Use of Scaling to Improve Reach in Virtual Reality for People with Parkinson's Disease

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***Abstract*—This research investigates the effect of scaling in virtual reality to improve the reach of users with Parkinson's disease (PD). People with PD have limited reach, often due to impaired postural stability. We investigated how virtual reality (VR) can improve reach during and after VR exposure. Participants played a VR game where they smashed water balloons thrown at them by crossing their midsection. The distance the balloons were thrown at increased and decreased based on success or failure. Their perception of the distance and their hand were scaled in three counterbalanced conditions: under-scaled ($scale = 0.83$), not-scaled ($scale = 1$), and over-scaled ($scale = 1.2$), where the scale value is the ratio between the virtual reach that they perceive in the virtual environment (VE) and their actual reach. In each study condition, six data were measured - 1. Real World Reach (pre-exposure), 2. Virtual Reality Baseline Reach, 3. Virtual Reality Not-Scaled Reach, 4. Under-Scaled Reach, 5. Over-Scaled Reach, and 6. Real World Reach (post-exposure). Our results show that scaling a person's movement in virtual reality can help improve reach. Therefore, we recommend including a scaling factor in VR games for people with Parkinson's disease.**

***Index Terms*—Virtual Reality, Parkinson's Disease, Rehabilitation, Reach, Scaling.**

I. Introduction

Virtual Reality (VR) has been a well-established medium for exercise and rehabilitation. With the recent development and commercialization of VR systems, VR games have been widely accessible to diverse population. Serious games running in VR have been used for rehabilitation for some time now [1], [2]. Users feel more immersed in a VR game since we can replicate a traditional exercise closely. Many VR games are proved to be effective for rehabilitation purposes for people with Parkinson's disease (PD) [3], [4], Multiple Sclerosis [5], [6], stroke [7], [8], etc. In this research, we focus on using VR to improve the reach of people with Parkinson's disease.

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Previous research has shown that Parkinson's disease affects the reach of patients [9]. Virtual reality is effective in improving postural stability for people with PD [10]. Since postural stability is related to reach, we hypothesize that VR can also help to improve it. Scaling the reach of participants in VR has been shown to be effective for people with stroke [11]. We hypothesize that scaling would also play a factor in improving reach.

We worked with physicians from Warm Springs Rehabilitation Hospital of San Antonio to develop a virtual reality version of one of their exercises that challenge the participants to cross their mid-line. The idea behind this game was that people with Parkinson's Disease often suffer from limited reach because of their impaired balance. We used scaling of their movements to change their perception of reach and investigated how scaling of their reach can help improve their reach (See section IV-D for more details). We have used a modified version of the multi-directional reach test for measuring participants' reach. The multi-directional reach test is a well-established test to measure the balance of a person [12].

II. Background

A. Virtual Reality and Parkinson's Disease

Virtual reality has certain advantages over traditional rehabilitation exercises. Lee et al. showed that VR dance exercise has a positive effect on balance, activities of daily living, and depressive disorder status of people with PD [13]. They reported that the VR group performed significantly better than the control group. VR also improved gait [14], balance [15], [16], and quality of life [17] for people with PD.

B. Parkinson's disease and reach in virtual reality

Ma et al. demonstrated the successful use of VR to improve movement time and peak velocity when reaching for real stationary balls [18]. Participants with PD were trained using fast-moving virtual balls and improved significantly compared to the control group. This study proves the effectiveness of improving motor performance on functional reaching movements. In our study, we focus on how to improve reach using scaling.

C. Reach and Balance

The multi-directional reach test is one of the highly used tests to measure a person's balance [12]. The test relies on the idea that a person with better balance can also reach further. However, it is unknown if the imbalance induced by visual stimuli will affect the reach. Therefore, we studied the effect of virtual reality on participants' reach.

