Motion Recognition of Self & Others on Realistic 3D Avatars

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Abstract

Current 3D capture and modeling technology can rapidly generate highly photo-realistic 3D avatars of human subjects. However, while the avatars look like their human counterparts, their movements often do not mimic their own due to existing challenges in accurate motion capture and re-targeting. A better understanding of factors that influence the perception of biological motion would be valuable for creating virtual avatars that capture the essence of their human subjects. To investigate these issues, we captured 22 subjects walking in an open space. We then performed a study where participants were asked to identify their own motion in varying visual representations and scenarios. Similarly, participants were asked to identify the motion of familiar individuals. Unlike prior studies that used captured footage with simple "point-light" displays, we rendered the motion on photo-realistic 3D virtual avatars of the subject. We found that self-recognition was significantly higher for virtual avatars than with point-light representations. Users were more confident of their responses when identifying their motion presented on their virtual avatar. Recognition rates varied considerably between motion types for recognition of others, but not for self-recognition. Overall, our results are consistent with previous studies that used recorded footage, and offer key insights into the perception of motion rendered on virtual avatars.

Keywords: animation, perception, avatar, gait, virtual reality

1 Introduction

Recent advances in capturing and rendering technology have enabled the rapid creation of virtual 3D avatars that resemble the human subject and can act as a representation of the human subject in 3D simulations. Coupled with advances in virtual reality, 3D avatars are increasingly being used to create immersive experiences for military training simulations, telepresence and social interaction-based applications, virtual counselling, and treating psychological disorders such as social anxiety and PTSD. In addition, there is a growing body of research that studies the psychological effects of seeing your avatar within a simulation [1, 2].

Rendering realism has been shown to have a major impact on the level of acceptance towards virtual characters. The extent to which embodied agents resemble human beings affects social judgements of agents in interaction and the level of presence felt by the user [3, 4]. Current state of the art methods are capable of generating highly photo-realistic 3D avatars of human subjects. On the other hand, motion realism has its own challenges [5]. Owing to complexities in accurate motion capture, it is common to reuse motion captured data generated from a single subject for use on multiple 3D characters via a retargeting process. While this can produce natural looking motion, a drawback is that the motion is not representative of the person who represents the 3D avatar, but rather of the motion captured actor. Recent studies have established the importance of individualized gestures [6] and facial animation [7] on animation realism. However, the role of subject's particular gait in identifying with the virtual 3D avatar has not yet been studied.

The perception of human gait has been well studied in the psychological community. However, most research has been restricted to using captured footage with simple "point-light walkers" [8], wherein the subject's motion is depicted by small point lights attached to the main joints. Despite evidence that biological motion is recognizable in case of self and others [9, 10, 11], there is little work to study its relevance in terms of virtual 3D avatars. It is possible that behavioral or motion realism coupled with appearance realism may lead to greater co-presence in immersive virtual environments [3].

Thus, it would be valuable to know the role of motion in recognizing virtual avatars of others. Similarly, it would be interesting to know whether subjects can recognize their own motions when presented on their own avatar since this may contribute to an increased sense of ownership and agency. Additionally, we would like to investigate the varying factors that affect perception of motion on virtual avatars. To investigate these questions, we designed and conducted two user studies. We first generated virtual 3D avatars and captured motion data for 22 individuals. We chose two specific motions to evaluate, a straight walk and a circular walking motion. These 22 individuals participated in Study I and another set of 22 participants were recruited for Study II. Each study consisted of a 2-Alternative Forced Choice design across two tasks. The first task had users evaluate each of the target motions (their own captured motions in Study I, those of two familiar individuals for Study II) against a reference motion in the point-light display and using the target's captured avatar. In the second task, the participant evaluated a target motion against a larger set of reference motions retargeted onto the avatar.

