Evaluation of Visual Perception Manipulation in Virtual Reality Training Environments to Improve Golf Performance

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ABSTRACT

In the real world, prior research in the field of perception and action has shown that individuals visually perceive objects differently based on their actual performance of an action on those objects, especially for sporting activities. For example, a golfer who performs well on putting a ball into the hole, will perceive that ball as larger (easier to hit) and the hole as larger (easier to put the ball in). We asked the following research question, can manipulation of visual perception of objects influence actual performance in the real world? Virtual objects are easily manipulated in Virtual Reality environments, therefore we investigated the use of Virtual Reality training where the properties of objects, such as size, were manipulated to influence perception on a golf putting task. In this paper, we present the results of our experimental user study. Putting performance increased after virtual reality training exposure when virtual objects were larger (perceived as easier to hit) and decreased when virtual objects were smaller (more difficult to hit). Our research has the potential to broaden the study of how virtual reality training can be used to improve sports training in a unique way.

Keywords: Virtual Reality training, perception and action, visual manipulation, virtual environments, sports training, change in size of virtual objects, sports performance, golf task.

Index Terms: CCS [Human-centered Computing]: Human-computer interaction (HCI)- Interaction paradigms- Virtual Reality; [Human-centered Computing]: CCS Human-computer interaction (HCI)- Empirical studies in HCI; CCS [Software and its engineering]: Software Organization and properties- Virtual worlds software- Virtual worlds training simulation.

1 INTRODUCTION AND MOTIVATION

Virtual Reality (VR) has been shown to be valuable for training as it can be less costly and incorporate more variations of scenarios. However, there is still a lot unknown in how we can use virtual reality for training, especially for sports performance. In this research, we seek to study a novel design of virtual reality training for active sports based on perception and action research, instead of muscular, memory, or other type training. Previous research on perception and action has shown that after a human performs a physical action on an object, their perception of the object involved changes based on their performance [1-5]. One perceptual change is that the size of that object is perceived differently by that human based on whether he/she performed well or poorly on that action with the object [3-5]. The research showed that if an individual is performing well, the target object for the action is perceived as bigger (or easier to hit) and an obstacle as smaller (or easier to avoid). If an individual is performing poorly, the target object for the action is perceived as smaller (or more difficult to hit) and an obstacle as larger (or more difficult to avoid). For example, a field goal kicker will perceive the ball as larger with better performance [3]. A softball player, who hits a ball well, then perceives the ball as bigger and easier to hit than one who hits a ball poorly [4]. A golf player, who putts the ball into hole more times and is closer to the hole, perceives the ball as larger (easier to hit) and/or the hole bigger (easier to aim and putt the ball in) than a golfer who misses the hole more frequently [5].

This perception and action phenomenon discussed from [1-5] has only been shown to be present in the real world after performing an action. In this study, we investigated the use of VR technology to determine if the inverse effect is true for the use of VR training. Our research question was that since perception can change based on an athlete's performance [1-5], then could manipulating perception (or visual properties that influence perception) influence performance? It is known that in Virtual Environments (VEs), visual representations more easily manipulated (than in the real world) to potentially change how a user might perceive objects during a task.

In this paper, we present the results of an experimental study that investigated how virtual objects, where a user performs an action, can be visually changed in a VE to influence performance in the real world. In the study, participants completed a golf putting task, similar to [5], in the real world twice: pre- and post- perception and action training exposure. Four training exposure conditions were manipulated between subjects: a) same object size in real-world, b) same object size in a VE, c) larger object size in a VE, and d) smaller object size in a VE. In the cases where we manipulated virtual objects to influence perception, the between-subjects conditions were the change in size of the ball and the change in size of the hole. These conditions were used because it was similar to the results on size of object in [5]. Our hypothesis was that virtual objects presented in the training exposure condition as larger or smaller than the real-world object, would then influence task performance post-training exposure. We hypothesized:

H1: *If the visual properties of the objects in VR are manipulated to perceive an easier task, then the performance would improve.*

H2: *If the visual properties of the objects in VR are manipulated to perceive a more difficult task, then the performance would decline.*

Our results showed that performance in the real world increased from pre- to post-virtual exposure when the virtual objects were perceived as easier to perform the action and virtual performance was high. Our results also showed the reverse was true, that performance in the real world decreased when virtual objects were perceived as harder to perform the action and virtual performance was low. Implications for virtual environment and interaction design could affect individual's performance either positively or negatively post virtual reality experience. Our contribution can be used to design virtual environments for training for real world performance, especially where training may be difficult to perform a full action and visual elements can be used more strategically.

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2 Related Work

2.1 Virtual Reality for Sports

VR technology has been used to train and study certain sports in the past years. A study investigated training for Basketball (Covaci, Olivier, & Multon, 2015) [4], Handball goalkeeping (Bideau et al 2009)[5], Rugby union (Brook, Croft, & Mann, 2010) [6], skiing (Solina et al., 2008) [7], and pistol shooting (Argelaguet Sanz et al., 2015) [8] were performed. As an example of success stories, the handball VR system for goalkeepers was adopted by a national handball federation. It is being used for training young national-squad members and for talent identification. A Head-mounted display based system was created to help train the speed skaters for the 2002 Winter Olympic Games [9]. The environment of the competition was created. It allowed the athletes to navigate within the scene of the event and get used to the surroundings. The scene was developed as close to the actual room as possible and the athletes spend a considerable amount of time in getting used to it. They found that the athletes had positive experiences with the system. However, no experiment in a controlled environment was performed to validate the results. VR technology has been used to assist a golfer in relaxation techniques [10]. Biofeedback training was provided to a college athlete using a Golf simulator. This was done over a period of 10 weeks and psychometric tests and physiological measurements were recorded. The results demonstrated that the athlete had improved anxiety control after using the training system.

VR technology has been used to analyze sports performance, how perception influences choices about which action to perform, and how those choices influence subsequent perception [11]. They investigate which perceptual information is important by asking players to predict what will happen in certain scenarios—for instance, where the ball will go when the end of the ball's trajectory is cut off. For the Rugby experiment, they tested 8 novice and 8 expert level players. The total number of correct answers for the deceptive movement was significantly greater for the experts than the novices. This gives us a cue in the perception and performance cycle. The athletes that had a higher skill level, had a better perception of the deceptive movements by the opposing athlete. Current knowledge and understanding suggest, that VR currently has the greatest potential for discrete skill development and perceiving/decision-making applications.

However, there are several barriers that continue to exist. For example, in training for field games such as football or soccer, the real-world area of play is huge compared to the area in which a VR game would be played. A track event might include an area of 25 meters, where as a room in which the VR setup has been done could be a mere 20 sq ft space. To study the effect of perception and action, Gibson advocated that 'the laboratory must be like life' [12]. It means that to accurately study the effects of training on the perception and the action, the training ground must closely resemble the real-life environment where the task will be carried out. Researchers also studied if expert rugby players are able to detect deceptive movements compared to novice players [13]. However, they were not able to show what information was used by the expert players to inform their judgments. Criag, 2013 [4] studied the use of VR for understanding the perception and action in sport. Based on that research, it was demonstrated that VR technology can be used to better understand the role of VR for action perception. The researchers allowed the players to act on the information in a Virtual environment. The players were able to move as if to intercept the opposing action. VR was used to study feasibility and usefulness of using VR for sport psychology training. Because of the challenges with training for sports in VR, there has been very limited research about effects of training in VR on a human's performance.

