second, what is the contribution of simultaneous kinematics? The first open question arises from the fact, that most studies applied HMD-based or desktop virtual environments with often additional limitations to hardware (no or limited tracking, no stereoscopic representation, *etc.*), and that only basic virtual humanoid methods have been employed. No study on avatars and presence has been reported that applies fully interactive virtual humanoids in combination with realistic representation of the avatar in current, room-mounted virtual environments. Reasons for this situation are not obvious and may lie in the highly sophisticated VR-hardware and the complexity of the simulation. The work required for realization of a virtual humanoid that could be used in such a study should not be underestimated. Another reason can be derived from the fact that room-mounted virtual environments do not restrict vision to computer generated stimuli only as in HMD scenarios. The user is aware of and can see his natural body throughout the mediated experience. This fact, i. e., the observation of one's own avatar while perceiving one's real body, leads to the essential open issue that in a room-mounted set-up the user has to identify with two bodies on spatially shifted positions—his natural real body, and the virtual body of the avatar—whereas equipped with an HMD only the virtual body of the avatar is visible to the user. Thus, it can be concluded that additional research in room-mounted virtual environments regarding avatars and presence is imperative. The second open question addresses the main factor of kinematics of the avatar that seems to have the largest impact on the sensation of presence induced by the avatar. It is of large interest to identify factors that contribute most to the sensation of presence. For a designer of virtual environments it would be helpful to know how to model a virtual avatar and, for example, where to invest more computational resources and development time for algorithms: for a better degree of realism, or for kinematic simulation. However, this has not been researched sufficiently so far and needs further clarification.

3. Experimental Evaluation

The study presented here contributes to the understanding of the influence of avatars in room-mounted virtual environments on users. It extends the research on the influence of kinematics on presence, whilst utilizing current virtual humanoid technology, in particular, whole-body avatars and synchronous kinematics. In addition, several presence measurement techniques are used, thus allowing for a discussion and comparison of metrics and their sensitivity to presence.

A focus of this evaluation is the utilization of avatars in room-mounted virtual environments. The user perceives his avatar on a spatially shifted position and is also (visually) aware of his natural body. The key point in this study is whether a synchronous avatar in a stressful virtual environment is capable of absorbing the body schema, the mental representation of one's own body. As described previously more research needs to be done in this particular room-mounted scenario with a doubled visual information, i. e., the simultaneous perception of the own natural body and the virtual avatar. A discussion of this problem is crucial in the application of avatars viewed from an exocentric perspective that can be found in collaborative environments, teaching and tutoring scenarios, gaming applications, as well as in complex working environments such as surgical simulators and industrial assembly systems.

In this study, the impact of avatars with different kinematic simulations is measured. Since approaches to presence measurement remain a subject of controversy, two presence measures are going to be applied in this study: a subjective questionnaire and objective physiological measures. Objective data related to presence are most likely to be measured in stressful virtual environments. Therefore, a sports application in the form of a virtual snowboard ride has been chosen.

3.1. Methods

3.1.1. Participants. A total of 27 normal subjects participated in the study (14 males and 13 females, age: 19 to 32 years, mean: 23.6 years). 24 subjects were right handed as assessed with the Edinburgh handedness inventory [15]. Subjects were asked about their experience in riding a snowboard to estimate the foot to be placed in front of the board, i. e., the footedness. Those who could not determine their footedness were asked to perform a test: they had to run approximately 2 meters, jump in the air, and land sideways turned by 90°. The same orientation was afterwards used on the board input device. A total of 66.7 % of subjects used the left foot in the front (so-called regular stance, mostly favored by right handers). In 44.4 % of cases the footedness did not correspond to the handedness, i. e., right-handed subjects used the right foot in front (and vice versa). All subjects had normal or corrected-to-normal vision (acuity both eyes far $\geq 20/30$, acuity both eyes near $\geq 14/14$ Sneller equivalents), as measured with the Titmus vision tester (A. Zeiss, Petersburg, Virginia). Binocular ability ranged between 30 % and 95 % on the Shepard-Fry scale (mean: 88.7 %). One subject with binocular ability at 70 % reported difficulties with 3D vision. One subject developed strong symptoms of simulator sickness (nausea) after completion of all trials. Four subjects reported vertigo and traces of nausea during the experiment which, therefore, has been immediately aborted. The subjects were not previously briefed about the purpose of the study.