Main Results:

Our studies provided several interesting insights into motion recognition on photo-realistic avatars of the subject. In particular, we found that virtual avatars lead to an increase in self-recognition, compared to point-lights. The highlights of our evaluation are described as follows:

- The recognition rate for self-recognition varied between 47.05% and 82.35% depending on the conditions. In particular, we found higher recognition accuracy when participants were evaluating a virtual avatar as compared to point-light displays (82.35% vs 52.94%). Further analysis suggests that users were more confident when identifying their motion presented on their avatar than with point-lights.
- Recognition rate seemed to vary marginally between straight walk motion and circular walk motion for self-recognition. However, in case of identifying others, recognition rates were higher for circular walk compared to straight walk for avatars (50% vs 22.72%), suggesting viewpoint dependent effects.
- Surprisingly, recognition rate was higher for point-lights compared to virtual avatars in case of recognition of others.
- Our results for point-light representations are consistent with previous studies on recognition of motion of self and others, despite the fact that previous studies have relied on replaying captured footage while our study is simulation driven.

The rest of the paper is organized as follows. In Section 2, we survey related work in virtual avatars, motion synthesis and perception. We present details of modeling and rigging the virtual avatar in Section 3. We describe our evaluation framework and methodology in Section 4. We present results in Section 5 and discuss the implications of the results in Section 6.

2 Related Work

There is extensive literature in psychology on the perception of human gait in recorded footage. Johansson introduced the concept of point-light walkers [8] which allowed for the separation and study of motion cues alone. Point-lights have been shown to contain enough to determine the gender of a person [12], identify individual persons [11], distinguish between actions of adults and children [13], and recognize emotions [12]. Surprisingly, studies have shown that users can even recognize their own point-light displays which highlights the role of our motor system on the perception of motion [9]. This is evident from the study by Jokisch et al. [10] which showed that the viewing angle of point light displays had significant impact in the case of recognizing others but was a negligible factor in case of self-recognition. We use several of these studies to guide our research.

There has also been work in perception of motion in simulation. Hodgins et al. [14] determined that motion characteristics can be affected by the character model. Chaminade et al. [15] used varying degrees of anthropomorphism, from point lights to stylized humanoids and performed a study on whether a motion was biological or artificial, although the most humanoid characters in the study were not photo-realistic looking, nor representative of a particular person. Cook et al. [16] studied the ability of participants to recognize their own facial movements on an avatar. Hoyet et al. [17] investigated the distinctiveness and attractiveness of a set of human motions. They asked participants to compare a reference gait against a set of comparative gaits, all presented on the same avatar. Our work is complementary to theirs since we seek to evaluate the role of gait in avatar identity. On a similar theme, Mcdonnell et al. [18] found that varying appearance has a greater impact on perceived crowd variety than varying motion. Feng et al. [6] studied the role of gestures in avatar identity and found that participants rated avatars with gestures of their modeled human subjects as more like that subject. Of close relevance, Wellerdiek et al. [19] had twelve participants perform 5 different actions, including walking, and displayed the motion on a point light representation and on a gender-appropriate character model. They found a higher recognition rate for their participants on the point light representation, and that the gender appropriate humanoid model did not matter in self-recognition.

3 3D Avatar Synthesis and Rigging

We generated 3D models using a 100-camera photogrammetry cage based on Raspberry Pis to generate photo realistic avatars of the subjects, similar to the one described in [20]. The process required the subjects to stand still in an A-pose in the photogrammetry cage consisting of 100 Raspberry Pi cameras, as shown in Figure 1 for 5 seconds. We used commercially available software (Agisoft Photoscan) to reconstruct a 3D model from the static 2D images, thereby generating the static geometry for the virtual avatar within 10 minutes. The resulting 3D human scan is shown in Figure 1.

A hierarchical skeleton and skin binding weights are then added to the 3D model using the automatic rigging and skinning method proposed by Feng et. al. [21]. The skeletal joints and skin binding weights are transferred from the morphable model to 3D human scans to create skinned virtual characters. The speed of capture and rigging allows for the construction of a controllable, 3D avatar that resembles the capture subject within the time constraints of the study participation.

3.1 Motion Capture and Retargeting

We utilize a commercially available motion capture suit (Noitom Perception Neuron suit) to capture the motions of the subjects. We use the method proposed by Feng et al. [22] to retarget the captured motion to the rigged skeletal mesh.

