Avatar et Sentiment d'Incarnation : Étude de la préférence relative entre l'apparence, le contrôle et le point de vue

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Avatar and Sense of Embodiment: Studying the Relative Preference Between Appearance, Control and Point of View

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Figure 1: The four tasks implemented in the subjective matching experiment with the avatar's appearance at maximum level of realism. From left to right: *Punching*, *Soccer*, *Fitness* and *Walking*.

ABSTRACT

This paper presents a study that was conducted at Inria Rennes laboratory, of which the aim was to better understand the inter-relations among avatar appearance, avatar control and user point of view and their relative preference when embodied in an avatar in virtual reality. More precisely, this paper described the methodology used to conduct this study based on subjective matching technique and the results. An extended version of this work (including related work, a first study and discussion) can be found here [2].

KEYWORDS

Avatar, Sense of Embodiment, Immersive Virtual Reality, Psychophysics, Subjective Matching Technique

1 INTRODUCTION

The use of virtual avatars has become a striking feature in the latest developments of Virtual Reality (VR) applications. This increasing importance given to virtual avatars reinvigorates the research interests in the approaches to design them in such a way that users feel embodied. However, the design and conception of avatars is tailored by a number of technical (e.g. motion capture capabilities), data (e.g. 3D model reconstruction) and algorithmic (e.g. animation) constraints. Indeed, a fully functional avatar requires a vast amount of choices, and yet little is known about how the combination of choices are accepted by users, and affect their perception of the resulting avatars.

In the past years, many studies have tried to better understand how users perceive their avatar in VR by evaluating their Sense of Embodiment (SoE). More precisely, they focused on three subcomponents of the SoE [5]: the Sense of Self-Location, the Sense of Ownership and the Sense of Agency. From those researches emerged different "factors of influence" towards these three subcomponents, e.g., the avatar's appearance [1] or the user's point of view [4]. However, despite the worthwhile highlights brought by these studies, the inter-relations between the factors influencing the SoE remain uncertain. Indeed, if we start to better understand the influence of isolated factors on the SoE, we still have little information regarding the relative contribution of each factor towards the SoE, or regarding the user's preference for a factor over another while being embodied in an avatar. As for today, several questions remain open: Is there a dominant contribution between the factors of influence towards the SoE? Should some of these factors be prioritized in the creation of virtual avatars?

In order to provide insights to these questions, we present two experiments exploring user preference and perception of three factors commonly found in the literature to influence the sense of embodiment, namely the avatar's visual appearance, the avatar's control, and the user point of view. The first experiment (baseline experiment, n=20) had the objective to create an ordered list for the levels within each factor (e.g., ranking between the different degrees of realism for an avatar appearance, ranging from abstract to personalised avatars). For each factor, participants experienced all levels while performing a task and had to rank the preference for each level in a scale from 0 to 100. The task consisted in recreating a yoga posture in front of a mirror.

The second experiment (n=40) used the results obtained in the baseline experiment in order to explore through a subjective matching technique how participants combined them to reach a given level of SoE. Subjective matching experiments have already been successfully conducted on the factors impacting Place Illusion and Plausibility Illusion in VEs [9]. Such experiments aim at studying qualia, i.e. a quality or property as perceived or experienced by a person such as the Place Illusion, the Plausibility illusion or what interests us in this paper, the Sense of Embodiment, avoiding the use of subjective questionnaires or purely physiological and behavioral measures. More precisely, in our case the experiment consisted in having participants experiencing an "optimal" configuration of an avatar and then "recreate" the experienced SoE by iteratively increasing, one level at a time, one factor, starting from a "minimal" configuration. The final matched configuration, named accepted configuration, should match the same SoE experienced with the "optimal" configuration. The initial "optimal" configuration was supposed to elicit a high SoE as it considered a partially customized avatar, full-body motion capture and a first-person point of view, while the "minimal" configuration consisted in a minimal avatar, with automatic animations and a third-person point of view. These configurations were defined according to ranking results from the baseline experiment. The choices of the participants provide insights about their preferences and perception over the three factors. In addition, to assess the potential impact of users actions while being embodied in an avatar, the subjective matching experiment considered four different tasks which covered four actions that can be done in a virtual environment: a) an interaction with the upper-body, b) an interaction with the lower-body, c) mimicking the actions of another virtual character full-body motions, or d) a constrained walking task. We had three main hypotheses. First, that we could create a monotonic ranking for the different levels of each factor. Second, that some factors would be prioritized over other factors. Finally, we expected the task to have an impact on the results.