3.1.2. Design. Subjects were asked to perform a snowboard ride on a virtual slope. The snowboard was steered by shifting the weight to the left or to the right side of the input board. The ride was accelerated by leaning forward and slowed down by leaning backwards. The subjects were required to ride as fast as possible without hitting obstacles or leaving the track. Two main factors were manipulated in the study: the avatar viewed from the third person perspective, and the kinematic simulation of the avatar. Either the avatar was displayed (+) or not (–). For the displayed avatar the kinematic simulation was altered from no simulation (N), animation using pre-recorded motion sequences (A), and synchronous full body tracking (T). Therefore, the within-subjects design consisted of four different experimental conditions: N–, N+, A+, T+ as illustrated in Fig. 2.

3.1.3. Procedure. The study consisted of an introductory, a training, an experimental, and a debriefing session.

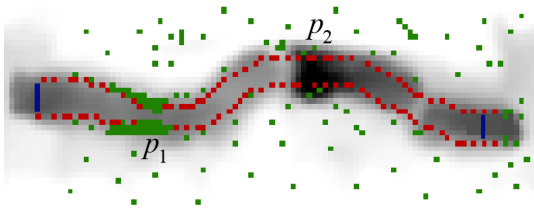

Figure 3: Design of the experimental course (top view): gray values correspond to the steepness of the slope, pixels define the position of the slope limits, and the position of trees. The start and finish gates are defined as blue lines. p_1 marks the funnel-shaped constriction (FUNNEL) and p_2 the steep part of the slope (JUMP).

During the introductory session subjects were presented the hardware and the task of steering an avatar in a sports application. They were informed about simulator sickness and asked to immediately report any occurrence of symptoms. Prior to VR exposition a vision test has been conducted. In order to adapt the stereo rendering individually the eye base has been measured with the PD meter PM-600 (Nidek, Gamagori, Japan). All participants answered a pre-test questionnaire. During the training session subjects have been placed on a virtual snowboard device and provided with optical tracking sensors on their limbs and electrodes for physiological measures. The subjects were given time to accommodate to the hardware and the application and were asked to perform four test rides under condition T+ followed by four test rides under condition N–. The experimental session included four blocks for the conditions N–, N+, A+, and T+. The blocks have been executed in a pseudo-randomized order and consisted of four trials. Subjects were instructed to ride as fast as possible without leaving the virtual course, or colliding with trees. In addition, they were asked to lift their dominant arm immediately when passing the point of interest JUMP (*cf.* Fig. 3). An electrocardiogram, the galvanic skin response, and the expansion of the chest have been measured during the trials. After each block subjects were required to answer an online version of the IPQ presence questionnaire (*cf.* Fig. 4) on a Samsung Q1-900 tablet PC (Samsung, Seoul, Korea). The debriefing session included a post-test questionnaire. The subjects were asked to remain in the laboratory until they fully re-accommodated to reality.

