The Action Consistency of Casting in Virtual Environment*

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***Abstract*—Interactive techniques in Virtual Reality (VR) is rapidly developing in the recent years. However, the consistency of the interaction activities in VR and real-world remains a subject to be further studied. In this work, we study the consistency of casting action between VR and real-world. In our experiments, we let participants cast a ball to a walking human virtual agent, which is driven by a motion capture system in the virtual environment. By comparing to the casting accuracy in real-world, we found that the participants' performance under various of the experimental configurations is consistently reduced in VR. We also found that the moving 'speed' factor of the casting target barely affected the accuracy in VR, which was different in the real-world environment. This study will provide an important experimental reference to develop future VR systems based on casting actions.**

***Index Terms*—computing methodologies, computer graphics, graphics systems and interfaces, virtual reality, human-centered computing, human computer interaction (HCI), interaction paradigms**

I. INTRODUCTION

Due to the recent advancement of the VR technologies, VR systems are growing popularly applied in various of domains such as the psychological studies, skill training, etc. VR systems are important because they can provide immersive environments. Moreover, the motion capturing technologies allow to capture real human motions to drive the virtual agents with real-time accurate tracking and measurement of human movements, which can be further fed back to the display and control system. This allows VR users to observe virtual agents performing real actions in virtual environments.

Although VR users can visually experience immersive environments, there exists insufficient study about the action consistency of VR users in virtul and real-world environment. Hence, it becomes important to explore if VR users can perform actions equally in virtual environment as in the real scenarios. Particularly in this paper, we investigate the consistency of casting in real and virtual environments. In specific, we first develop a VR system with a motion capture data driven walking virtual target. Then, we design an evaluation experiment and recruit participants to perform casting actions both in our VR system and in real-world scenarios. Such studies can provide important information for the understanding human actions and faithfully simulating in the VR system developments.

The contributions of this paper can be summarized as follows:

- In our experiments, we have applied the motion captured data to drive the virtual agents, so that participant can cast objects to the virtual human target with real movements.
- We have studied the action consistency of casting in virtual and real environments, and obtained important observations of the casting action in VR.

The remaining of the paper is organized as follows. We first review the studies of visual perception and interactive activities in virtual environment in Section II. Then, we introduce the procedure, design, device and environment of our experiments in Section III. After presenting the experimental results in Section IV and discussions in Section V, we finally conclude the work in Section VI.

II. RELATED WORKS

A. Visual Perceptions in Virtual Environments

Same to real-world scenes, the visual information is also an important cue in virtual environments. In [1], Thompson et al. introduced the technical aspects in computer graphics domain that are related to the visual perception, including material properties, illumination, spatial cognition, etc. Loomis

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Fig. 1. Experimental settings for the action consistency evaluation of casting in real (left) and virtual (right) environments. Our walking casting target in Virtual Reality (VR) environment is driven by using motion captured data, which ensures the 'reality' of the movements in the virtual environment.