2.2 Perception of Performance

When a human performs any task in the real world, a number of factors affect the performance. It can be time, space, resources or even the ability of the human to perform the task. The action-specific account suggests that successful performance makes people perceived target is bigger and obstacle is smaller. Witt and Profitt studied that a softball player who hits a ball better sees a ball bigger than a player who does not play as well does [1]. Witt, Linkenauger, Bakdash, & Profitt studied that a golf player who putts the ball into hole more times sees the hole bigger than a golfer who misses the hole does [3]. Witt, South, and Sugovic studied the influence of an individual's own perception even while he was observing others [14]. All participants were a part of a two-stage training phase. They were shown and asked to distinguish between two speeds, slow and fast. The participants were then asked to complete the task. On each trial, the ball moved across their screen and the participants were asked to stop the ball with a paddle. If the ball was stopped on the paddle, the participant was successful. If the ball didn't stop, the ball kept moving on till it rolled past the edge of the screen. After the trail, the participant switched with the observer. The researchers found that the participants in the participant mode that blocked the ball better responded to a slower ball speed than the ones who blocked lesser balls. When the observer turned to be participants, they had the same observations.

The research shows that the performance perception depends on an individual's performance only. If we concentrate on the fact that an individual's performance dictates his/her perception of the target tasks, we can use that to study the behavior of an individual in a performance setting. What if we manipulate the parameters of the task in an alternate environment, can we use that to influence that to perception of the individuals' performance in the task? Liang, et all studied skill training of Lathe boring operations in a virtual reality environment [15]. In the study, a person who was trained with high stiffness at the beginning and its stiffness was lowered gradually would perform better than a person who was trained with the same stiffness with the real world all the time would do. George Scott of the Boston Red Sox said, ''when you're hitting the ball [well], it comes at you looking like a grapefruit. When you're not, it looks like a black-eyed pea''. From those examples, we see that the perceiver's ability influences the perception. The players who hit the ball well, saw the ball bigger in size than the ones who do not hit it as well. Once we have established the connection between an individual's ability and their perception of their performance. Then seeing the target (golf hole or baseball ball) as bigger leads to an enhanced performance.

Witt et al studied the golfers' performance with 3 distinct experiments [3]. In the first experiment, they studied the performance of the golfers over the day. At the end of the day, they were shown black cardboard cut outs in different sizes resembling golf holes. The golfers who had lower scores that day saw the hole as bigger. Players who took less putts to put the ball in the hole, saw the hole as bigger than the players who took more attempts at getting the ball into the hole. There was a significant co-correlation between the performance on the same day and the perception of the size of the golf hole. In the second experiment, participants were assigned to the same putting task, in two different conditions. The indoor practice mat was sloped upwards towards at a 10-degree angle at a distance of 0.42m before the hole. In the first condition, Hard, participants stood 2.15 meters away from the putting hole. In the second condition, Easy, participants were made to stand 0.4 meters away from the golf hole. In both conditions, participants were made to guess how many putts they would make successfully. They found that the participants with the Easy condition predicted they would do more number of putts than the ones with the Hard condition. Participants in the Easy condition also made a higher number of putts than the ones in the Hard condition. With respect to the size estimation of the hole, the participants in the Easy condition estimated the hole larger than the ones in the hard condition. In the third experiment, the participants were assigned the same Easy and Hard tasks as experiment 2. They were also made to draw the golf hole with a paper and pen while looking at it. After the task was completed, participants were asked to draw the size of the hole using computer tools. They found that participants in the Easy condition drew a bigger circle than the participants in the hard condition. The researchers observed that even though the participants had a full view of the hole, they perceived it differently based on the condition they were assigned.

This demonstrates that the participants perceive the size of the hole with a direct relation to their performance. It means that, an individual's perception of the same entity changes as their performance changes. This allows us to revisit the findings of [1] and investigate whether there is a relationship between performance and the visual aspect of perception and can training in VR environment impact that perception and in turn the performance in real world. The ball is only one size but appeared larger when the player was performing well. There is a two-way communication channel between perception and performance. Can we manipulate the size of the hole in VR impact their performance in real world and in turn impact the perception of their performance in real world? Several studies in other performance domains, such as medicine, have reported that skills learned in a VR setting can improve performance in real world. Such as the operating room [16, 17]. VR for skill development in sports has not been as successful due to the limitations on various aspects. Previously sports training is most effective when performed in a realistic environment.