3.1.4. Apparatus. The experiment has been carried out in a CAVE-like environment with five sides (four walls and the floor) with a resolution of 1600×1200 pixels per plane delivered by Sim6 Ultra projectors (Barco, Kortrijk, Belgium). While the back side was left open the stereoscopic images for the remaining four walls were generated by a Linux PC cluster, consisting of eight clients (Pentium IV, GeForce FX6800, 4GB RAM) and a server (Dual Xeon, 4 GB RAM). An optical tracking system consisting of four ARTtrack1 cameras has been applied (Advanced Realtime Tracking, Weilheim, Germany). Clusters of markers have been used to drive the tracking algorithm with markers on each forearm, each upper arm, the head, the neck, and two on the pelvis. A board input device configured with four weight sensors has been used to steer the virtual snowboard and the avatar. The physiological measures have been retrieved with the BioSemi biofeedback device (BioSemi, Amsterdam, Netherlands). Two electrodes have been fixed on the thenars of the non-dominant hand with a distance of $\approx$4–5 cm from each other to measure the galvanic skin response; the electrocardiogram was retrieved with three electrodes: one on the left, one on the right lower forearm, as well as an electrode on the left ankle. The expansion of the chest during respiration has been retrieved with a flexible belt around the thorax. The device uses two electrodes for normalization / grounding of the measured data: an active electrode is placed on the right ankle, a passive electrode is fixed atop of the right upper tibia. All physiological measures have been recorded for offline analysis. In addition, the BioSemi system recorded a set of triggers that have been manipulated by the application.

The environment was realized with NeuroMan [34] based on the ViSTA software utilizing the OpenSG library and media extensions [1]. In addition, the software used code from the TuxRacer project [30] for physics simulation and the game engine. The course was designed as a slope of 400 m length, started and ended with gates, and was marked with flagged poles on each side. It furthermore contained two points of interest: a funnel-shaped constriction made of tree obstacles (FUNNEL), and a surprisingly steep part of the slope that mostly required a jump (JUMP) as depicted in Fig. 3. The application generated triggers for the BioSemi device for all events.

The avatar was displayed and simulated with the virtual humanoid toolkit VRZula [31]. The virtual humanoid was defined as an H-Anim model with joints according to the level of articulation one. The geometry consisted of 8,884 vertices and was displayed with VRZula using GPU-based vertex blending. In all conditions the application was steered with the board input device. In condition N+ the orientation of the rigid avatar was adapted to the current curvature of the slope. To realize the animated condition A+, five motion sequences have been recorded: neutral standing, acceleration, slowing down, turning left and right. These sequences have been connected with motion graph techniques integrated in VRZula. Data from the board input device were used to synthesize the motion of the avatar from the motion graph. Finally, the avatar was tracked by the motion of the body of the user in condition T+. Body tracking was realized with the VRZula toolkit, as well.

3.1.5. Data Processing and Analysis. For each subject continuous physiological data have been measured in 24 trials

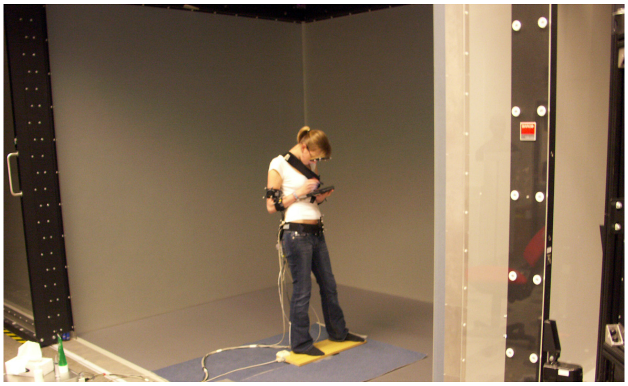

Figure 4: A subject answering the presence questionnaire on a tablet PC.

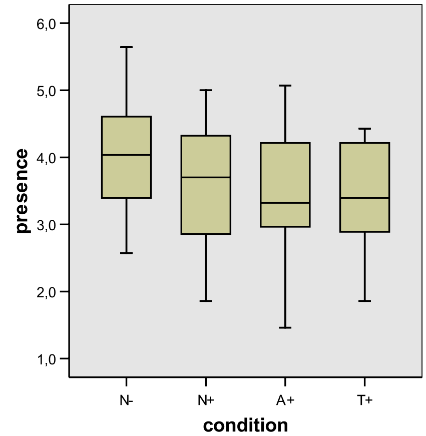

Figure 5: Presence scores.