Overall, our results validate our main hypotheses. First, a monotonic ranking for selected levels of each factor was successfully created. Second, it was shown that point of view and control levels were consistently increased by users before appearance levels. Third, several configurations were identified with equivalent SoE as the one felt in the optimal configuration, but tend to vary between the tasks Taken together, our results give insights of which factors to prioritize to enhance the SoE towards an avatar, and about configurations which lead to SoE judged to be similar to the SoE experienced in the optimal configuration.

In summary, the main contributions of this paper are threefold. First, an experiment measuring the relative user preference of three factors related to the SoE: the avatar appearance, the avatar control and the user's point of view. Second, the first subjective matching experiment assessing the relative contribution of these three factors on the sense of embodiment when performing four distinct tasks. Third, the highlight of valuable insights about which factors to prioritize in order to enhance the SoE towards an avatar in different tasks, and about configurations which lead to fulfilling SoE in VE.

2 OVERVIEW AND GENERAL EXPERIMENTAL DETAILS

The main objective of this paper was to identify potential preferences within factors of influence towards the SoE. To do so, we first conducted a baseline experiment to define the number and order of the different levels for each factor of influence towards the SoE. We then conducted a subjective matching experiment, similarly to the studies on Presence of Slater et al.[9] and Skarbez et al.[8], in order to better understand the inter-relations between these factors. In this section, we detail the subjective matching technique used in our main experiment as well as the experimental details common to both experiments.

2.1 Subjective Matching Technique

The subjective matching technique is a method commonly used in color science where a particular color sensation is considered as an equivalence class over a number of different wavelength distributions. Typically, users are presented with a color, then asked to reproduce the same color by additively mixing the three primary colors.

In the context of this paper, a particular SoE could similarly be considered as an equivalence class over different levels of factors that may influence it, and users were therefore asked to reproduce a given SoE by combining different levels of these factors. A combination of several levels of factors is called hereafter "configuration". In our case, these factors are the Appearance, Control and Point of View, leading to numerous possible avatar configurations with many potential degrees of SoE. Moreover, the SoE felt in a specific configuration combining the three factors might by be equivalent to one felt in another configuration of these factors. The subjective matching technique used in the experiment therefore involves users trying a specific "optimal" configuration of avatar, and remembering their SoE in this configuration. They are then asked afterwards to combine several levels of factors to match again the SoE felt in the initial configuration. More precisely, to each factor is associated a number of levels of improvement, assuming that having all the factors at their maximum level would lead to the best configuration in which users are more likely to have the highest SoE. This method therefore enables to highlight a) which factors participants are more likely to improve and in which order, and b) which configurations will elicit a SoE equivalent to the one felt in the best configuration.

2.2 Factors and Levels

To do such an experiment, we chose to focus on three factors (independent variables), with the objective of covering as much as possible the different degrees of SoE likely to be felt towards an avatar. The visual *Appearance* of the avatar was chosen to encompass visual feedback of the avatar that relates to graphical features. The *Control* was chosen to embrace any capabilities of having the avatar animated in the VE. Finally, the *Point of View* was chosen to include different perspectives taken from a user towards the virtual body of the avatar. For each factor several levels were identified with an initial pre-supposed ranking which was refined in a baseline experiment. The main requirements for choosing the factors and levels were to ensure good coverage of potential implementations of an avatar according to each factor, as well as allowing the combination of levels between factors. For instance, we did not separate *Appearance* into texture and shape as realistic textures would hardly be combinable with abstract geometrical representations. Similarly, we did not include finger animation since it could not consistently be combined with all the appearance levels..

Figure 2: Levels of the *Appearance* factor. From left to right: (A_a) Abstract avatar, (A_b) Stickman, (A_c) Dummy avatar, (A_d) Opposite realistic avatar, (A_e) Neutral realistic avatar and (A_f) Personalized realistic avatar.