Our process of creating a photo-realistic virtual avatar of the human subject and capturing the needed walking motions motions was completed in approximately one hour per subject. The skeletal topology between the subjects is identical, differing only in bone length. This allows us to more easily retarget motions captured from other subjects to the avatar being modeled, and thus enable us to study the perception of biological motion, as seen on a virtual avatar.

4 Experimental Evaluation

The following section provides details on two user studies conducted to evaluate the ability to recognize one's own gait as well as that of familiar individuals when presented on a virtual avatar.

4.1 Study I. Recognizing Personal Gaits on Virtual Avatars

In this study, we aim to explore if the subject could recognize their own motions compared to those of others, when presented on their virtual avatar. We seek to answer the following questions: Is motion more recognizable when presented on a virtual avatar as compared to previously used point-light displays? Are some motion types more recognizable than others? Are there motions that are perceptually similar/dissimilar to that of the subject? Answers to these questions may be valuable for applications where the

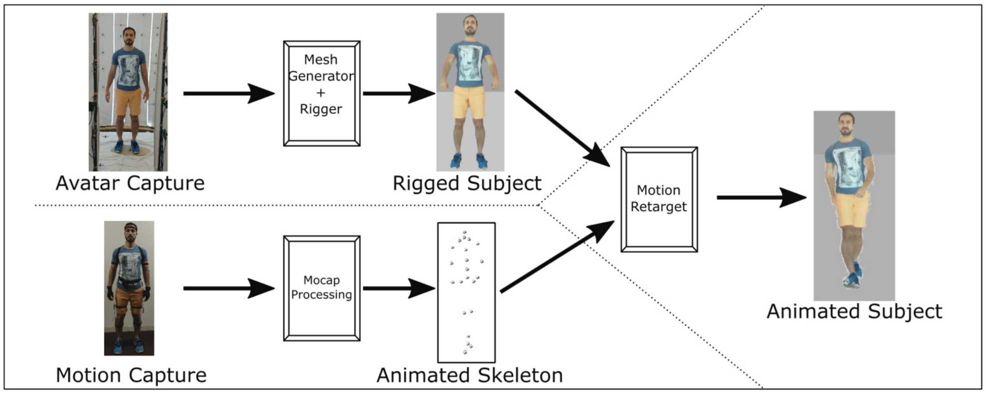

Figure 1: **System overview.** Generation of a 3D avatar using a subject's appearance and motion.

virtual avatar of the subject is used to influence the behaviors of the subject [1].

Participants: 22 participants (11 men, 11 women, average age 27.13 years, std. dev. 6.24) were recruited on a university campus and consisted of students and staff members. Previous studies [11, 9, 23, 19] used similar number of participants i.e. $6 - 12$. Our study was spread across two sessions. The first session required on site participation and lasted about 45 minutes per participant. This was followed by an off-site session which consisted of an on-line questionnaire which lasted about 15 minutes. Participants were paid an equivalent of $15 for participation. Motion capture data for 5 participants was found to be too noisy and discarded from the analysis.

Procedure: Participants were welcomed and were instructed on the overall process and purpose of the study. They signed a consent form and provided demographic information about their gender and age. Participants were then asked to step inside the photogrammetry stage and stand still for 5 seconds. Following the 3D scan as shown in Figure 1, participants were instructed on wearing the motion capture suit. Once the suit was calibrated, they were instructed to perform several motions in an open unobstructed space. These included walking 10m in a straight line, walking in a circle of radius 3m as well as other motions such as turning in place, side stepping etc. Loula et al. [23] found a performance decrement for treadmill-based actions which they attribute to the temporal structure imposed by treadmills on locomotor activities. Given their observations, we chose to have the participants walk on an unobstructed pathway. They were instructed to walk at a "comfortable pace".

We used the captured data to generate the motion for the virtual avatars. The motion captured data was edited to extract a walk cycle with three full gait cycles in case of a straight walk and a full 3m radius circular walk. We then generated a questionnaire which was sent via email to the participants three weeks after the initial data capture. Details of the questionnaire are provided below.