(two blocks in the training session, and four blocks in the experimental session, each containing four trials), altogether 5 channels and 16 triggers at a sampling rate of 2,048 Hz. The average length of a trial was 30.6 s (±4.5). The following data channels have been measured: three channels for the electrocardiogram, the galvanic skin response, the expansion of the chest for measurement of respiration, and triggers indicating the start and the end of the course, reaching the points of interest, leaving the course, colliding with tree obstacles, and jumping. The electrocardiogram channels have been used to compute the heart rate. An approach for detection of R waves similar to [16] has been applied. This method is intended for real-time detection and, hence, needs a final integration step. The integration has been replaced by a search for local maxima yielding the peaks of the R waves, resulting in the intervals between successive heart beats, the so-called inter-beat intervals. The galvanic skin response channel delivered the current resistance of the skin surface ρ and has been used to compute the skin conductivity; however, most of the data have been biased due to the motion of the subjects and was, therefore, not submitted for statistical analysis. The continuous data obtained from the expansion of the belt around the chest have been used to compute the breath rate through application of a local maximum search algorithm on the bandpass-filtered data. The continuous data have been analyzed in two ways, as a function of the time, and as a function of the position on the slope. The latter approach was used when comparing the data for the particular points of interest. In addition to physiological values the following performance data have been recorded: the time needed to complete the rides, collisions with tree obstacles, position and orientation for all optical tracking markers, and data from the board input device. Verbal remarks expressed by the subjects have been recorded, as well. Multiple questionnaires have been used to gather further information, like demographic data and experience with virtual reality and sports (pre-test questionnaire), and personal preferences concerning the conditions as well as feedback (post-test questionnaire). The subjects completed the IPQ presence questionnaire after each one of the four blocks in the experimental session. The presence score has been computed according to [22]. Continuous data have been analyzed with Matlab (The MathWorks, Natick, MA) and customized modules. Statistical analysis has been performed with SPSS (SPSS Inc., Chicago, IL).

Data obtained from the five subjects that reported symptoms of simulator sickness and data from one subject that reported serious difficulties with 3D vision have been excluded from the statistical analysis. Due to technical problems the physiological data for one subject have been biased and therefore falsified. The presence questionnaire data for one subject have not been saved in the data base. These data have not been used in the corresponding analyses, as well. Altogether, data from 20 subjects have been used for further analysis.

3.2. Results

3.2.1. Presence Scores. The presence scores have been analyzed with a one-way ANOVA with repeated measures. A significant main effect due to the subjective estimates of presence was observed. The reported mean presence score was higher in the N– condition ($M = 4.052 \pm 0.186$) than in the conditions using an avatar: N+ ($M = 3.593 \pm 0.205$), A+ ($M = 3.505 \pm 0.186$), and T+ ($M = 3.450 \pm 0.167$), *cf.* Fig. 5. This difference was significant: $F(3,57) = 5.36$, $p = 0.003$. A post hoc pairwise comparison of all conditions revealed that condition N– significantly differs from all other conditions at the $p < 0.05$ level, and that presence estimates for conditions N+, A+, and T+ can not be significantly separated from each other.

3.2.2. Physiological Measures and Performance. The repeated measures one-way ANOVA showed no significant effect between the conditions neither for the heart rate ω^{HR}

Table 1: Mean values and standard deviations for physiological and performance measures: mean breath rate ω^{BR}, and mean heart rate ω^{HR} at points of interest p_1 (FUNNEL) and p_2 (JUMP), the average speed v and the achieved maximal speed v_{max}, time for completion of a ride t, as well as the mean number of collisions n_{col} and jumps n_{jmp} per trial given for each experimental condition.