D. Scaling in Virtual Reality

Virtual reality can be an effective tool to manipulate participants' perception of their movement and reach. It can be used to boost motivation by over-scaling the movement of the participants. It also can be used to challenge people to improve their reach by under-scaling their movement. Previous researchers have successfully used scaling to improve upper limb reach for people with stroke patients [11]. However, the effect of scaling on multi-directional reach is not yet known.

III. Hypothesis

The goal of this study is to use scaling to improve reach in VR. Based on knowledge from the literature, the following hypotheses are to investigate the effect of scaling on reach in VR:

- **H1:** A person's reach is negatively affected by virtual reality.
- **H2:** A person's reach can be improved using virtual reality games.
- **H3:** Scaling a person's movement in virtual reality can be helpful in improving reach.
- **H4:** Participant's post-exposure reach is improved from pre-exposure reach.

IV. Methods

A. Participants and Selection Criteria

For this study, we have collected a UPDRS-8 survey from seventeen persons with Parkinson's Disease from Warm Springs Rehabilitation Hospital of Thousand Oaks and Warm Springs Rehabilitation Hospital of San Antonio. UPDRS-8 is a brief clinical assessment scale for Parkinson's disease with a possible score from 0 to 40 [19]. As the study design required participants to stand without any aid, any person who required an assistive device or had a UPDRS-8 score greater than 9 was excluded from the study. Therefore, we excluded ten out of seventeen participants. Two of the remaining seven did not wish to participate in the study. We collected and analyzed five participants' data. Every participant had a normal or corrected to normal vision. Table I shows detailed information about the participants.

TABLE I
DESCRIPTIVE STATISTICS FOR PARTICIPANTS' INFORMATION FOR 'SCALING TO IMPROVE REACH' STUDY.

Participant Group	No. of Male	No. of Female	Age (Years) Mean (SD)	Weight (Lbs.) Mean (SD)	UPDRS-8 Mean (SD)
Participants with PD	5	0	68 (3.74)	217.04 (19)	4.8 (2.99)

Fig. 1. A participant is doing a T-pose for initial calibration

B. Study Conditions

We designed a within-subject study to investigate the effect of scaling on participants' reach in VR. There are three conditions we considered to examine how participants' reach is changed in VR: under-scaled *(scale = 0.83)*, not-scaled *(scale = 1)*, and over-scaled *(scale = 1.2)*. Participants' movement was modified according to the scale value in different study conditions. The scaling values were determined using a pilot study. Any extreme values than these were affecting the hand-eye coordination of the participants. In all conditions, participants played the water balloon smash game in VR. See section IV-D for more details about the game. Participants' reach was measured out of the virtual reality before and after these three conditions. The order of the conditions was counterbalanced among the participants.

C. System Description

In this study, we designed a virtual reality system to measure the participants' reach in different conditions described earlier (see Section: IV-B). A Nintendo Wii Fit Balance Board (WFBB) measured participants' balance. The Vive controllers measured the reach and tracked the participants' hands in different study conditions.

The virtual environments (VE) were designed in Unity. This fully immersive VE made use of the Vive, an head mounted display (HMD) developed by HTC [20]. The HTC Vive has a resolution of 2160 x 1200 pixels with a refresh rate of 90 Hz and a 110 degree field of view.

D. Virtual Environment

We used a virtual environment that is a virtual representation of the room where the experiment took place. There is a virtual character named 'Jim' who threw water balloons toward the participants. The participants have to reach left or right to catch the ball and smash it with the other hand. The reaching part is motivated by the multi-directional reach test [12]. The distance d that Jim threw the balls was modified based on a staircase pattern. The participants' initial reach was calibrated based on the distance of their left to right hand while they extended their arms sideways to form a T-pose. Figure 1 shows a participant doing a T-pose for initial calibration. Let i be the initial distance. The first ball was thrown at $d = p * i$, where p is initially set to *1.0*. If a participant successfully caught and smashed two virtual water balloons in a row, the next one was thrown a little further than the previous one. The following formula was used to calculate the distance:

$$p_{new} = p_{old} + 0.1/p_{old} \tag{1}$$

The distance continues increasing with each successful catch. If a participant failed to catch two water balloons in a row, the distance was reduced using the following formula:

$$p_{new} = p_{old} - 0.05/p_{old} \tag{2}$$

Using these formulas, we implemented an adaptive staircase pattern where the step-down value is half of the step-up value, and both the step-up and step-down value becomes smaller as the total value becomes larger. The participants attempted to catch 50 balloons in each study condition, and the study duration per condition was approximately 3 minutes. Participants sat and rested for 1 minute between the conditions. The participants did not know about the study's aim and were only instructed to catch as many balloons as possible. Figure 2 shows a participant playing the water balloon game in the VE.

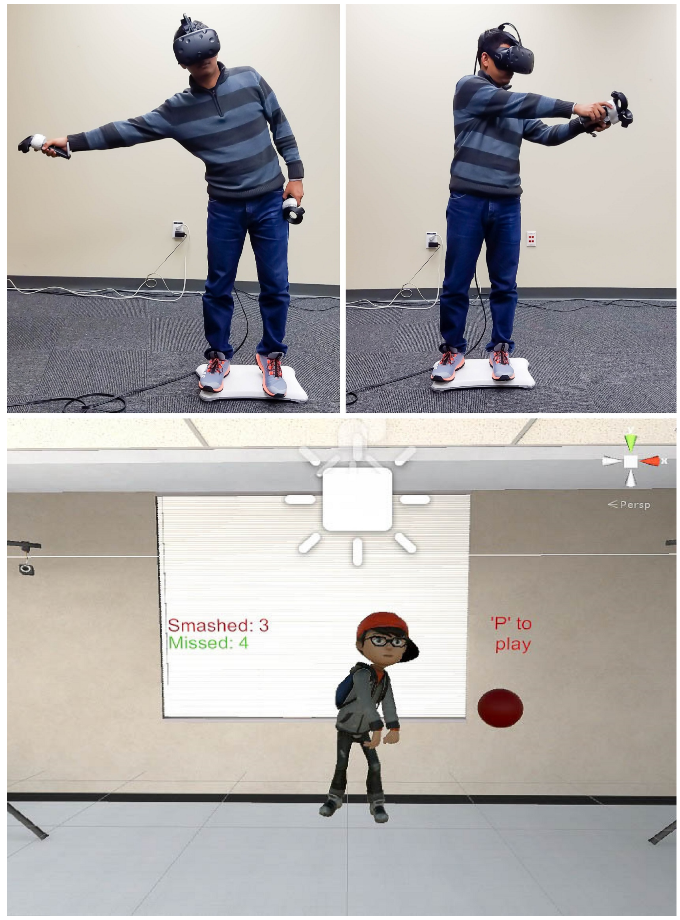

Fig. 2. A participant is playing the water balloon smash game.

E. Study Procedure

The study procedure consisted of the following seven consecutive steps:

1) Consent and Pre-Study Questionnaire: At the beginning of the study, each person signed a consent form to participate in the study. The study design was approved by the Institutional Review Board (IRB) of The University of Texas at San Antonio. Afterwards, the participants filled out a basic information form and a Simulator Sickness Questionnaire (SSQ) [21].

2) Baseline Data Measurement: The participants stood on a WFBB while the WFBB measured their baseline balance data for one minute while they tried to stand still and gazed straight ahead. This was repeated for both eyes open (EO) and eyes closed (EC) positions. In between two conditions, the participants sat for at least one minute to rest.

3) Real World Baseline Reach Measurement (Pre-exposure): Participants' Real World Reach (RWR) was measured in the real world using a multi-directional reach test [12]. We only measured their lateral (side by side) reach. They did a T-pose (See figure 1) and then tried to reach as far as possible to their left and right. The displacement on each side is the baseline data for participants' reach. In all conditions, participants' feet were placed at the same location on the Wii balance board to ensure that their foot position did not influence their reach.