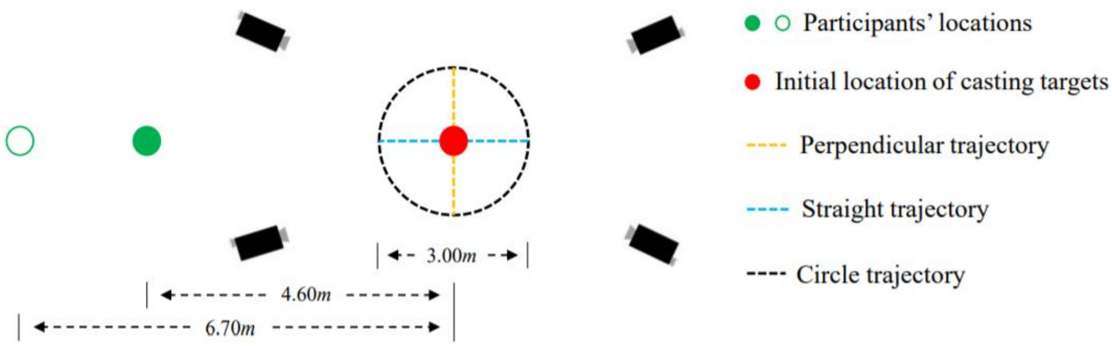

Fig. 2. The design of the casting experimental. The green circles indicates the participants' casting locations, with distance of $4.6m$ and $6.7m$, respectively. The red circle is the initial location of target in our motion capture system. The three dashed lines correspond to the three walking trajectories of targets, i.e., perpendicular, straight and circle.

and Joshua studied the egocentric distance perception in VR [2], in which they revealed the incongruence caused by a biasing of estimates of perceived distance and the distances to targets in full cue VR environments were underestimated. The experimental results in [3] showed that visual information becomes calibrated to mechanical aspects for gait transitions and contributed to the control of locomotor behavior. In [4], Ward et al. conducted a set of perceptual simulation experiments in the present/absence of another person, the results suggested that visual perspective taking reflected a spatial-navigational ability, i.e., the spatial location of another person instead of their gaze. In [5], based on an interactive throwing-catching task, i.e., participants catching a ball thrown by a virtual character, Antonella et al. studied human predictive power which is key to optimize interpersonal interactions. In [6], Cynthia et al. studied the difference between throwing and walking for distance perception in both real and virtual environments. The results showed walking was significantly underestimated in VR. In [7], Alexander et al. studied a novel user authentication approach in VR via personal behaviors while performing specific tasks such as picking/throwing.

Many research works in neuro-science and psychological domain have been conducted to study the visual perceptions in virtual environments. In [8], Gonzalez and Jaron proposed a neuroscientific model to explain the underlying perceptual and cognitive mechanisms of the illusions in VR, i.e., users might feel altered situations and identities and respond "realistically". Slater experimentally explained that both Place Illusion and Plausibility Illusion can facilitate the realistic behaviour in VR, because: 1) Place Illusion is constrained by the sensor contingencies provided in VR; 2) Plausibility Illusion determined by VR system can produce events that directly relate to users. To obtain a deeper understanding of the sense of agency in VR contexts, in [9], Jeunet et al. introduced a theory based on the feeling and the judgement of agency based on the principles of priority, exclusivity and consistency. Based on the recorded participants' EEG signals in the sense of agency experiments in VR, the results suggested users' locus of control can influence both their level of immersion and sense of agency. Similarly in [10], Kilteni et al. investigated the sense of embodiment in VR with three subcomponents: the sense of self-location, the sense of agency, and the sense of body ownership. While VR has been a promising tool for psychological studies and training applications, in [11], Harris demonstrated the limitations of VR with dorsal and ventral controls, due to fewer cues to depth and the limited haptic feedback.

B. Interactive Activities in Virtual Environments

The usages of the interactive technologies in virtual environments is one of the key important advantages of VR applications. A large amount of works have been studying the interactive behaviors in virtual environments. In [12], [13], Bonsch et al. presented an algorithm for an agent's behavior during social locomotion among several virtual agents to model the user-agent dynamics and the inter-agent dynamics. Bonsch et al. studied the relations between personal space and virtual agents' emotions in [14]. The results suggested that angry agents had larger distance and single agents were allowed closer. Camporesi et al. proposed an interactive virtual human modeling technique in [15], which was based on an parameterized model driven by real-time motion capture data with the inverse blending optimization technique. In [16], Narang et al. presented an interactive algorithm with high-dimensional human motion constraints and bio-mechanical constraints to generate collision-free interaction movements among human agents in a VR. In [17], Dong et al. developed a multiuser walking VR system that allowed physical interactions, which incoporated with the automatic collision avoidance techniques [18] to avoid overlaps of the virtual scenes. In [19], Krum et al. examined and showed that locomotion techniques for interpersonal space in VR can significantly affect the proxemic behavior. In [20], Sanz et al. learned that the walking speed was decreased and the clearance distance was increased when walking with obstacles in large immersive projection environments by comparing to real scenes. In [21], Lee et al. investigate the potential improvement on the proxemics interaction with virtual humans in augmented reality with the unaugmented periphery and vibrotactile feedback. Lafortune et al. presented a dance training VR system in [22], in which the results showed that the virtual instruction did not require immersion to be effective.