The questionnaire was divided into two blocks. The first block comprised of a sequence of four pairs of motion clips, presented in a 2-Alternative Forced Choice design. Each pair of motion clips compared the motion of the participant with that of another randomly chosen participant of the same gender. The four pairs of motion clips varied in visual representation and motion type (Figure 2), given as:

- Straight walk with point lights
- Straight walk with avatars
- Circle walk with point lights
- Circle walk with avatars

The order of presentation of the motion type as well as the visual representation was counterbalanced across participants. The left and right order of presentation of the motion clips was counter-balanced as well.

Experimental Design:

For each pair of motion clips, the participants were asked to rate the clips using a 7 point Likert scale with values labeled (Left much better, Left Better, Left

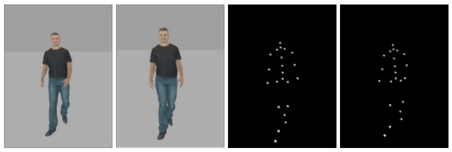

Figure 2: **Visual representations.** Pairwise comparison of motion on 3D avatar (left) and point light (right).

Slightly Better, No Difference, Right Slightly Better, Right Better, Right Much Better). In this response format, a value of one indicates a strong preference for the clip listed on the left of the comparison. The specific questions were:

- Which video shows a better depiction of yourself?
- Which video depicts your gait (walking style)?

The second question focuses the attention of the subject on the depicted gait whereas the first question may be influenced by the subject's acceptance of the visual representation.

The second block also comprised of a series of pairwise comparisons. In contrast to the previous block, motion clips presented in this block were restricted to straight walks with avatar representation. Each pair of motion clips compared the participant's motion against that of another participant of the same gender. Responses gathered in this block are part of ongoing research and are not reported as part of this analysis.

Variables: *Independent:* In this study, there are two independent variables First, the type of motion being evaluated, and second the type of visual representation. *Dependent:* The dependent variable is the participant's response to the questions for each pairwise comparison.

4.2 Study II. Recognizing Gait of Familiar Individuals on Virtual Avatars

In the second study, we aimed to explore whether the subject could recognize the motions of familiar individuals, when presented on those individuals' virtual avatars. Similar to Study I, we sought to determine whether motions are more recognizable when presented on a virtual avatar as compared to previously used point-light displays. We seek to answer questions such as: are some motion types more recognizable than others? Are there motions that are perceptually similar/dissimilar to that of the subject? Answers to these questions may be valuable for the purpose of immersive training. For example, military groups often use VR for training teams and squads. Members of such teams are likely to recognize each others motion in the real world and thus, should be able to do the same in case of virtual avatars in a training simulation. This is evidenced by studies which show that behavioral realism coupled with rendering or appearance realism may lead to greater co-presence [3].

Participants: 22 Participants were recruited on a university campus and consisted of students and staff members. No identifying or demographic information was collected.

Procedure: We used the data gathered for two subjects (1M, 1F) from the study described in Section 4.1. A mass recruitment email was sent to a university department which explicitly stated the names of the subjects. Only participants who certified knowing both subjects were deemed eligible to participate. Participants were directed to an on-line questionnaire which lasted about 15 minutes.

Experimental Design: The questionnaire consisted of two parts: one for subject A and the next for subject B. Each part consisted of two blocks, similar to the ones described in Section 4.1. For example, the first block for actor A consisted of 4 pairs of motion clips comparing subject A's motion with a randomly chosen reference motion of the same gender with varying motion type and visual representation. The order of presentation of the subject as well as the motion type and visual representation was counterbalanced. However, both blocks of the first subject chosen to be presented were shown before beginning the blocks for the other subject. Participants were asked questions similar to those described in Section 4.1, except that they explicitly mentioned the subject's name.

In contrast to Study I, Study II helps to evaluate the perception of biological motion in the context of familiar individuals.

5 Results

In this section, we detail the results of the two user studies and offer some insights into the observed trends.