4) Virtual Reality Baseline Reach Measurement: Participants' Virtual Reality Reach (VRR) was measured in a similar way described in section IV-E3 while they put on a Vive HMD and experienced the virtual environment.

5) Virtual Reality Reach Measurement in Study Conditions: The participants put on a Vive HMD and played the water balloon smash game described in section IV-D. First, they played the game once for training. Then, they played the game with three conditions described in section IV-B and their during-game reaches - Not-Scaled Reach (NSR), Under-Scaled Reach (USR), and Over-Scaled Reach (OSR), were measured. The order of the study conditions was counterbalanced. Each condition lasted about three minutes.

6) Real World Reach Measurement (Post-exposure): After playing the water balloon smash game in different study conditions, the participants' Post-exposure Reach (PER) was measured in the real world in a similar way described in section IV-E3.

7) Post-Study Questionnaire: At the end of the study, the participants filled out an SSQ. Participants received a payment of $50 after that.

V. Metrics

A. Reach

$Reach$ is defined as how far a person can reach by leaning on her left or right. $Reach$ is measured as a distance from the tip of the hand when a person extends his hand as far as possible to the tip of the hand when the person is doing a T-pose. The following equation can be used to describe reach:

$$Reach = HandPosition_{extended} - HandPosition_{T-pose} \tag{3}$$

Participants' left hand and right hand $Reach$ were used for analysis.

B. Simulator Sickness Questionnaire

$Simulator\ Sickness\ Questionnaire\ (SSQ)$ is a sixteen-item questionnaire where each item asks about participants' different physiological discomforts [21].

VI. Statistical Analysis

All of the participants were right-side dominant. Interestingly, PD also affected them more on the right side for all participants. Therefore, we analyzed their right side (i.e., dominant side or affected side) *Reach* and left side (i.e., non-dominant side or non-affected side) *Reach* separately. First, we ran a repeated-measures ANOVA with all participants' data to find a significant effect of any study conditions on balance. If any significance was found, we performed a paired sample t-test for within-group comparison. As the study is exploratory, we do not need Bonferronwe correction [22]. Moreover, all of the comparisons are planned comparisons. Therefore, we do not need a Bonferroni correction [23]. All statistical analysis was performed using IBM SPSS version 19.

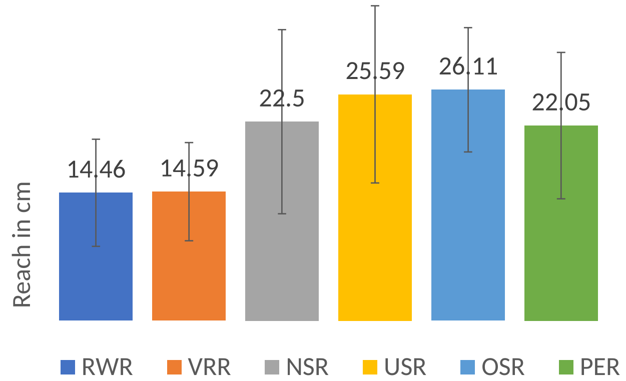

Fig. 3. Right side reach in different study conditions.

VII. Results

A. Reach

1) Right Side: We performed a repeated-measures ANOVA among the right side reach measurement from six conditions (RWR, VRR, NSR, USR, OSR, PER) and detected a significant effect of difference on reach; $F(1.948, 7.792) = 6.328$; $p = 0.024$. Mauchly's test indicated that the assumption of sphericity had been violated. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. Figure 3 shows the comparison of right side *Reach* in different study conditions.