Researchers in neuroscience are also exploring human neural processes in virtual environment. By studying the participants in a virtual ball-tossing game, David et al. learned that the perspective taking and agency represented independent constituents of self-consciousness. Fan et al. presented in [23] a volleyball cast training VR system, which was equipped with various of advanced sensors including virtual reality helmet, motion bracelet, statistics and processing system, sound system, etc. In [24], olade et al. Proposed that biometric user recognition method for human movement in virtual reality systems. By collecting the data show that these data can be used as a biometric discriminant of high confidence using machine learning classification methods such as kNN or SVM, thereby adding a layer of security in terms of identification or dynamically adapting the VR environment to the users' preferences.In [25], Hai-Ning et al. The effects of collaboration and competition on navigation tasks and spatial knowledge acquisition in virtual reality environments were evaluated. The results show different patterns of user behavior for the two paired groups and single users. In addition, they indicate gender differences in behavior and performance.In [26], Xu Wenge et al.This study aimed to evaluate the difference between playing a full-body gesture-based iVR standing exergame and seated exergame in terms of gameplay performance, intrinsic motivation, and motion sickness. The results show seated exergames have the potential to lead to higher exertion, provide higher value to players, and be more applicable in small spaces compared with standing exergames. However, gestures for seated exergames need to be designed carefully to minimize motion sickness, and more time should be given to users to perform gestures in seated exergames compared with standing exergames.

III. THE CASTING EXPERIMENTS

In this section, we describe the experimental configurations to evaluate the consistency level of casting in VR and real world. In specific, we have conducted two sets of experiments, which allowed a participant to cast at a motion captured driven agent in VR and an actor in real world, respectively. Note that the collision between the cast object and the target is considered a success. Furthermore, the participants were casting at different distance, with the targets behaved different walking motions.

A. Participants

We recruited 12 participants in total, including 8 males and 4 females. The ages of 6 participants were distributed between 26 to 35; 4 participants were under 25 years old and the other 2 were between 36 to 45. All the participants were professors and students at university, majored in either the computer science and technology domain or the digital media domain. Based on the questionnaires, 3 were playing basketball regularly, 4 were playing basketball occasionally and 5 barely played basketball. 10 participants were right-handed, 2 were left-handed; 8 participants were right-footed, 4 were equal-footed; 4 participants were right-eyed, 8 were equal-eyed;

8 participants wore glasses, including 3 participants wore contact lenses during the experiment. No participant reported red-green color weakness. All participants reported previous experience with VR, but only 4 among them experienced for more than 1 hours.

Fig. 3. The real casting target (left) and the corresponding motion captured data driven virtual target (right).

B. Procedure

Participants were instructed to cast a soft object at a specific target based on their natural efforts and skills. In order to provide a comfortable environment to perform the casting action, we set the background scene as a basketball field and the cast object as a basketball with the diameter of $16cm$ in VR [27]. As the participants cannot feel the weight of the virtual basketball, in the real world scenario, the cast object is a soft and light toy basketball of $0.195kilograms$ with $16cm$

in diameter, so that participants can easily pick it up with one hand. Specifically in VR, we set the initial position of the virtual agent in the center of the field for the following reasons: 1) There will be no obstacles to the participant; 2) The agent can be easily identified out from the background scene; 3) The agent will not exceed the virtual field while walking.