Figure 3: The two levels of the *Point of View* factor: (P_a) Third-person PoV, (P_b) First-person PoV

2.2.1 Appearance. The appearance of an avatar can be addressed over several characteristics: the general structure of the virtual body, the shape and dimension of body parts, the render style, etc. Those characteristics combined together contribute to different levels of avatar realism, anthropomorphism and fidelity towards the user. Many visual configurations of avatars have been tested in order to evaluate their influence on the SoE and more precisely on its subcomponents. For our experiment, we have selected 6 levels that we believed were the most represented in past studies (see Figure 2), ranging from low to high realism and anthropomorphism representations (including the distinction of three realistic avatars in terms of fidelity):

- (A_a) Abstract avatar. Only extremities of the body are visually represented with white spheres.
- (A_b) Stickman. Extremities and main body joints are visually represented with white spheres and cylinders.
- (A_c) Dummy avatar. An avatar with a human body shape but a robotic appearance.
- (A_d) Opposite realistic avatar. A realistic gender-matched humanoid avatar that participants chose among a list of 20 different avatars (20M, 20F) (see supplementary material) with the instruction of choosing one that they considered to be their opposite in terms of resemblance.
- (A_e) Neutral realistic avatar. A realistic gender-matched humanoid avatar that participants chose among a list of 20 different avatars (20M, 20F) with the instruction of choosing one that did not evoke them anything particular.
- (A_f) Personalized realistic avatar. A realistic gender-matched humanoid avatar that participants chose among a list of 20 different avatars (20M, 20F) with the instruction of choosing one that they considered to resemble them the most. This avatar could then be slightly personalized in terms of hair, eye and clothes color.

2.2.2 Control. Similarly, we selected four levels of Control based on previous works, that we believed were most likely to have different effects on the SoE.

- (C_a) Automatic animation. When participants enter a specific zone in order to perform the task, an animation is automatically launched on the virtual body which makes the avatar do the task while the participants actually have no control over it.
- (C_b) Triggered animation. Pressing a button, participants can trigger themself the animation performing a task in the VE (same animation as in C_a).
- (C_c) Inverse Kinematics. The virtual body is animated using Inverse Kinematics, enabling the animation of the avatar from participants' head, hands and feet positions and orientations.
- (C_d) Motion capture. The virtual body of the avatar is animated using a motion capture system (Xsens system).

2.2.3 Point of View. Two levels were chosen for the PoV depending on participants perspective towards the virtual body (see Figure 3).

- (P_a) Third-person PoV. Users see their virtual body from a classical over-the-shoulder PoV, as commonly used in video games.
- (P_b) First-person PoV. Users see their virtual body as if they were in the avatar's head (as they would see their own body in real life).

2.3 Apparatus

For both experiments, the virtual environment was developed in Unity (version 2018.3.14f1) and displayed using an HTC Vive PRO Head-Mounted-Display (HMD). For head tracking, the internal tracking of the HTC Vive HMD was used. For body tracking, participants wore an IMU-based (Inertial Measurement Unit) motion capture system (Xsens). IMU sensors were equipped on the participants using motion capture suit and straps. The body tracking was handled by the Xsens MVN Animate software platform and streamed to Unity in real time. When using Inverse Kinematics, the FinalIK plugin was used to animate the avatar by following the feet, hand

and pelvis positions provided by the Xsens software. Participants also hold Vive Controllers in their hands to interact with the virtual environment.

2.4 Participants

Twenty participants took part in the baseline experiment (17 males and 3 females; mean/S.D. age: 25.8±5.6). Forty participants (20 males, 20 females; mean/S.D. age: 32.5±10.1) were recruited for the subjective matching experiment. For both experiments, participants were recruited from the university campus, were naive with respect to the purpose of the experiment and had normal or corrected-to-normal vision. The studies conformed to the declaration of Helsinki.

Before each experiment, participants were first briefed about the experiment, signed an informed-consent form and completed a demographic questionnaire. After this process, they were equipped with the Xsens motion capture system before undergoing a calibration procedure that would ensure the efficiency of the motion capture system but also allow to resize the avatar to participants dimensions. Finally they were equipped with the HTC Vive PRO HMD and started the experiment.

3 SUBJECTIVE MATCHING EXPERIMENT

The goal of this experiment was to study the relative contribution of the *Appearance*, *Control* and *Point of View* factors towards the SoE, using the pre-selected levels for each factors obtained from the Baseline experiment. In other words, do users have preferences between those factors when it comes to enhance their SoE towards an avatar?