a) Effect of Virtual Environment: The difference between RWR and VRR conditions was that RWR is measured in the real environment while VRR is measured in a virtual environment. Therefore, we ran a paired sample t-test between RWR and VRR *Reach* data to investigate the effect of the virtual environment on reach and discovered a **non-significant** difference of *Reach* between RWR $(M = 14.46,\ SD = 6.06)$ and VRR $(M = 14.59,\ SD = 5.54)$ condition; $t(4) = 0.52,\ p = 0.961;\ d = 0.02$.

b) Effect of No Scaling in Virtual Reality Game: Both VRR and NSR were measured in the virtual environment, but VRR was measured without playing the balloon smash game while NSR was measured using the game. Therefore, we ran a paired sample t-test between VRR and NSR *Reach* data to investigate the effect of no scaling in virtual reality games on reach and discovered a *non-significant* difference of *Reach* between VRR $(M = 14.59,\ SD = 5.54)$ and NSR $(M = 22.5,\ SD = 10.45)$ condition; $t(4) = 1.607,\ p = 0.183;\ d = 0.94$.

c) Effect of Scaling in Virtual Reality Game: Both VRR and USR were measured in the virtual environment, but VRR was measured without playing the balloon smash game while USR was measured using the game with an under-scaling $(scale < 1)$ applied to participants' movement. We ran a paired sample t-test between VRR and USR *Reach* data to investigate the effect of under-scaling on reach and discovered a **significant** difference of *Reach* between VRR

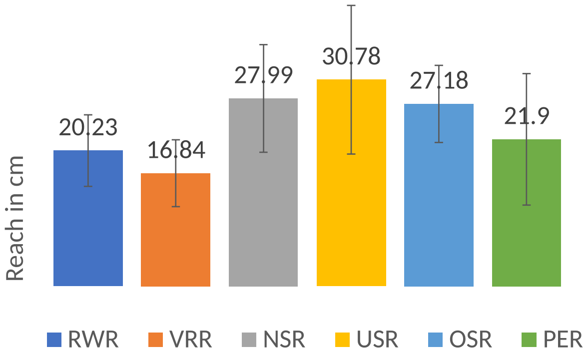

Fig. 4. Left side reach in different study conditions.

TABLE II
PAIRED SAMPLE T-TEST RESULTS OF REACH DATA.

		Right Side			Left Side		
	Conditions	Mean	SD	p	Mean	SD	p
Pair 1	RWR VRR	14.46 14.59	6.06 5.54	0.961	20.23 16.84	5.33 4.98	0.106
Pair 2	VRR NSR	14.59 22.50	5.54 10.43	0.183	16.84 27.99	4.98 8.01	0.004
Pair 3	VRR USR	14.59 25.59	5.54 10.01	0.046	16.84 30.78	4.98 11.06	0.014
Pair 4	VRR OSR	14.59 26.11	5.54 7.03	0.027	16.84 27.18	4.98 5.75	0.018
Pair 5	RWR PER	14.46 22.05	6.06 8.28	0.016	20.23 21.90	5.33 9.80	0.635

$(M = 14.59,\ SD = 5.54)$ and USR $(M = 25.59,\ SD = 10.01)$ condition; $t(4) = 2.848,\ p = 0.046;\ d = 1.35$.

Similar to USR, OSR was measured with an over-scaling $(scale > 1)$ applied to participants' movement. We ran a paired sample t-test between VRR and OSR *Reach* data to investigate the effect of over-scaling on reach and discovered a **significant** difference of *Reach* between VRR $(M = 14.59,\ SD = 5.54)$ and OSR $(M = 26.11,\ SD = 7.03)$ condition; $t(4) = 3.42,\ p = 0.027;\ d = 1.82$.

d) Pre vs Post Exposure Reach: We have collected the post-exercise reach (PER) to see the effect of virtual reality exercise on reach. We ran a paired sample t-test between RWR and PER *Reach* data to investigate the effect of virtual reality exercise on reach and discovered a **significant** difference of *Reach* between RWR $(M = 14.46,\ SD = 6.06)$ and PER $(M = 22.05,\ SD = 8.28)$ condition; $t(4) = 3.991,\ p = 0.016;\ d = 1.04$.