Figure 1: User putting in real world (left) and in a VE wearing a Head-Mounted Display during Virtual Reality training (right).

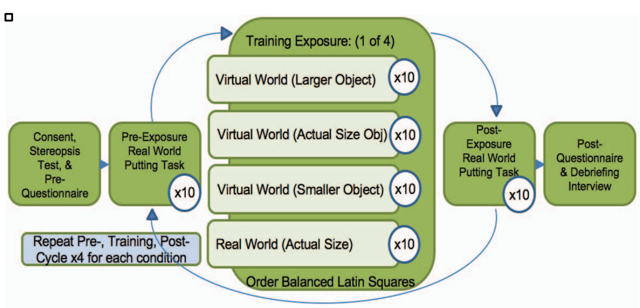

Figure 2: Diagram of procedure for the user experiment.

3 Experimental Design

Researchers found that the performance relates to perceived size [3]. Participants who putted from near the hole, perceived the size of the hole bigger, whereas the participants that putted from far from the hole, perceived the size of the hole smaller. To investigate these questions, we conducted an experimental study, where we replicated one of the prior perception and action studies but included a training exposure with virtual reality exposure. We designed a 2x4 mixed experimental design (Figure 2) where the object type condition manipulated (Ball, Putting Hole) was manipulated between subjects and the type of training exposure (Virtual-Larger Size Object, Virtual-Smaller Size Object, Virtual-Actual Size Object, and Real World) was manipulated within subjects and the order used Balanced Latin Squares. Participants had to complete a simple golf putting task (Figure 1) and we measured their performance in the real world both pre- and post-perception exposure. Participants were randomly assigned the training exposure condition. For virtual reality training exposure, we manipulated two conditions in VR separately: both the size of the putting hole and the size of the ball. The ball and the hole sizes were manipulated independently to replicate the previous study and to identify if there was an effect with either object. It is important to note that while manipulating the ball size but keeping the hole constant or vice versa, may cause the actual task to increase or decrease in difficulty due to physics, this is not the purpose of the virtual reality training. In the future we can investigate more sophisticated manipulations such as those. The purpose of this study is to use these visual manipulations change the users' perception of the objects (not the task) as they are performing the action. Our hypothesis is that these visual manipulations will change performance later. Performance is measured in real world pre- and post- exposure so any changes that influence task difficulty are not imposed on the data collection.

The participants were assigned to one of the 4 conditions for the between participants condition, Actual size, Smaller than Actual size, Larger than actual size and Real. In the 'Real' condition (Figure 1 left), participants completed the task with the real world ball or hole for the exposure condition. The real world condition and virtual world with actual size serve as two separate control conditions. The real world condition should not cause any differences other than a minor practice effect and enable the comparison of any effects beyond a practice effect. The virtual world – actual size condition allows us to test for any effects of the visual object manipulation beyond the novelty of practicing the task in virtual reality. the rest of the conditions, they completed the task with a virtual hole or ball in the control condition. The remaining sections detail the experiment.

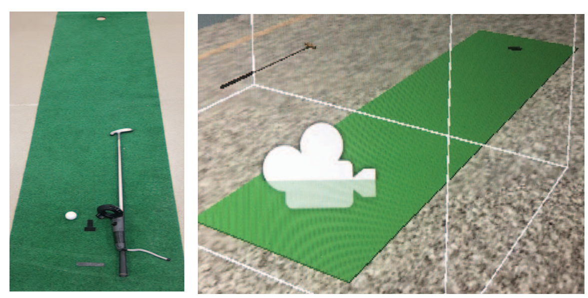

Figure 3: Putting green real (left) and virtual (right) environments.