3.1 Tasks

Potential preferences regarding factors influencing the SoE may depend of the task performed in the VE. Indeed, the way users interact with the virtual environment may induce them to look more or less to certain parts of their virtual body, or more generally to pay more or less attention to their virtual body. The presence of collisions between the virtual body and the VE leading to visible feedback of changes in the VE may also influence the perception of the virtual body and thus the SoE. More abstractly, the general context of the interaction, its gamification [10, 12] or social aspect [6] might influence on users perception towards the overall VE.

For these reasons we hypothesized that the type of action performed by users in the VE would influence the SoE, and therefore designed four different tasks with the goal of covering a wide range of actions that an avatar can do in a VE. First, we designed two tasks involving direct interaction between the virtual body and the VE, one involving the upper-body and one involving the lower-body. Second, we designed a task involving no direct interaction between the virtual body and the VE, but the presence of another virtual character. Finally, we designed a walking task, navigation being a main and one of the most common interaction task in VR. We describe the tasks more in detailed hereafter:

- The *Punching* task consisted in hitting a punching bag, involving the virtual upper-body to be interacting directly with the VE (see Figure 1, first).
- The *Soccer* task consisted in kicking a soccer ball, involving the virtual lower-body to be interacting directly with the VE (see Figure 1, second).
- The *Fitness* task consisted in following fitness movements instructed by a “fitness teacher” (see Figure 1, third).
- The *Walking* task consisted in walking straight while avoiding obstacles on the floor. Low walls constrained the direction of the path to walk on (see Figure 1, fourth).

These four tasks were entered in the same general context of a fitness scenario, and participants were immersed in a virtual fitness room in front of a virtual mirror. Participants started on a circular green carpet, and always moved towards another green carpet in front of them to perform the task. The levels of each factor were also the same for the four tasks, with the unique difference that the actual animation of C_0 (Automatically launched animation) was tailored for each task. For the *Punching* task, the automatic animation made the dominant hand punch the punching bag once, while for the *Soccer* task it made the dominant foot kick the ball. For the *Fitness* task the automatic animation displayed the same fitness movements shown by the virtual teacher. Finally, for the *Walking* task the automatic walking solution from FinalIK was applied to animate the feet so that they avoided obstacles when collisions were close, i.e., to step over the obstacles. The automatic animations specific to each task are presented in the accompanying video for illustrative purposes.

A mixed design was chosen for the experiment. Each participant performed randomly only two tasks. This choice was done to reduce experiment duration time and to ensure the engagement of the participants. The design ensured that each task was performed by 10 male and 10 female participants, the order of the tasks was counterbalanced.

3.2 Experimental Protocol

Participants started the experiment with a first exposure which had a threefold objective. First, it enabled participants to become familiar with the VE and the tasks to perform. Second, they were instructed to test and become familiar with all the possible levels of each factor. Finally, they then performed the tasks with the best avatar configuration (i.e., with the highest level for each factor: {3,2,1}[1]), and in that case were instructed to focus on their SoE towards the avatar. Considering that the notion of “Sense of Embodiment” was not instinctive to understand for participants, we detailed the instruction to participants based on the description made in Kilteni et al. work [5]: “Please be aware of your SoE towards your virtual body while doing the task, considering your SoE as a union of the feeling of ownership you have towards the virtual body, the feeling of control you have over it, and the feeling of being spatially located in this virtual body”. After making sure that participants had tested all the improvements they could do towards the virtual avatar, and had memorized their SoE in the best configuration for the tasks, the second part of the subjective matching procedure started. Participants were instructed beforehand that for each task, they would perform several trials in which they would start in a low level configuration of avatar, with the goal of reaching the same SoE they had experienced in the “optimal” configuration. The initial configuration could either be all the factors at level 0 ({0,0,0}) or just one factor at level 1 ({0,0,1}, {0,1,0},

[1]Notation {i,j,k} represents an avatar configuration with levels A_i, C_j, P_k

{1,0,0}). Each participant started once with each configuration giving 4 trials per task. In order to minimize ordering effects, the order of the starting configurations for each task was counterbalanced following a Latin square design.

Participants then increased a factor by telling the experimenter which factor they wanted to improve. Similarly, they were also instructed to notify the experimenter when their SoE matched the one felt in the "optimal" configuration of avatar. However, participants were asked to keep on making choices to improve the factors until they had reached the final configuration, even if the match happened before reaching the "optimal" configuration.