Regarding to the targets for casting at, as shown in Figure 3, we use a motion captured driven agent in VR and an actor in the real-world scene, respectively. In our experiment, we enrolled an average man (1.78m height, 0.47m shoulder width, 0.3m depth) for the real world target. In VR, we take the *Space Robot Kyle* agent and set the same size to the actor in real world scenario.

In order to focus the participants on the tasks, after warming up training with instructions, experimenters were not allowed to communicate with the participants during the experiments. Moreover, to avoid of posing unnecessary stress to participants, participants were told about the target and then simply casting all the basketball on sheves in VR. While casting the balls, participants were asked to cast toward the target. To perform the casting in VR (the visualization of the virtual basketball is directly below the trigger) , the participant needed to pull the trigger on handle at the moment of dropping the basketball. In the meantime, we acquired the handle's velocity and assigned to the basketball, which corresponded to the participant's casting velocity.

Furthermore, participants could break at any time to re- lax. In practice, participants could have a short break while randomize the experimental configurations, i.e., the casting distance and the target's walking types. Additionally, to avoid instinctual responses for being hit, the motion captured driven target agent in VR and the target actor in real world were strictly not allowed to have eye contact with neither the participants and the casting basketball.

C. Apparatus

Our virtual experiment was conducted in a standard basketball field of 28m×15m; The real world casting experiment was conducted in the motion capturing room, in which we captured the motions with Qualysis motion capture system [28] to drive the target agent in VR. This ensures the similar walking behaviors for the targets both in captured motion in VR and in the real world.

To drive the virtual agent *Space Robot Kyle* , we capture the motions of the human target by using the mocap system from Qualisys based on 12 cameras of 225Hz. Moreover, the participants are equipped with HTC VIVE headset and handles for the virtual casting experiments.

D. Design

In this work, we apply the Multi-Factor Analysis of Variance (MFAV) approach to reveal the consistency of casting in VR. In our experiments, we analyze the following factors: the two environments including VR and real world scenario; target's walking 'trajectories' including statics, horizontal, vertical and circle; target's walking 'speed' of being either constant or random; participants' initial 'distance' to the target. Note that a static target is not be affected by the 'speed' factor. Thus, with all the possible combinations of the factors, we conducted 14 sets of experiments for each participant. Note that our experiments were based on the within-subjects design, and the ordering of trials performed by each subject were randomized. For each combination of the factors, one participant repeat the casting for 10 times. Therefore, each participant conducted 280 times of the casting action including both VR and real world scenarios. For each casting of each participant, we had recorded the order and result of the casting, i.e., on or off the target.

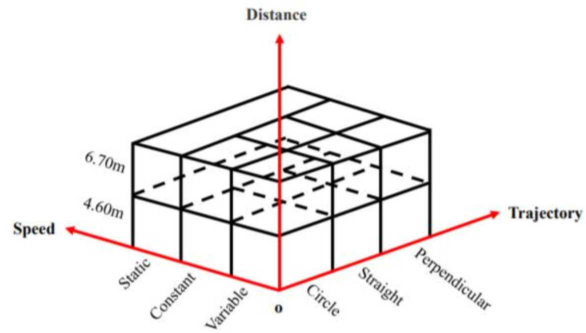

Fig. 4. Combinations of the factors. Note that the 'static' targets did not move and thus were not affected by the walking 'trajectory' factor.

Furthermore, we collected the demographic information before the experiments in VR to measure the background knowledge of participants with questionnaires. The total time for the pre-questionnaires, instructions, training, breaks and debriefing were limited within one hour. Among them, the casting in VR experiments took approximately 25 minutes, and the casting in real world took about 18 minutes.

IV. RESULTS

We have conducted the statistical analysis of the experimental results and using the Kolmogorov-Smirnov test to compute the normality. In this section, we evaluate the significance of casting accuracy with multiple factors, including environments (2: virtual or real), target walking trajectory (3: perpendicular, straight, circle) and speed (3: static, constant, random), distance (2: 4.6m and 6.7m, i.e., penalty line and 3-point line in the basketball field, respectively), etc. Additionally, we conduct the multi-factor variance analysis with the collected data.