	Condition			
Measure	N–	N+	A+	T+
presence	4.05 ($\pm$ 0.833)	3.59 ($\pm$ 0.917)	3.51 ($\pm$ 0.830)	3.45 ($\pm$ 0.748)
ω^{BR} / min^{-1}	21.95 ($\pm$ 3.118)	22.01 ($\pm$ 3.575)	22.00 ($\pm$ 3.189)	22.35 ($\pm$ 3.346)
ω^{HR} / min^{-1}	104.3 ($\pm$ 11.17)	104.6 ($\pm$ 15.11)	103.2 ($\pm$ 11.58)	104.6 ($\pm$ 11.93)
$\omega^{HR}_{p_1}$ / min^{-1}	103.6 ($\pm$ 11.17)	103.4 ($\pm$ 14.63)	103.0 ($\pm$ 11.60)	104.1 ($\pm$ 12.08)
$\omega^{HR}_{p_2}$ / min^{-1}	104.6 ($\pm$ 11.70)	103.8 ($\pm$ 14.61)	103.8 ($\pm$ 11.68)	104.7 ($\pm$ 12.41)
v / m/s	15.04 ($\pm$ 1.229)	14.99 ($\pm$ 1.022)	14.86 ($\pm$ 0.895)	14.68 ($\pm$ 1.177)
v_{max} / m/s	21.85	22.18	22.01	21.78
t / s	30.49 ($\pm$ 4.213)	30.09 ($\pm$ 2.773)	30.86 ($\pm$ 2.556)	31.44 ($\pm$ 3.619)
n_{col}	0.97 ($\pm$ 0.776)	0.87 ($\pm$ 0.800)	1.05 ($\pm$ 0.740)	1.06 ($\pm$ 1.208)
n_{jmp}	5.24 ($\pm$ 0.712)	4.79 ($\pm$ 0.658)	4.96 ($\pm$ 0.943)	4.71 ($\pm$ 0.766)

($F(3,57) = 0.423$, n. s.), nor for the mean breath rate ω^{BR} ($F(3,54) = 0.281$, n. s.).

The use of an avatar had no significant influence on the performance metrics. While the amount of collisions with trees n_{col} did not change over conditions ($F(3,60) = 0.209$, n. s.) there is a (non-significant) tendency in the amount of jumps n_{jmp} during a ride ($F(3,60) = 2.584$, $p = 0.062$). Subjects jumped 5.24 times per trial on average without an avatar compared to 4.82 jumps in conditions presenting an avatar. Yet another tendency was observed in the mean speed v ($F(3,60) = 1.728$, $p = 0.160$) and the time t ($F(3,60) = 1.757$, $p = 0.165$). Subjects were slightly faster with an avatar (30.49 s at an average speed of 15.04 m/s) than without (30.80 s at 14.84 m/s).

All values for the measured physiological and performance metrics are given in Table 1.

3.2.3. Subjective Reports and Preferences. Mainly, the subjects did not comment their performance during the trials, however, eleven have expressed surprise by verbal remarks, mostly during the training session, after the switch from training condition T+ to N–. The remarks have been as follows:

- "Where am I?"
  (expressed independently by three subjects)
- "Where do I see myself?"
- "I don't see myself. Is that right?"
- "I need the guy in order to steer!"
- "I think I'll perform worse without [*the avatar*]."

In contrast, a subject clearly asked if the avatar could be switched off again after completing the training with condition N– and starting the experiment with block A+. Another subject was suddenly scared during the experimental session while switching from block T+ to condition N– and asked to be warned in advance if the avatar will be switched off again. Interesting behavior has been observed in two subjects: the first apparently enjoyed interacting and playing with the avatar by moving his limbs in condition T+. The second observed his own arm doubtfully during the optical–kinesthetical mismatch that occurred when the subject lifted his arm without optical feedback at the JUMP point of interest, after completing condition T+ and switching to A+.

After completion of the experimental session subjects were asked to estimate the condition they preferred most during the experiment. On average, 66.7 % of subjects preferred the N– condition over the conditions with an avatar N+, A+, and T+. In conditions presenting an avatar the choice was 29.6 % on average for the tracked condition T+, 2.2 % for A+, and only 1.5 % for N+. The results are presented in Fig. 6.