3.1 Set-up and Apparatus

An actual putting green was set up in the research laboratory (Figure 2). A tracked real world golf putting club, golf ball, and putting green with a putting hole. The putting green was flat and straight (no mounds or curves). The virtual environment was designed to match the putting green exactly. Furthermore, to reduce any other spatial depth differences, we measured the walls and ceiling of the physical environment to match exactly that of the virtual environment. A VIVE head-mounted display and tracking system were used. The VIVE trackers were used to track the golf club. An opti-track wide-area optical tracking system was used to track the hole and golf ball through use of retro-reflective markers. The tracking environments were calibrated to match the real world environment as precisely as possible. Unity 3D was used to design the virtual environment and log each participant's data.

3.2 Measures

We collected data using pre- and post-questionnaires, stereopsis test, and spatial ability test. During the golf putting task, we collected tracked data on the golf putting club, ball, and hole both in the real world and virtual environment. We collected data on the mean Euclidean distance error the ball was from the hole as a standard measure of performance as well as number of 'holes-in-one'. During the putting tasks, each trial participants could hit the ball once and then the distance error was collected. The ball was then reset and the participants completed the task for the next trial.

Procedure

Figure 3 provides a diagram outlining the procedure of the experimental study. First, a participant was asked to complete a signed consent to take part in the study. Then s/he was given a viewing test to assess ocular ability, stereopsis ability, and spatial ability. Each participant then completed a pre-questionnaire to inform the background of usage for Virtual Reality environments. Each participant was asked to complete a golf putting task in the real world for 5 practice trials and 10 trials to measure performance. In the real world condition, participants used a real golf ball and hole. S/he used a tracked real world golf club to hit the ball into the hole. Participants were asked to complete the task as accurately as possible. Next, participants were given the training exposure condition. Each participant was assigned to one of the two between-subjects conditions in VR environment that manipulated the size for only one of the objects, either the Ball or the Putting Hole. Participants were not told that objects were being manipulated until debriefing. During the virtual reality training, participants completed the putting task in a virtual environment with the size of the ball or hole manipulated larger, smaller, or no change-actual. For the training exposure condition, each participant was given 5 practice trials and 10 trials. Post-training exposure, participants completed 10 additional trials in the real world to measure performance differences from the first set of trials. Participants repeated this process of task completion from real-training-real four times for each of the within subjects training exposure conditions. Once completed, participants completed a post-questionnaire and open-ended interview inquiring about their experience. Participants were debriefed on visual changes, asked a few questions regarding their perceptions on those changes and thanked for their time.

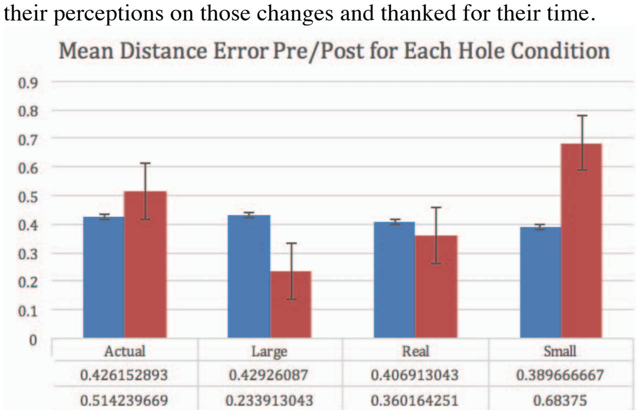

Figure 4: Mean Distance Error Pre (left/blue) to Post (right/red) for each (Virtual-Actual Hole, Virtual-Larger Hole, Real World Hole, and Virtual-Smaller Hole sizes).