5.1 Recognizing Personal Gait

As described in section 4.1, this study sought to evaluate the ability of participants to recognize their own motions under varying factors of visual representation and types of motion being shown. We use the participant's responses, given on a 7 point Likert scale, to compute absolute recognition rates, depicted in Figure 4. The overall recognition rate varies between $47.05\% - 82.35\%$, depending on the motion type, visual representation and question asked. There is a significantly higher recognition rate for avatars as compared to point-lights. For example, for the question of depiction in the straight walk motion, recognition rates were found to be 82.35% and 52.94% respectively. Recognition rate was higher for straight walk motion as compared to circle walk motion. Also, both questions i.e. depiction of self and depiction of self gait, yielded similar recognition rates, see Figure 3.

Figure 3: **Walking styles:** Two 3D avatars with differing appearance and gait.

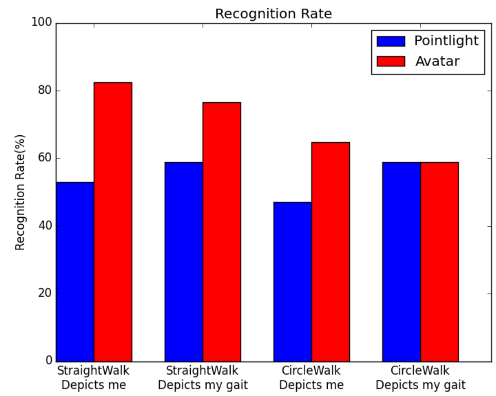

Figure 4: **Self-recognition accuracy.** 3D avatar vs. pointlight representations, as well as straight walks vs. circle walks.

Additional analysis using the frequency of user responses (Figure 5) suggests that users were confident about their responses. Across all conditions, $47.05\% - 58.82\%$ of the responses were two or less i.e. users identified their motion as "Much Better" or "Better". In particular, users were most confident when identifying their motion presented on their avatar for straight-walk motion with 41.176% giving it the highest possible rating, compared to 17.64% for point-light (Figure 5 (a)). Recognition rate is marginally higher for a straight walk as compared to a circle walk, (Figure 4). When responding with respect to their avatars on the self depiction question, straight walk motion yielded a recognition of 82.35% with 58.82% giving it a rating of two or less (Figure 5 (a)), compared to 64.70% and 41.17% for circle walk motion (Figure 5 (c)). There was a negligible difference between the responses for the questions on depiction of self and depiction of self gait for a given visual representation and motion type.

5.2 Recognizing Gait of Familiar Individuals

In this study, we wish to evaluate whether participants can identify the motion of individuals familiar to them, under varying forms of visual representation and motion type.

Recognition rate was lower for Actor 1 (Figure 6 (a)) than Actor 2 (Figure 6 (b)), falling below chance. Recognition rate for Actor 1 was 45.45% for circle walk motion with point-light visuals and 9.09% for straight walk motion with point-light visuals. In contrast recognition rates for Actor 2 were significantly higher, ranging from 22.72% to 63.63% across conditions. Such accuracy for recognition of others motion is consistent with previous studies [9, 11, 23]. Surprisingly, recognition rate was generally higher for point-lights as compared to avatars for the same motion type and question. For example, the combined recognition rate for point-lights is 63.63% compared to 31.81% for avatar representation, in case of straight walk on the question of depicting the actor's gait. Circle walk was found to be more recognizable for both actors as compared to straight walk motion. This was especially true for avatars, where recognition rate for circle walk was 50.0% and 54.54% on the two ques-