3.2.4. Correlation between Objective and Subjective Measures. A significant negative correlation was found between the reported presence scores obtained by questionnaires and all measured heart rates, i. e., for the mean heart rate ω^{HR} ($r(79) = -0.332$, $p = 0.003$), the value at the FUNNEL point of interest $\omega^{HR}_{p_1}$, ($r(78) = -0.349$, $p = 0.002$), and at the JUMP point of interest $\omega^{HR}_{p_2}$, ($r(78) = -0.334$, $p = 0.003$). A gender specific analysis of the mean heart rates revealed even a stronger correlation with presence for males ($r(39) = -0.484$, $p = 0.003$) than for females ($r(43) = -0.313$, $p = 0.039$). The data are presented in Fig. 7. By contrast, no correlation was found between the measured breath rate and the presence scores ($r(79) = 0.081$, n. s.).

The analysis of the performance metrics yielded two significant correlations with presence scores: a positive correlation between the mean speed v and the reported subjective presence score, $r(83) = 0.250$, $p = 0.023$ and a negative correlation between the mean time t and presence, $r(83) = -0.217$, $p = 0.048$, It has to be noted that even though both values t and v are strongly correlated, $r(84) = -0.962$, $p < 0.001$, they are independent of each other, because subjects traveled different distances during trials. While several subjects preferred to ride straight ahead, others made extensive use of the steering possibilities and produced tracks with a higher curvature and therefore longer distance.

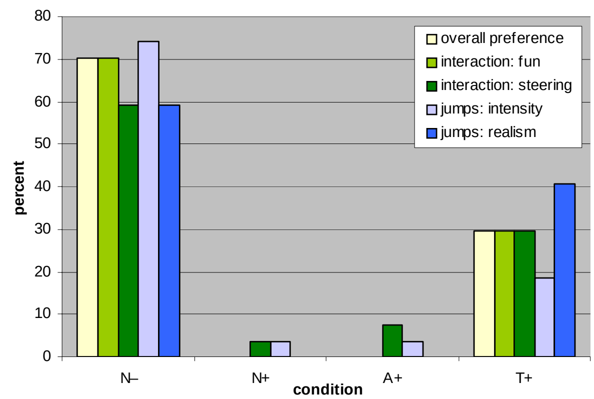

Figure 6: Personal preferences as estimated by questionnaires after completion of all experimental blocks. Subjects were asked to choose the most preferred condition with regards to personal preference, interaction and the experience of jumps on the virtual track.

3.3. Discussion

The results of the study clearly show that while the representation of an exocentric avatar decreases presence in room-mounted virtual environments, body tracking is subjectively preferred over animated or rigid avatars. The study also reveals a correlation between presence scores and physiological measures, as well as between presence scores and performance metrics.

3.3.1. Identification with exocentric avatars is not persistent and therefore decreases presence. The reported presence is strongly dependent on the use of an exocentric avatar. The score is significantly higher in the condition without an avatar N– than in all conditions using variations of the exocentric avatar. Room-mounted virtual environments—as used in the study—strongly immerse the user within a virtual world without restricting the view on his own body. The application of an avatar in such a configuration is therefore bound to mental processes that resolve the identification of the body schema with the two competing body representations. Evidence for this mental process has been found in the comments of subjects on the avatar principally referred to as oneself (“Where am I?”, “Where do I see myself?”, *etc.*) that were mostly expressed during the training session. However, the decrease in the subjective presence for conditions presenting an exocentric avatar indicate that the avatar did not attract the user’s body schema permanently and was therefore perceived as disturbing in the experience of the virtual world. Apparently, the avatar was not permanently preferred as a mean for identification within the virtual world, as concluded in [29]. Our findings also allow an interpretation in terms of the results by David *et al.* who investigated the dependence of perspective on the quality of agency: avatars viewed from a more exocentric perspective induced a lesser quality of agency than egocentric avatars [4]: agency can be seen as a consequence of the identification of the body schema with the avatar. In contrast to the presence scores obtained, no significant differences have been found for the physiological and the performance measures, implying that subjects performed equally well in all conditions. However, the tendencies observed for changes in the heart rate at the FUNNEL point of interest, as well as the amount of jumps, and the mean speed allow the conclusion, that subjects tend to perform better in condition N–. This implies, that more attention has been paid to the completion of the task in condition N– and that, presumably, attentional ressources have been allocated in the remaining conditions for the mental processes involved in identification with the avatar.