2) Left Side: We performed a repeated-measures ANOVA among the left side reach measurement from six conditions (RWR, VRR, NSR, USR, OSR, PER) and detected a significant effect of difference on reach; $F(2.92, 11.68) = 5.425;\ p = 0.015$. Mauchly's test indicated that the assumption of sphericity had been violated. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. Figure 4 shows the comparison of left side *Reach* in different study conditions.

a) Effect of Virtual Environment: The difference between RWR and VRR conditions was that RWR is measured in a real environment while VRR is measured in a virtual environment. Therefore, we ran a paired sample t-test between RWR and VRR *Reach* data to investigate the effect of virtual environment on reach and discovered a **non-significant** difference of *Reach* between RWR $(M = 20.23,\ SD = 5.33)$ and VRR $(M = 16.84,\ SD = 4.98)$ condition; $t(4) = 2.083,\ p = 0.106;\ d = 0.65$.

b) Effect of No Scaling in Virtual Reality Game: Both VRR and NSR were measured in the virtual environment, but VRR was measured without playing the balloon smash game while NSR was measured using the game. Therefore, we ran a paired sample t-test between VRR and NSR *Reach* data to investigate the effect of no scaling in virtual reality games on reach and discovered a *significant* difference of *Reach* between VRR $(M = 16.84,\ SD = 4.98)$ and NSR $(M = 27.99,\ SD = 8.01)$ condition; $t(4) = 5.774,\ p = 0.004;\ d = 1.67$.

c) Effect of Scaling in Virtual Reality Game: Both VRR and USR were measured in the virtual environment, but VRR was measured without playing the balloon smash game while USR was measured using the game with an under-scaling $(scale < 1)$ applied to participants' movement. We ran a paired sample t-test between VRR and USR *Reach* data to investigate the effect of under-scaling on reach and discovered a **significant** difference of *Reach* between VRR $(M = 16.84,\ SD = 4.98)$ and USR $(M = 30.78,\ SD = 11.06)$ condition; $t(4) = 4.18,\ p = 0.014;\ d = 1.62$.

Similar to USR, OSR was measured with an over-scaling $(scale > 1)$ applied to participants' movement. We ran a paired sample t-test between VRR and OSR *Reach* data to investigate the effect of over-scaling on reach and discovered a **significant** difference of *Reach* between VRR $(M = 16.84,\ SD = 4.98)$ and OSR $(M = 27.18,\ SD = 5.75)$ condition; $t(4) = 3.86,\ p = 0.018;\ d = 1.92$.

d) Pre vs Post Exposure Reach: We have collected the post-exercise reach (PER) to see the effect of virtual reality exercise on reach. We ran a paired sample t-test between RWR and PER *Reach* data to investigate the effect of virtual reality exercise on reach and discovered a **non-significant** difference of *Reach* between RWR $(M = 20.23,\ SD = 5.33)$ and PER $(M = 21.9,\ SD = 9.8)$ condition; $t(4) = 0.513,\ p = 0.635;\ d = 0.21$.

Table II summarizes the results of the paired sample t-test that was described above in this section.

B. Simulator Sickness Questionnaire

We ran a two tailed paired sample t-test between pre-VR exposure SSQ $(M = 16.45,\ SD = 19.36)$ and post-exposure SSQ $(M = 10.47,\ SD = 9.68)$ and detected no significant differences; $t(4) = 0.886,\ p = 0.426;\ d = 0.39$

VIII. Discussion

A. Effect of Virtual Environment

There is a non-significant difference between RWR and VRR for both right *(p = 0.961)* and left *(p = 0.106)* sides. Even though there is a medium effect size *(Cohen's d = 0.65)* of the virtual environment on the left side reach, the effect size was small *(Cohen's d = 0.02)* on the right side. Considering all of these, we cannot accept hypothesis 1: A person's reach is negatively affected by virtual reality. One possible explanation may be that the less reliable the visual information, the more subjects relied on prior knowledge of displacement statistics to adjust their movement [24].