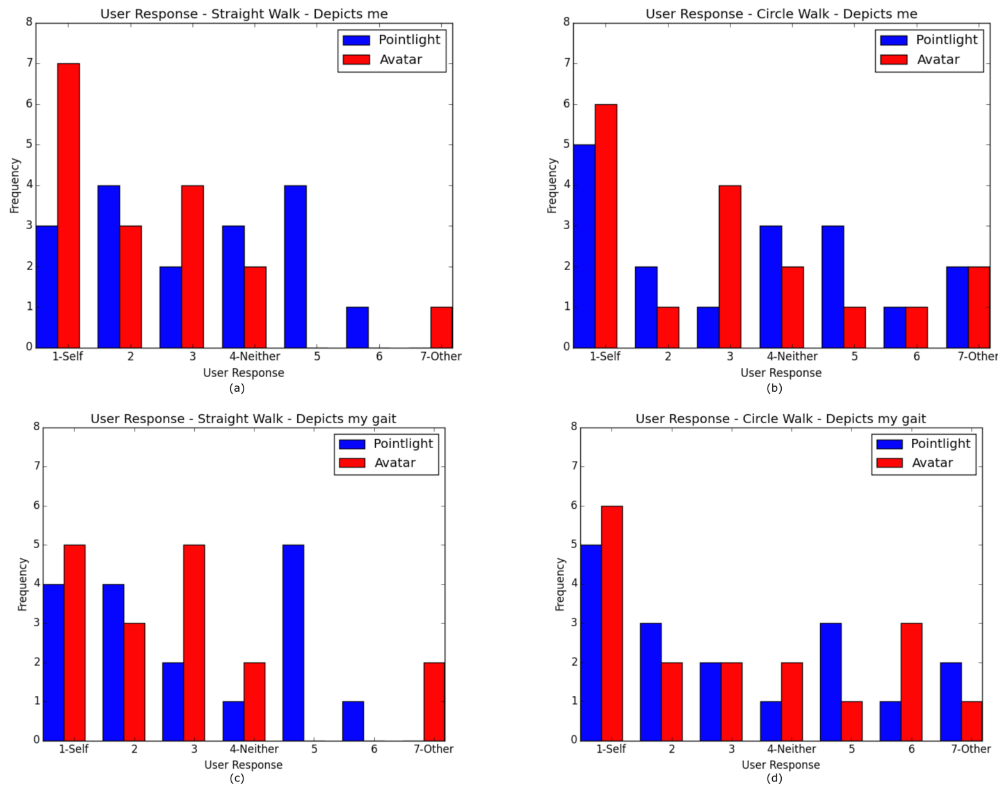

Figure 5: **Frequency of user response for self-recognition.** User responses for the question on depiction of self for (a) straight walk motion and (b) circle walk motion. User response for the question of depiction of ones gait for (c) straight walk motion and (d) circle walk motion. A response of 1 indicates strong preference for self-motion, 7 denotes strong preference for other motion and 4 denotes a preference for neither of the two motions.

tions, compared to 22.72% and 31.81% for straight walk respectively. Also in contrast to the Study I, the question of depicting the actor's gait yielded a higher recognition accuracy than the question of depicting the actor. This is likely due to the significantly high frequency of response 4 on the question of depicting the actor for both scenes, suggesting that "Neither" video depicted the actor. Users responded with a 4 in 47.6% responses on the question of depicting the actor as compared 11.36% on the question of depicting the actor's gait, in case of straight walk across visual representations.

6 Discussion

Our results verify previous studies that have focused on point-light displays for studying perception of biological motion. Recognition accuracy for self-recognition with point-light visuals ranged between 47.05% and 58.82%, depending on the question and the motion type. This range is similar to prior studies conducted by Beardsworth et. al. [9](58.33%), higher than those presented by Cutting et. al. [11](43%), and lower than that of Loula et. al. [23](69%). Their study design varied significantly from ours and thus, a number of factors could explain the discrepancy. One explanation for this may be the number of participants in their study (6) compared to ours (17). As for recognition of others, Cutting et. al. [11], Beardsworth et.