After completing all the trials for the two tasks, participants completed a post-experiment questionnaire, including the standardized embodiment questionnaire [3] , the SUS presence questionnaire [11], as well as a series of questions to rate the factors regarding their preference when improving their avatar. While participants were asked to answer the presence questionnaire and rate the factors focusing on the general experiment (including both tasks), they were instructed to answer the embodiment questionnaire thinking of the avatar in the latest task tested, for which they had matched the high SoE. The whole experiment, including welcoming of participants, reading and signing the consent form, and answering questionnaires lasted around one hour.

3.3 Recorded Data

The recorded data includes participants choices during the experiment as well as the answers to the post-experiment questionnaire. First, there is the "Accepted Configurations", i.e. the configurations at which participants declared to feel an equivalent SoE compared to what they felt in the "optimal configuration". Second, there is the transitions set, meaning the order of improvements made by participants to go from one configuration to another. Finally, there are the answers to the embodiment and presence questionnaire (respectively 7-point and 5-point Likert scale) as well as the ratings made by participants regarding their general preference of factors (7-point Likert scale), all collected from the post-experiment questionnaire.

4 RESULTS

In this analysis we made the same assumption than Slater et al. [9] and Skarbez et al. [8], namely that the results for each repetition are statistically independent. Since there were performed by the same participant, they are not truly independent, but each trial started with a different initial configuration, forcing participants to reconsider their first choices each time. In this section, we report our analysis according to three measures: the identified Accepted Configurations, the transitions made by participants from the initial configuration to the optimal one, and finally their responses to the post-experiment questionnaire.

4.1 Accepted Configurations

To analyse the results concerning the Accepted Configurations, we first computed separately for each task the probability of accepting a configuration (Figure 4, top), which corresponds to the number of times participants reported a match of SoE for a given configuration over the total number of accepted configurations (4 trials $\times$ 20 participants = 80 accepted configurations in total). If there was no match before the optimal configuration, this configuration was considered as the Accepted Configuration. For example, in the *Punching* task, the configuration {1,2,1} was accepted 9 times, which thus represents 11% of the total accepted configurations. We can observe that configuration {1,2,1} was the most accepted configuration for all tasks except *Punching*, for which the most accepted configurations are spread between configuration {2,2,1} and {3,2,1}.

Second, we computed for each task the conditional probability of participants reporting a match when experiencing a configuration (Figure 4). For instance, the configuration {1,2,1} in the *Punching* task was attained 35 times, while a match was only reported in 9 trials, meaning that there is a 26% probability for participants to report a match when attaining this configuration. Results are overall in line with the global probabilities computed, but also give additional information regarding configurations that may not have been often reached, but were mostly accepted when they were. For instance, in *Fitness* and *Walking*, configuration {3,1,1} was only reached 12 and 6 times, but when they were, they had more than 75% chance to be accepted.

Third, we computed for each task the probability of accepting a configuration depending on the participants' gender (see Figure 7), since several studies already showed that the perception of the virtual environment [8] and avatar [7] may vary accordingly. We can observe differences between males and females in *Punching* and *Walking*. In both tasks while males mostly accepted configurations {2,2,1} (44%) and {1,2,1} (45%) respectively in *Punching* and *Walking*, women

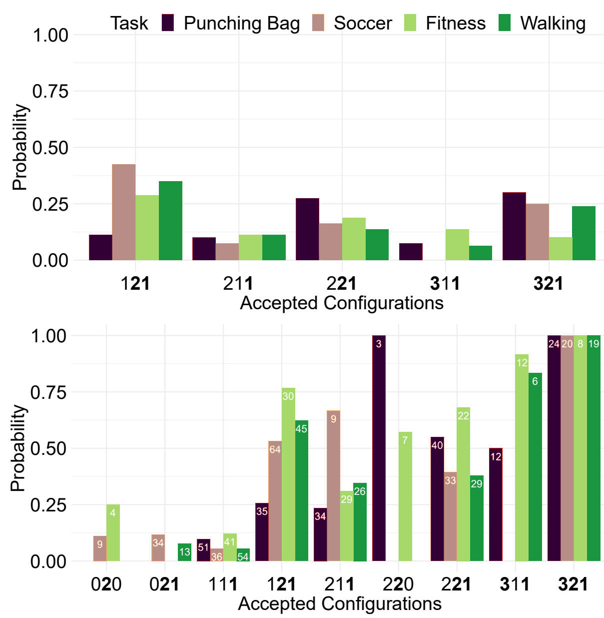

Figure 4: Probability for configurations to be accepted (top) and conditional probability for configurations to be accepted if reached (bottom). The number written on each bar represents the number of times the configuration was reached. The levels of factors are in bold format when at their maximum. For readability purpose, only configurations with a probability of acceptance higher than 10% are shown.