By way of an overall conclusion, the effect observed proved to be not strong and persistent enough for creating a significant identification with the avatar albeit a mental binding of the body schema to the avatar took place. Therefore, the reported presence was lower in conditions involving an avatar compared to the condition without one.

3.3.2. Synchronous kinematics is the preferred choice for avatars. While the analysis of the subjective presence scores has not revealed statistical differences among the conditions using an avatar N+, A+, and T+, subjective preference estimates clearly indicate T+ to be the favorite condition. On average $1/3$ of subjects have identified with the exocentric avatar and have therefore deprecated the condition N–. Among those subjects 88.9 % preferred the tracked exocentric avatar. Going more into detail, only 4.4 % and 6.7 % of these subjects preferred the condition N+ an A+, respectively when asked about the interaction and steering, as well as the intensity of jumps. It is most likely that these subjects have identified with the avatar on the one hand, yet have chosen among the conditions that do not attract the proprioceptive attention on the other hand. Surprisingly, the clear preference for T+ was not reflected in the presence scores obtained. It is safe to conclude that an important number of users prefer to identify with an exocentric avatar whose motion is directly bound to the user's body. Furthermore, it is noteworthy that this identification does not lead to an important negative influence on user performance. Therefore, the application of avatars with synchronous kinematics has some potential to ameliorate the overall usability of the system.

3.3.3. Increased performance in higher presence scenarios. As mentioned in section 2 presence is regarded as a factor of usability. To date, task and system performance are used to assess the usability of a system. The results revealed a correlation between presence scores and task performance. In particular, a correlation has been found for the mean speed v and mean time t. Subjects performed better with increasing presence, i. e., they have been faster and they needed less time to finish the task. This correlation has been further substantiated by the intra-individual analysis of the four conditions where (non-significant) tendencies have been found for v, t, and, in addition, the number of jumps n_{jmp}. The interrelationship between presence and performance leads to the conclusion that higher presence is perceived in systems with higher usability.

3.3.4. The ambivalent role of the heart rate in estimating presence In view of the estimation of presence by objective measures, such as physiological metrics, the study revealed several significant results. Most importantly, it has been found that the subjective presence score correlates with the heart rate in an inter-individual comparison. This correlation was continuously negative for the heart rate measures ω^{HR}, $\omega_{p_1}^{\text{HR}}$, and $\omega_{p_2}^{\text{HR}}$. It has been further substantiated by a gender specific analysis. The correlation implies that the higher the presence score, the lower the heart rate. Heart rate has been shown to be an objective measure for presence, e. g., in [14]. Meehan *et al.* conclude that higher presence is bound to a higher heart rate. They argue that "higher presence" virtual environments should evoke stronger physiological reactions because they are closer to reality. The difference in Meehan's studies compared to our work is the comparison of virtual environment set-ups that induce stress in the users dependent on their degree of realism. This is achieved by stimuli for additional modalities (like haptics) and by variation of the content of the virtual world. By contrast, our study used one task (snowboard ride) in one specific virtual environment that induced a certain amount of stress and physiological reaction. The measured heart rate was therefore dependent on the variations in the application and kinematics of the exocentric avatar. As concluded previously, the decrease in the reported subjective presence scores was due to a non-persistent identification with the avatar which was perceived as perturbing. The additional stress induced by the concurring representation of the exocentric avatar explains the increase in the measured heart rate combined with a decrease in the presence scores.