4 Results

4.1 Participants

We collected data from 39 participants in this experimental study. Of the total 39 participants, N=29 of 39 participants had not used VR based applications extensively. All 39 participants were well versed with using a computer daily for advanced uses. N = 10 of 39 participants were familiar with the VIVE and had used the application for educational purposes. 8 participants were familiar with Unity 3D. When asked what their anticipation about the study was, all 39 participants replied that they were very excited to try out the experiment and learn about VR environments. All 39 participants were not color blind and N= 22 of 39 participants were able to see 20/20 without the need of corrective glasses or contacts, while the remaining wore corrective lenses during participation. All participants passed the stereopsis test. 35 of 39 Participants used the computer desktop extensively, 3 participants reported moderate use and 1 participants used it very often. N = 30 of 39 participants were not exposed to VEs, while the remaining responded that they have rarely used those features. All participants were volunteers from the University of Wyoming (UWYO) and this study was approved by the Institutional Review Board at UWYO.

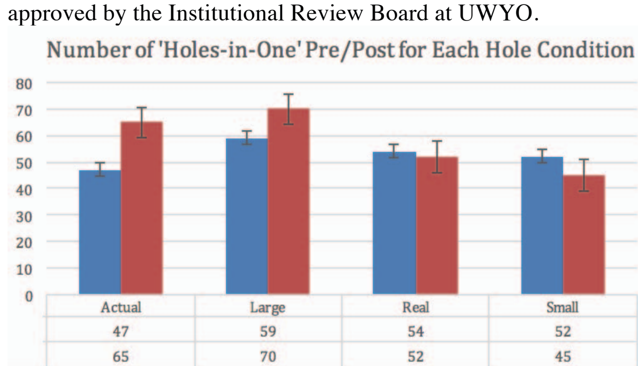

Figure 5: Times ball successfully went in putting hole, Pre (left/blue) to Post (right/red), for each (Virtual-Actual Hole, Virtual-Larger Hole, Real World Hole, and Virtual-Smaller Hole sizes).

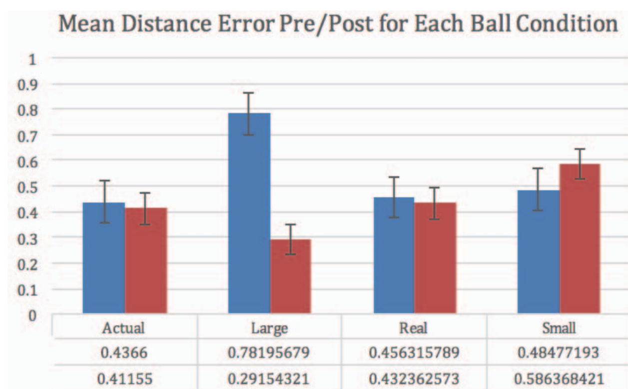

Figure 6: Mean Distance Error Pre (left/blue) to Post (right/red) for each (Virtual-Actual Ball, Virtual-Larger Ball, Real World Ball, and Virtual-Smaller Ball sizes).

4.2 Performance when Manipulating Perception of Putting Ball Size

We measured the performance within participants for pre- exposure to the VR condition, during the VR exposure and post VR exposure. For the data analyzed in this section, the "Hole" size remained constant between participants. Each condition was executed per the predefined order, assigned at random to each participant. We conducted a paired samples t-test on each distance measure of the putt task, averaged across the trials, from the pre- and post-exposure. The test revealed a near significant difference of means, $t(17)=1.98$, $p=0.064$, when the exposure used a larger virtual ball from pre- ($M=0.64$, $SD= 2.23$) to post- ($M=0.25$, $SD=0.33$). This indicates that the performance increased when the ball was larger. There was a significant difference of means, when the exposure used a smaller virtual ball, t(19)=-1.01, p=0.02, when the exposure used a larger virtual ball from pre- (M=0.48, SD= 0.22) to post- (M=0.58, SD=0.33). This indicates performance decreased when the ball was smaller. There was no significant difference from pre- to post- after VR training where the ball was the actual size, t(19)<1, nor for the real-world condition, t(18)<1. This indicates that there was no significant change in performance in the post exposure condition, when the actual size virtual ball was used or the real ball was used during the exposure condition. It means that there was no impact to performance in the post exposure condition.