We have recruited 12 participants to perform the casting both in virtual and real environments, with all sets of factor combinations shown in Figure 4. The statistical analysis results of each factor is shown in Figure 5.

Casting Distance.

- With the distance of 4.6m, the averaged casting accuracy is 51.9% in VR, and 68.2% in real-world scenario which is 31.4% higher than in VR.

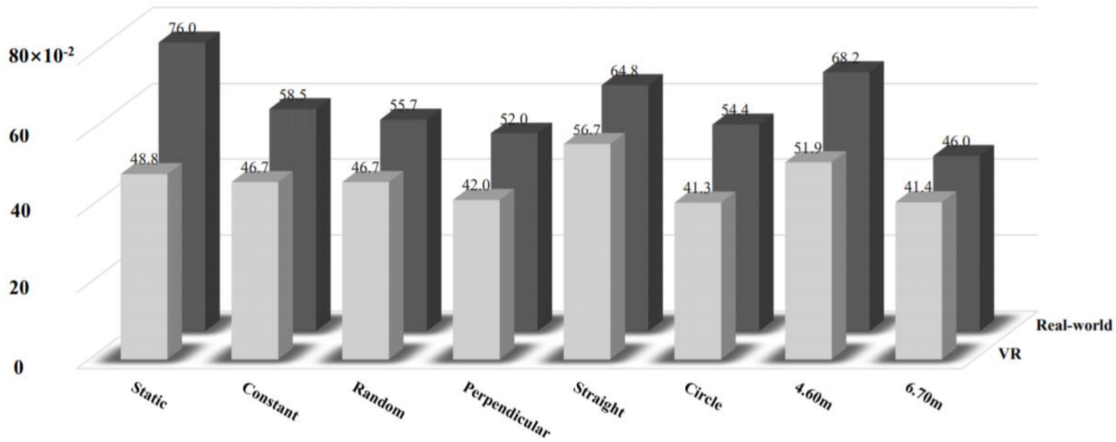

Fig. 5. The overall casting accuracy by different factors in both real and virtual environments.

- With the distance of $6.7m$, the averaged casting accuracy is 41.4% in VR, and 46.0% in real-world scenario which is 11.1% higher than in VR.

Thus, on the one hand, the action is consistent in VR and real-world that the accuracy is reduced with larger distance; On the other hand, the gap between VR and real scene is significantly less with larger distance. These observations can be independent from the walking 'trajectory' factor based on Figure 6(Middle). Moreover, the significance factor is $P < 0.01$ in VR and is $P < 0.001$ in real-world, which means the 'distance' factor is more dominating in the real-world environment.

Walking Speed. In our experiments, the walking targets can stay 'static', and walking with 'constant' or 'random' speeds.

- With the 'static' target, the averaged casting accuracy is 48.8% in VR, and 76.0% in real-world scenario which is 55.7% higher than in VR.
- With the walking target with 'constant' speed, the averaged casting accuracy is 46.7% in VR, and 58.5% in real-world scenario which is 25.3% higher than in VR.
- With the walking target with 'random' speed, the averaged casting accuracy is 46.7% in VR, and 55.7% in real-world scenario which is 19.3% higher than in VR.

As can be seen in the left 3 pairs of bins in Figure 5, in the real environment, the casting accuracy is reduced with the walking targets, and is further reduced if the target moved with a random speed. However, in the virtual environment, the casting accuracy is barely changed disregarding to the walking speed of the targets. In fact, we obtain this observation because the significance factor is $P > 0.05$ in VR and is $P < 0.001$ in real-world, which means the 'walking speed' factor is dominating in the real-world environment but is not affecting in VR.