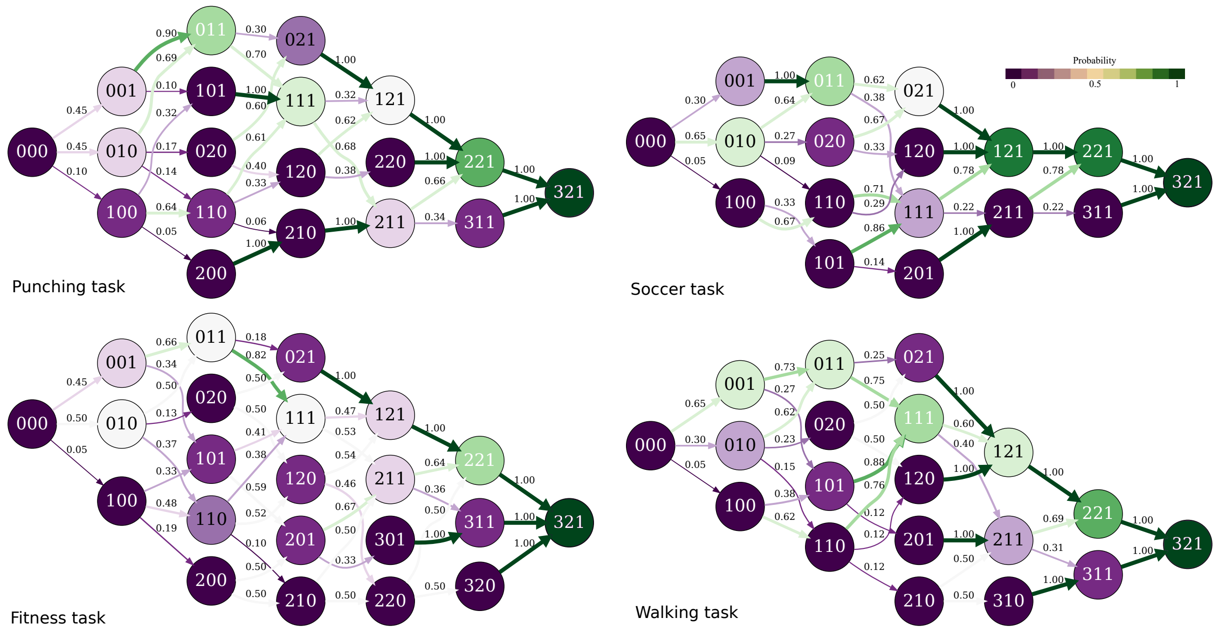

Figure 5: Markov chains representing the transition matrix probability for each task. The color of a node represents the probability that the node is reached. The color and the thickness of the edges represent the transition probability from a given node.

tended to need higher level of appearance by accepting in majority configuration {3,2,1} (46% in *Punching* and 53% in *Walking*).

4.2 Transitions

A transition probability matrix was constructed with the configurations chosen by the participants. Since all participants were asked to improve the configurations until the optimal configuration, there were 6 improvements for each trial starting in configuration {0,0,0} and 5 improvements for the other trials. This makes a total of 21 improvements per participants per task, and a global total for all participants and all tasks of 1680 improvements. This matrix enabled us to compute the probability distribution over the configurations for any given configuration, and the elaboration of a Markov chain for each of the four tasks (Figure 5). Each graph represents the probability distribution for each possible transition (configurations most explored are represented in green, while those barely explored are represented in red). The most likely path were also identified for each task and presented in Figure 6.