4.3 Performance when Manipulating Perception of Putting Hole Size

We measured the performance within participants for pre- exposure to the training condition, during the training exposure and post training exposure. For the data presenting in this section, the "Ball" size remained constant between participants. Each condition was executed per the predefined order (Balanced Latin Squares), assigned at random to each participant. We conducted a paired samples t-test on each distance measure of the putt task, averaged across the trials, from the pre- and post- exposure. The test revealed a significant difference of means, t(23)=-2.59, p=0.016, when the exposure used a smaller virtual hole from pre- (M=0.35, SD= 0.39) to post- (M=0.58, SD=0.71). This indicates that the performance of the participants decreased significantly after virtual reality training where the hole was smaller. There was also a significant difference of means t(22) =3.03, p=0.006, when the exposure used a larger virtual hole from pre- (M=0.34, SD=0.41) to post- (M=0.24, SD=0.34). This indicates that the performance of the participants improved significantly after virtual reality training where the hole was bigger. There was no significant difference from pre- to post- after VR training where the hole was the actual size, t(21)<1, nor for the real-world condition, t(22)<1. This indicates that there was no significant change in performance in the post exposure condition, when the actual size virtual hole was used or the real hole was used during the exposure condition. It means that there was no impact to performance in the post exposure condition.

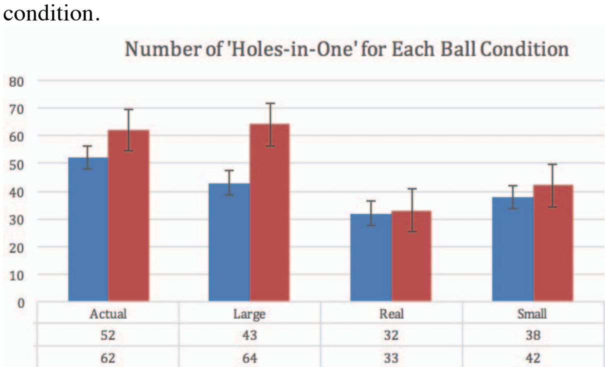

Figure 7: Times ball successfully went in the putting ball Pre (left/blue) to Post (right/red) for each (Virtual-Actual Ball, Virtual-Larger Ball, Real World Ball, and Virtual-Smaller Ball sizes).

4.4 Post-Questionnaire and Debriefing Interview

In the post questionnaire, after each block of real-training-real task cycle, we asked the participants about their overall feeling of visual changes, task completion, concentration for the task and their mental/physical condition. These are comments made prior to debriefing. One participant responded with the following: "It was better this time, the ball was acting weird the previous times. It was bigger and smaller. I had no intimation that it would keep changing. I guess the control parameters include the ball size. In my opinion, it does not work well for novice players like me." One of the participants commented how s/he felt about the task after a VR exposure: "well, for starters it was easier to hit the ball." A participant seemed to think that the ball in the real world was changing after VR exposure and that they were unsure if we were changing the distances: "I seemed to like the ball they used to play, this time [the ball] was slightly larger in real. I don't think it's a regular size ball. I will ask in the end if it was a different size or if they swapped out the put-put hole to a closer spot.".