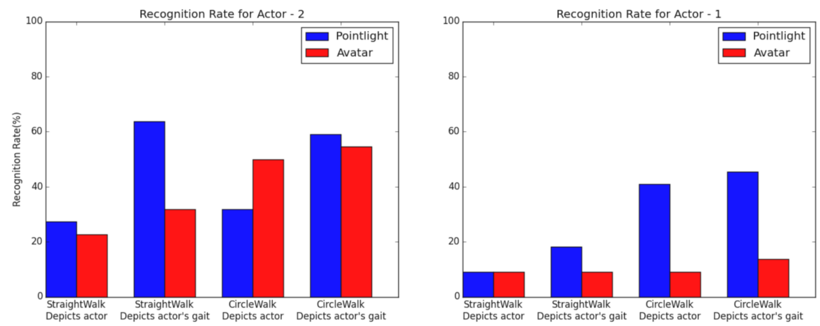

Figure 6: **Recognition of others.** We depict the recognition rates of straight walk and circle motion for Actor 1 (left) and Actor 2 (right), as rated by familiar individuals.

al. [9], and Loula et. al. [23] reported accuracies of 36.0%, 31.6%, and 47% respectively. For Actor 1, recognition rate was significantly lower than these. This can be attributed to the fact that the reference motion in our case was constant for all trials and may be perceptually similar to Actor 1's motion. However for Actor 2, performance was found to be 63.63% for straight walk motion and 59.09% for circle walk motion on the question of depicting the actor's gait with point-light representation.

The perception of walking motion rendered on a photo-realistic 3D virtual avatar of the subject has not been previously studied. In case of self-recognition, we found that recognition performance was higher in case of avatars as compared to point-light visuals, by as much as 29.41% in one case. Furthermore, users had greater confidence in their responses in case of avatars than with point-light visuals (Figure 5).

In contrast, point-light visuals yielded a higher recognition accuracy than avatars in case of recognition of others. This is somewhat surprising. One explanation could be the "Uncanny Valley" effect. McDonnell et. al. [7] show that animation artifacts were more acceptable on cartoons than on realistic, human-like characters. Participants in Study II were unaware of the avatar generation and motion capture process and may have been more critical of artifacts in judging others than participants in Study I. The significantly high number of "Neither"(4) responses in Study II supports this conclusion. The effect is also significantly more pronounced in straight walk motion than circle walk motion which warrants further investigation.

Previous studies have shown that some motions such as dancing are more distinguishable than others such as locomotion. In the context of locomotion, most previous work is restricted to straight walk motion. From an animation perspective, state of the art methods such as motion graphs require multiple motions. Thus, we sought to evaluate differences between straight walk and circle walk motion. We found that in case of self-recognition, straight walk motion has superior recognition accuracy than circle walk motion. However, when recognizing others, circle walk has superior recognition performance. This may be explained by results from Jokisch et al. [10] which established that recognition of others is viewpoint-dependent while self-recognition is viewpoint independent. In future work, we would like to explicitly investigate the effect of viewpoint on the recognition of motion rendered on virtual avatars.

7 Conclusions & Limitations

We evaluated the recognition of motion of self and others, rendered on photo-realistic 3D virtual avatars. Our results indicate a overall high recognition rate for self-recognition. Particularly, we found that virtual avatars yielded better recognition performance than previously used point-light representations. In case of recognition of others, we found that recognition accuracy was low but consistent with previous studies. Surprisingly, point-lights yielded better performance than avatars. Additionally, recognition accuracy was considerably different for the two types of motion in this case, but the same was not true for self-recognition. Overall, our results provide key insights into the perception of motion in the context of virtual avatars.

Our approach has some limitations. The motion data that represents a subject's walking style is degraded by the systems that were used in the study. Inaccuracies can be introduced due to the automatic rigging process and the retargeting algorithm. In addition, we used a IMU-based motion capture suit which is prone to noise. In the future, we would like to use a more accurate marker-based optical capture system. Our framework can be used to investigate several interesting questions. In particular, we would like to further explore the dependence of motion recognition on a diverse set of motions. We would like to study the ability of users to recognize their motion or the motion of others on different virtual avatars, in a similar setup to [19]. Furthermore, it would be beneficial to investigate the view point dependency of motion recognition on virtual avatars.

Acknowledgements

This work was supported by Institute for Information & communications Technology Promotion (IITP) grant (No. R0184-15-1030, MR AvatarWorld Service and Platform Development using Structured Light Sensor) funded by the Korea government (MSIP), National Science Foundation award 1305286 and ARO contract W911NF-16-1-0085.

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