Over all tasks, results show that a clear majority of participants preferred to increase first their level of *Control* or *Point of View* against their *Appearance*. When the first choice was to improve either the *Control* or *Point of View*, the second decision was mostly to improve the other one next, leading to configuration {0,1,1}. At that point, in all tasks except *Soccer* most participants tended to improve their appearance ({1,1,1}), except for the *Soccer* task where the next choice was in majority to increase again the level of *Control* ({0,2,1}). Afterwards, participants mostly attained the same configuration {1,2,1}, by increasing the *Appearance* in *Soccer* or the *Control* in the other tasks. From this configuration, only the

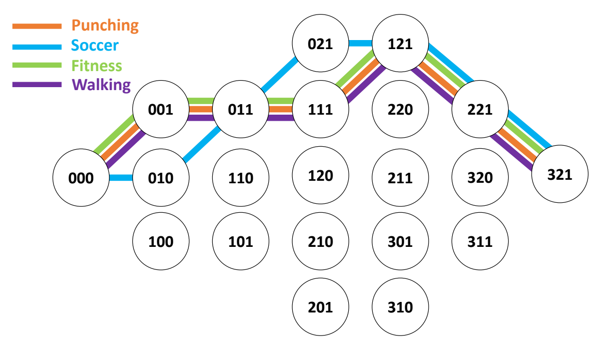

Figure 6: Most likely path for all four tasks.

Appearance could be further increased until the final configuration {3,2,1}.

4.3 Post-experiment Questionnaire

From the Presence and Embodiment questionnaires we computed the mean scores for Presence regarding the global experiment (4.70±0.89 (S.D.)) and Embodiment for each task (*Punching*: 5.07±0.69, *Soccer*: 5.23±0.80, *Fitness*: 5.04±0.51 and *Walking*: 5.26±0.75). Kruskal-Wallis tests were performed on embodiment scores showing no significant differences between tasks.

Moreover, mean scores of preference were computed for each factors (see Figure 8). Friedman tests showed significant differences between factors for the mean scores of preference attributed to each (p<.001). Wilcoxon tests were thus conducted, showing that *Control* and *Point of View* were both rated on average significantly higher in terms of preference in order to improve the avatar (p<.001).

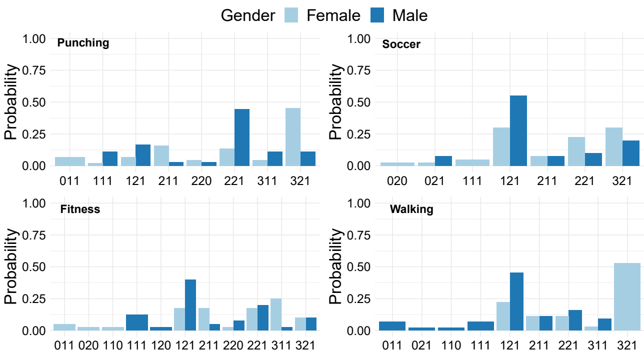

Figure 7: Probability of a configuration to be accepted per task and depending on participants gender.

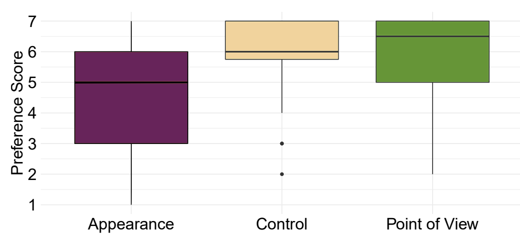

Figure 8: Mean scores from the post-experiment questionnaire according to users' preference of improving the given factor on the avatar.

5 CONCLUSION

In this paper, we presented two experiments exploring user preference and perception of three factors commonly found in the literature to influence the Sense of Embodiment in Virtual Reality, namely: the avatar's visual appearance, the avatar's control, and the user point of view. Our results first show that appearance of the avatar was given less importance than control or point of view. Second, we found that when it comes to virtual embodiment users do not necessarily need to reach the optimal avatar configuration to feel a fulfilling SoE, suggesting that VE designers may not always need to provide high-end graphics avatars but should provide a high degree of control. Third, we showed that the accepted configurations can vary depending on the task performed, stressing the importance of this aspect for future studies and applications. Taken together, our results provide valuable insights for designers of VR applications involving avatars, showing which factors among the three studied should be prioritized, and paving the way to future studies aiming at better understanding the inter-relations between factors influencing the Sense of Embodiment.

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