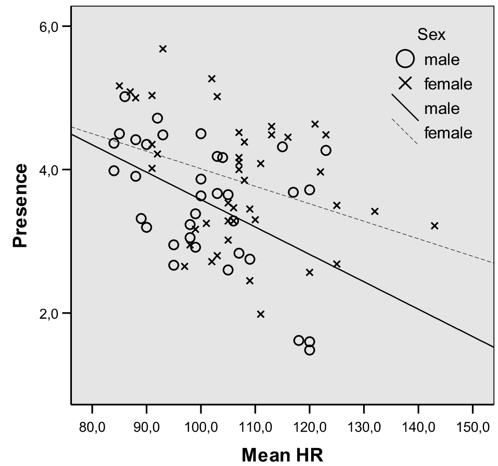

Figure 7: Correlation between the mean heart rate with the reported presence scores. The graph shows gender specific subgroups. The best fitting lines are displayed for the heart rate, which is significantly correlated ($r(79) = -0.332$, $p = 0.003$).

In summary, stressful situations or environments are capable of inducing different sensations of presence as well as different pace in the heart beat. However, while comparing the presence scores and physiology measures, the cause for variation in both has to be analyzed closely. Virtual environments whose degree of realism is directly related to the degree of stress will lead to an increase in both measures: a higher presence and a higher heart rate in a more realistic scenario. In our case, a conflict in identification with an exocentric avatar leads to increased stress and therefore an increased heart rate in spite of reduced presence. To conclude, if the relation between realism and the induced stress is known for a certain virtual environment scenario then the heart rate can be used as an objective measure for presence.

4. Conclusion

The study aimed at evaluating the influence of exocentric avatars on the sensation of presence, as well as at clarifying the influence of kinematics on user preferences. The study fully approved the hypothesis discussed in the introduction, i. e., it has been shown that presence is highest if the center of action is the user himself—if no avatar is used. The usage of an exocentric avatar led to a decrease in the presence scores. Even though users did identify with an avatar this effect was not persistent. The mental processes involved in the resolving of the identification dilemma of the body schema with the two concurring body representations created a conflicting situation that caused a decrease in presence. However, subjective reports showed that users indeed identified with the avatar. As discussed, this effect has not been transient. Avatars with synchronous kinematics were the preferred choice in conditions using an avatar. In addition, the study revealed an interrelation between physiological and performance data and subjective presence estimates, suggesting that the heart rate can be used as a measure for presence, and that presence affects usability to a certain extent.

The study has clarified the influence of exocentric avatars used in room-mounted virtual environments on the sensation of presence. It has been shown that avatars with synchronous kinematics lead—at least temporarily—to an identification with the virtual body representation. Yet, it has also been shown that exocentric avatars in virtual environments in general induce mental processes that allocate attentional resources needed to resolve the identification with the two concurring body representations, leading to a decrease in presence and performance. It is this interrelationship between the identification with the virtual avatar and the additional mental processes that bears the potential in application of virtual humanoids as avatars: on the one hand, the identification may strongly be used to positively influence the user; on the other hand, it can slow down the working process if used inappropriately.

As a consequence on the application of virtual humanoids, we suggest to use exocentric avatars in room-mounted virtual environments for manipulation in order to avoid the occlusion problem and in navigation, if an additional attention and focus on the avatar is desired, for example, in the case of avoidance of collisions or display of auxiliary visual information. An additional advantage of such an application of avatars is the frame of reference established between the user and the virtual world.

Virtual humanoids are an inevitable part of forward-looking applications in virtual environments. The reasons for this are manifold whilst most effects are still not well understood. Yet the strong identification with the representation of the virtual body and the intense induction of attentional processes outlined in this work demonstrate the capabilities of avatars in room-mounted virtual environments.

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