Furthermore, the gap between VR and real scene is significantly less with larger distance. These observations can be further confirmed with the data in Figure 6(top-left) and Figure 6(top-right), that the differences between 'constant' and 'random' are rather small with different walking trajectories (Figure 6(top-left)) and distance (Figure 6(top-right)). Based on these observations, we believe the casting performance of participants in VR are relying on their skills with the VR equipment, rather than their original skills and knowledge of basketball in real-world.

Walking Trajectory. In our experiments, the walking target can move in the 'straight', 'perpendicular' and 'circle' trajectories.

- While the target walking in 'straight' trajectory, the averaged casting accuracy is 56.7% in VR, and 64.8% in real-world scenario which is 14.3% higher than in VR.
- While the target walking in 'perpendicular' trajectory, the averaged casting accuracy is 42.0% in VR, and 52.0% in real-world scenario which is 23.8% higher than in VR.
- While the target walking in 'circle' trajectory, the averaged casting accuracy is 41.3% in VR, and 54.4% in real-world scenario which is 31.7% higher than in VR.

First, while the target walking 'straight' as forth-and-back, the vision of the targets is relatively static. With the above observations, the results again confirm that the casting accuracy is higher with 'static' targets than moving targets, which is consistent in VR and real-world.

Moreover, the significance factor is $P < 0.001$ in VR and is $P < 0.005$ in real-world, which means the 'speed' factor is more dominating in the virtual environment.

Environments. Finally, the overall averaged casting accuracy is 47.0% in VR and 59.8% in real-world scenario, with the significance factor $P < 0.001$. The performance of the participants is significantly 27.2% higher in real than in virtual environment.

Stability

Figure 7 shows the standard deviations of all the participants' casting accuracy with different factor combinations. As can be seen, participants' performance is more stable with 'random' walking speed in 'circle' trajectory at $6.7m$ distance,

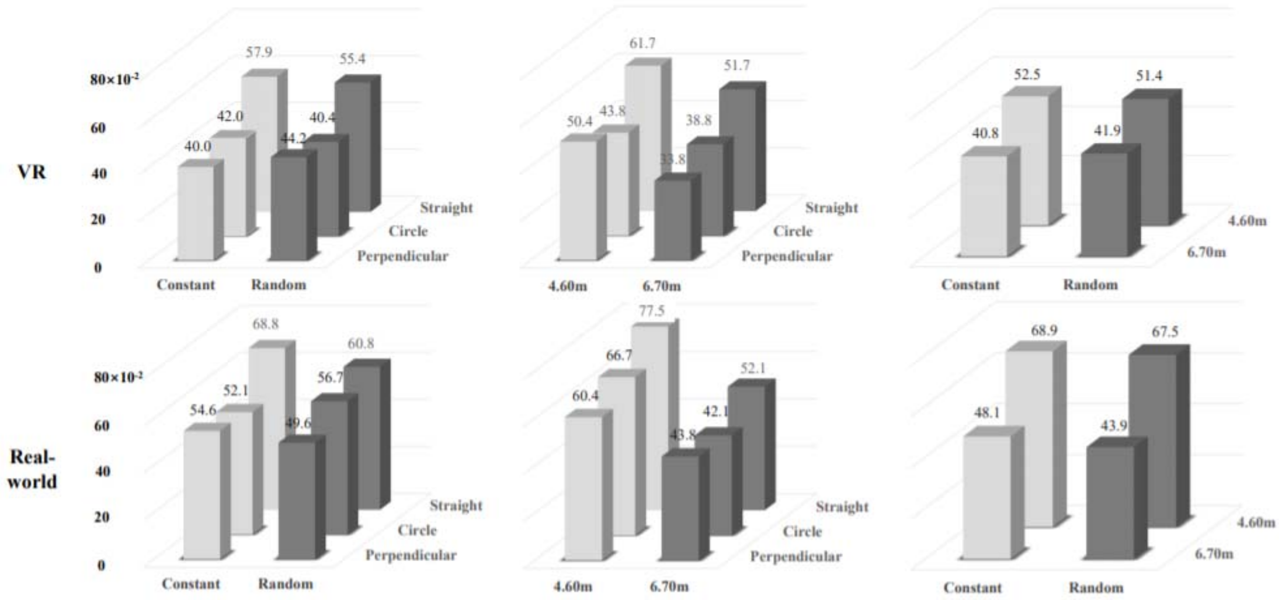

Fig. 6. The casting accuracy by factor pairs in both virtual (top) and real (bottom) environments: Left: 'speed' and 'trajectory'; Middle: 'distance' and 'trajectory'; Right: 'speed' and 'distance'.