B. Effect of No Scaling in Virtual Reality Game

There is a non-significant difference between VRR and NSR for the right side *(p = 0.183)* and a significant difference *(p = 0.004)* for the left side. The effect sizes suggest that there is a large effect of virtual reality games on reach for both right *(Cohen's d = 0.94)* and left *(Cohen's d = 1.67)* sides. However, as we find a non-significant result on the ride side, we cannot accept hypothesis 2: A person's reach can be improved using virtual reality games. The reason for this can be the small sample size. As we discovered a large effect size on both sides, it is arguable that a larger sample size might reveal a significant effect.

C. Effect of Scaling in Virtual Reality Game

We investigated two scaling conditions in this study: under-scaling and over-scaling. For the under-scaling condition, we discovered a significant difference between VRR and USR for both right *(p = 0.046)* and left *(p = 0.014)* side. The effect sizes also suggest there is a large effect of under-scaling on reach for both right *(Cohen's d = 1.35)* and left *(Cohen's d = 1.62)* sides.

For over-scaling condition, we discovered a significant difference between VRR and OSR for both right *(p = 0.027)* and left *(p = 0.018)* side. The effect sizes also suggest there are large effects of over-scaling on reach for both right *(Cohen's d = 1.82)* and left *(Cohen's d = 1.92)* sides.

Considering all these results, we can accept hypothesis 3: Scaling a person's movement in virtual reality can be helpful in improving reach. For under-scaling condition, it can be arguable that when people perceive less distance than they are actually reaching, they try harder to reach their desired reach. For over-scaling condition, the reason can be the enjoyment of reaching further than their original effort, and that may boost their confidence to try harder.

D. Pre vs Post Exposure Reach

The participants played the water balloon smash game four times for three minutes each, which results in a total of twelve minutes. We wanted to investigate if twelve minutes of playing the game improved their balance. While there is a significant difference between RWR and PER for the right (affected and dominate) side *(p = 0.016)*, there is a non-significant difference *(p = 0.635)* for the left side. The effect sizes suggest that there is a large effect *(Cohen's d = 1.04)* of virtual reality exercise on the right side but a small effect *(Cohen's d = 0.21)* of the exercise on the left side. Therefore, we cannot accept hypothesis 4: Participant's post-exposure reach is improved from pre-exposure reach. There can be two reasons for that. First, the sample size is smaller, and this small size rendered a positive result on the right side. A larger sample size may reveal a positive result on both sides. Second, the participants played the game only for twelve minutes. This is a very small time to actually increase the reach.

E. Cybersickness

There were no significant differences observed in SSQ scores between pre and post VR exposure. This is expected as we kept the VE and the task very simple. The highest possible SSQ score can be 235.62, whereas the average post-SSQ score in the study was 10.47. Therefore, it is argued that the environment that we used did not induce any cybersickness.

IX. Conclusion and Future Work

Our research demonstrated the potential benefit of scaling reach in virtual reality rehabilitation for people with Parkinson's disease. Both under-scaling and over-scaling can be beneficial. Post-exposure reach was also significantly improved on the affected (right) side. This indicates that the knowledge and confidence from our exercise are transferable to the real world. We did not get significant results while studying the effect of no scaling in virtual reality games. Participants reach more in over-scaling and under-scaling conditions than in no scaling conditions. There are many VR games for rehabilitation of people with PD, which can be benefited from incorporating a scaling condition. One limitation of our study is the small sample size. In the future, we will use scaling in other rehabilitation exercises to investigate the effectiveness of scaling in diverse simulations as well as diverse population (e.g., people with Multiple Sclerosis).

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