In the interview at the end, participants were asked open-ended questions about the overall experience and task. The following comments were provided prior to debriefing. When asked how they felt about the overall experience, most participants found the task interesting and easy to manage. Participants were asked to describe their experiences in the VR environment. One of the participants felt comfortable with the real world cues in the VR environment: "[I] felt the real world cues, like standing at the edge of the mat, the black anchor strip. It was pretty good." One of the participants felt that there should have been music or "in-ear" coaching related to the task, and that it would have made them concentrate better at the task at hand. Majority of the participants replied that the task was straight forward and fairly easy. One of the participants felt it was harder than they anticipated. S/he said that started out thinking it was a straight forward non-challenging scenario, but quickly became harder and harder as the trial progressed. "I started out thinking it would be pretty easy, how hard would a put-put golf task be? I quickly realized it's not as straight forward as it seems. Also, the practice hitting [the ball] a million times has made me a better golfer." At the end of the trials, we asked the participants if they had any fatigue from the participation. Most of the participants felt completely normal. Most participants responded that they had a great time and enjoyed the experience. One participant was less engaged and felt bored: "[The] first round was pretty cool. I was yawning by the second round. Sorry." Another participant provided feedback to change the task: "Maybe the task can be more relatable for students, [since] not a lot of us get to play golf on a regular basis. Maybe some kind of a throwing task might be better at connecting the students with the task. Good luck!". A few participants commented that the weight of the headset was too heavy to wear for a long duration: "the headset is very heavy, if there was a smaller headset. If there are no other changes that the body could feel between the real and virtual, the perception would be better." Another commented that the wires hanging behind them bothered them during the VR experience.

5 Discussion

We have conducted analysis on participants' performance in each condition type. During the Ball Condition, we manipulated the perception of the ball in VR by changing the size. We found that the distance that the ball stopped away from the hole was significantly less after participants were exposed to VR training when the ball size as well as when the target hole size was larger. This indicates that participants' performance significantly improved when objects were visually changed to be larger. We found that the distance that the ball stopped away from the hole was significantly more after participants were exposed to VR training when the ball size as well as when the target hole size was smaller. This indicates that participants' performance significantly decreased when objects were visually changed to be smaller. We did not expect to see significant difference for either of our control conditions: real world and virtual world with actual ball or hole size (no visual manipulation). Since the participants were exposed to the same size ball both in VR and real world for the exposure condition, there was no change in their perception of the object, leading to no change in their performance. Any slight improvement on the task from pre- to post- training after the control training conditions may be explained by a slight practice effect due to the repetition of the task. Another potential aspect might be if performance improved over time, we could expect that their perception of the object should change as well. We plan to investigate this further in the future. Furthermore, while we collected tracking data of the user and golf putt swing that could be used to understand any user changes in behavior, this additional analysis is out of the scope of this paper but will be analyzed and presented in future work. Not only can this work be used to help improve training for sports but it has potential to be used so that players can train in smaller physical areas and where it may be less feasible to perform the full action in the sport. It could even be used to amplify or enhance human abilities such as those found in superhuman sports [20,21].

6 Conclusion

We have conducted an experimental study to investigate manipulation of visual perception in virtual reality training to improve actual sports performance in the real world, specifically for a golf putting task. We based this study on research from [1-5]. Participants completed a putting task in the real world, then were exposed to a training condition, and completed the task again the real world. The training conditions were repeated within subjects using Balanced Latin Squares and included virtual environment training where objects were manipulated larger, virtual environment training where objects were manipulated smaller, virtual environment training where objects were not manipulated remaining the actual size, and a real world control condition. We measured change in performance from before to after training exposure. Participants were randomly assigned to one of either object types (Ball or Hole) that where the size was manipulated.

For both Ball and Hole conditions, our results found that if the objects were manipulated larger (or providing the perception of an easier task), then participants' performance on the putting task improved significantly in the real world post training exposure. Our results also found that if the objects were manipulated smaller (or providing the perception of a more difficult task), then participants' performance on the putting task worsened significantly in the real world post training exposure. Further, our results found that two control conditions, where participants completed the task in the real world for training or completed the task in the virtual world without object manipulation, did not significantly change performance. Future work needs to be done to investigate these effects further taking into account other factors of perception, other methods of performance perception, and in other types of sports. However, this paper presents a strong foundation of work to come.

In this paper, we conclude that the manipulation of visual objects or perception of those objects during virtual reality training has both a positive and negative impact on the individual's performance in real world task post training exposure. Future work needs to be conducted to further explore this phenomenon in other areas of perception and sporting areas. Our research lays the foundation that this type of training not only possible but that individuals who use virtual reality training to be aware of exactly how this type of virtual reality training can have both positive and negative consequences in sports training.

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