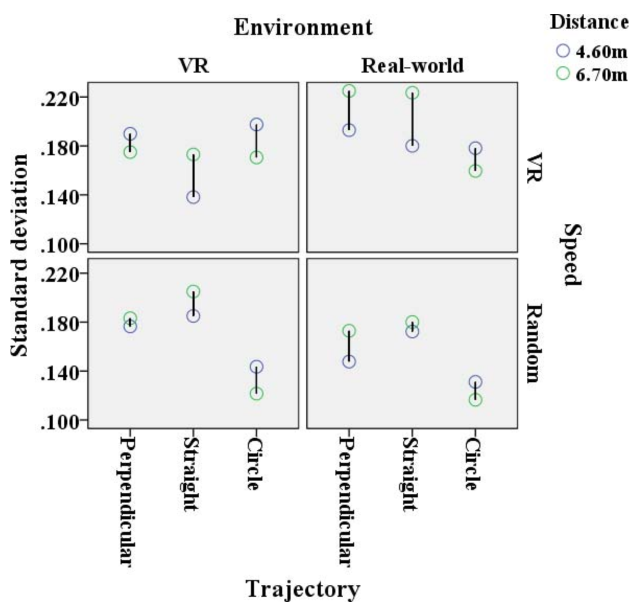

Fig. 7. The standard deviations of the casting accuracy with different factor combinations.

in both virtual and real environments. On the contrary, the performance is least stable with 'constant' walking speed in 'circle' trajectory at 4.6m distance in VR, and is least stable with 'constant' walking speed in 'perpendicular' trajectory at 6.7m distance in real-world.

V. DISCUSSION

In this section, we further discuss on the experimental data by investigating the participants' statistical attributes.

First, among the 12 participants, 3 were playing basketball frequently, 4 played basketball occasionally, and the other 5 barely played basketball. Based on the statistical data in Figure 8(1), the averaged casting accuracy is correlated with the participants' knowledge level of basketball, in both virtual and real environments.

Figure 8(2) shows the averaged casting accuracy for the participants at different ages, which indicates age (between 20 to 45) is not a significant factor to determine the casting accuracy. Furthermore, Figure 8(3) shows the averaged accuracy for the participants with different heights. As can be seen, the casting accuracy is correlated to the participants heights. In fact, this is not because the taller participants are born to be basketball player, but because the taller participants are more likely to be fond of the basketball games. In our statistics, all the 3 frequent-basketball-playing participants are taller than 170cm.

We were also aware 25% of the participants experienced the uncomfortable symptoms in the virtual environment. Based on the statistical data shown in Figure 8(4), the difference of the averaged casting accuracy for the participants with/without un-comfortable symptoms in VR is 8.1%, and this difference in real world is 3.2%. Therefore, although we allowed breaks during VR experiments, the un-comfortable symptoms by VR equipment still caused larger decreasing of accuracy in the virtual environment.

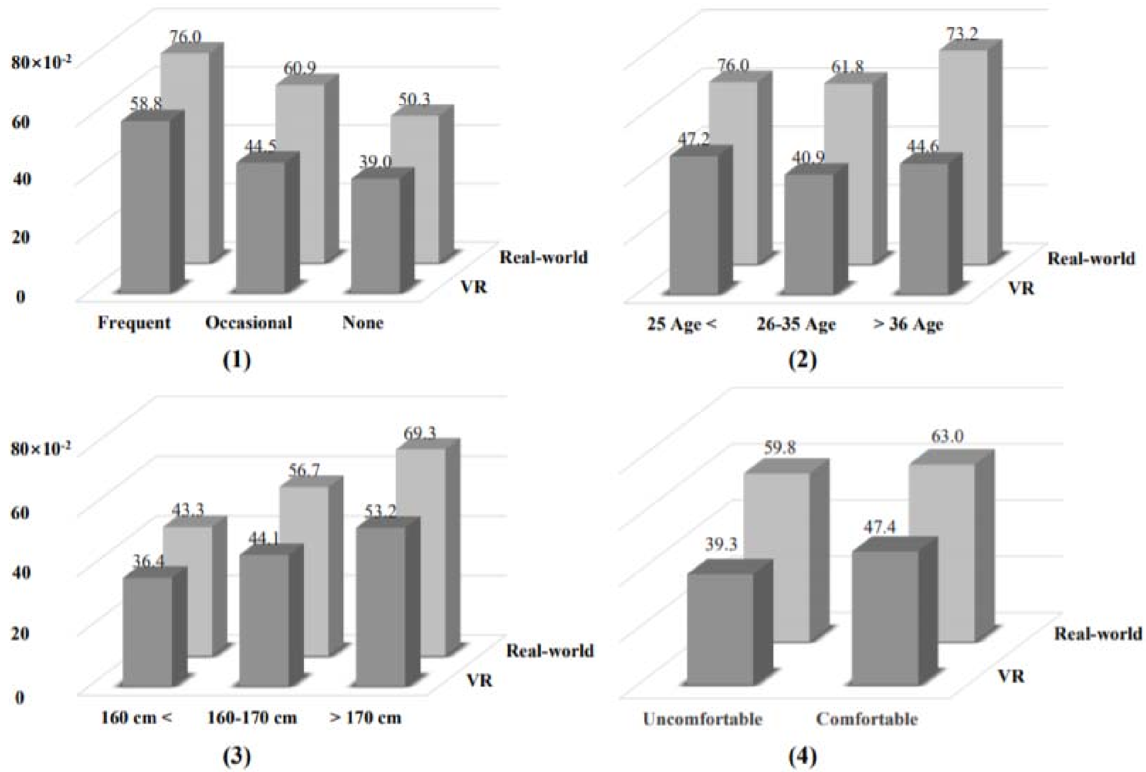

Fig. 8. Observations based on the participants' attributes. (1) The frequency that participants played basketball, and their casting accuracy. (2) The averaged casting accuracy for the participants at different ages. (3) The averaged casting accuracy for the participants with different heights. (4) The averaged casting accuracy for the participants with/without uncomfortable symptoms.

VI. CONCLUSION AND FUTURE WORK

In this paper, we have investigated the consistency of casting action in virtual environment with referring to the real-world scenes. It worth to mention that the casting target is a walking virtual agent with real motions, which is driven by the advanced motion capture data. This allows us to focus on evaluating the action consistency of casting in real and virtual environments. Based on our experiments, we have obtained important observations that the casting accuracy in VR is consistently reduced by comparing in real-world. More importantly, we have conducted the significance tests for the factors including the target 'distance', walking 'speed' and 'trajectory. We obtained many important findings, such as that the walking 'speed' factor barely affected the casting performance in VR, the average casting accuracy in real-world scenario was significantly higher than that in VR, etc. These observations will provide an important reference for the future studies of actions in virtual environments, and the future VR system developments that are related to the casting actions.

While working on the experiments and observing the results during this work, we are also aware of the related topics that worth to be further studied in the future. For example, given the facts that our casting targets are human and the casting object is a basketball, we plan to equip the target human with a VR helmet and joysticks. In this way, the casting target human can interact with the casting participants by trying to catch the casting objects. Therefore, we can study the consistency of the interactive actions in virtual environments.

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