Enjoyable Physical Therapy Experience with Interactive Drawing Games in Immersive Virtual Reality

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ABSTRACT

While virtual reality games have shown a lot of potential for rehabilitation, research on creative virtual therapy is still growing. Considering many possibilities for therapeutic interventions in VR, we can create activities with an appropriate balance between intensity level of therapy intervention with enjoyment and entertainment. In this paper, we propose a creative line art drawing game in an immersive VR environment as a tool for enjoyable upper extremity physical therapy. To examine the validity of the proposed virtual therapy system, we conduct a human-subjects experiment in a mixed design varying the drawing content (Easy vs. Hard; a between-subjects factor) and the user's position (Seated vs. Standing; a within-subjects factor). Our results with 16 non-clinical participants (8 females) show that the change of drawing content objectively influenced their drawing performance, e.g., the completion time and the number of mistakes, while they did not feel the difference in the difficulty level between the contents subjectively. Interestingly, participants reported more enjoyment from drawing the Hard content than the Easy content, and more substantial body stretches in the Seated setting than the Standing setting. Here, we present the main effects of the study factors and the correlations among the objective and subjective measures, while discussing implications of the findings in the context of enjoyable and customizable physical therapy using the creative VR drawing game.

CCS CONCEPTS

• Human-centered computing → User studies; • Software and its engineering → Interactive games.

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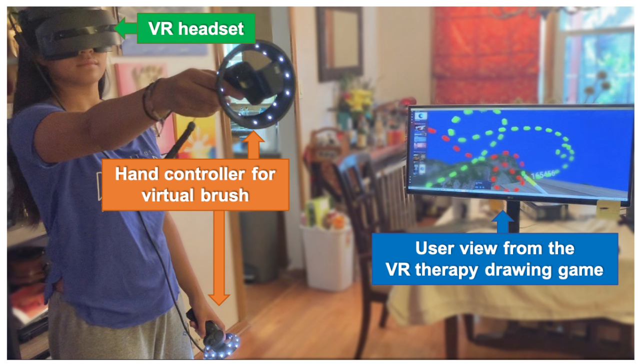

Figure 1: The immersive VR drawing game developed for our upper extremity virtual therapy intervention.

KEYWORDS

virtual therapy, virtual reality, interactive drawing, upper extremity rehabilitation, enjoyment

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1 INTRODUCTION

Musculoskeletal injury is one of the leading causes of disability in most developed countries, and approximately 1.71 billion people have musculoskeletal conditions worldwide [25]. An estimated 126.6 million Americans (roughly one in two Americans) live with a musculoskeletal condition according to the American Academy of Orthopedic Surgeons' report [23]. With the increasing number of post-stroke survivors, who often have certain types of musculoskeletal conditions, such as upper extremity functional limitations, the need for more effective therapeutic methods and research is continuously growing [24]. Physical therapy (PT) is well-known for being effective for rehabilitation. However, low adherence to PT exercises among patients has been reported due to different reasons, including lack of motivation, slow or invisible recovery progress, and absence of supervision and mental support.

To address these issues, virtual reality (VR) has a lot of potential as a tool that provides more engaging PT experience with appealing visual effects and interactive sensory feedback [11, 30, 32]. Prior research has shown that VR is preferred in rehabilitation for various reasons, e.g., its portability for home-therapy, ability to attenuate pain, independence from external pressures and distractions, game-like characteristics that engage users, and ability to simulate real-life tasks in an environment that makes it easier to measure and evaluate performance [2, 18]. By transforming rehabilitation into an entertaining game in VR, the intense, repetitive, task-oriented therapeutic exercises necessary for rehabilitation could become more engaging and enjoyable [11]. On the other hand, however, there are still questions that we need to explore for more effective and widely acceptable VR therapy; for example, how we can effectively control the perceived level of difficulty in different VR therapy interventions, i.e., customization of therapy intensity, and how the VR intervention settings can influence the user's (patient) therapy experience.

In this paper, we introduce an interactive drawing game, in which the users can complete different shapes of line art drawings using hand-held controllers, as a PT exercise—in particular for upper extremity rehabilitation (see Figure 1). The drawing game can be performed with a different level of the user's bodily involvement, e.g., while standing and seated, to investigate the effects of the body position on their drawing and therapy experience. The game encourages broad arm motions while still being entertaining as the user strives to connect the dots of the drawing. Overall, we aim to investigate how effective the VR therapy interventions with different drawing contents are in terms of the user's perception of difficulty and enjoyment, and how the perceptions can be related to each other, establishing three research questions below:

- **RQ1**: Do simple, yet objective adjustments of VR contents, such as the length or shape of line art drawing, influence the subjective perception of difficulty (or intensity) in the VR drawing therapy system?
- **RQ2**: How does the user's position influence the VR drawing therapy experience?
- **RQ3**: How is the perceived enjoyment of the drawing game associated with the perceived difficulty of the therapy?

The remainder of this paper is structured as follows: Section 2 covers prior work related to our research in this paper. In Section 3 we describe our creative drawing game and the conducted experiment. The results are presented in Section 4, which are discussed in Section 5. Section 6 concludes the paper addressing future research directions.

2 RELATED WORK

In this section, we review some previous work related to virtual therapy for physical rehabilitation and the user's body position impacts on the VR experience. We also cover some interactive drawing applications in immersive VR settings, which are related to the drawing intervention that we use for our own study reported here.

2.1 Virtual Therapy for Physical Rehabilitation

Despite the known effectiveness of PT interventions for rehabilitation, various limitations, including the time commitment, intensity of labor and resources, dependence on patient compliance, geographical availability of special facilities, and costs/insurance coverage, have been reported [11, 16, 28].

Virtual therapy has shown the potential to engage the patient and improve their therapy experience. Henderson et al. [11] presented a therapy system with multiple VR game simulations to improve the hand function of post-stroke patients, resulting in the participants' enjoyment in the task. Other studies also showed VR treatments to be supplemental or interchangeable by conventional therapy. For example, Feng et al. [7] showed that virtual therapy could improve gait and balance in certain cases, e.g., Parkinson's patients saw an improved gait and balance after training with VR games. Kim et al. [14] also presented a study that showed the VR treatments could lead to functional improvements in the stroke patients, in both upper extremity function and visual perception. Together with haptic stimuli using datagloves in VR, multiple studies showed positive results for hand movement rehabilitation in post-stroke patients [1, 2, 13].

One of the biggest advantages of using VR for PT could be that it is portable; patients can take their therapy home to do it frequently at their convenience. Li et al. [19] developed a VR therapy home-based system (VRT-Home) for children with hemiplegic cerebral palsy to practice hemiplegic hand and arm movements. Their results showed that the system successfully targeted hand/arm movements of the hemiplegic upper extremity, especially reaching activities that involve the shoulder and elbow. Additionally, the child participants reported "[having] lots of fun" and "would like to take the games practice therapy activities home to play."

However, while the research addressed above showed that there are positive effects of VR intervention for physical rehabilitation, some research also stated that there is still limitation of the existing literature. Multiple reviews on the efficacy of VR therapy concluded that the current evidence on the effectiveness of using VR in the rehabilitation of upper limb mobility in patients with stroke is still limited and we need more studies to support this effect while investigating different intervention types through rigorous studies [11, 17, 29].

2.2 Effects of Body Position on Virtual Experience

One interesting research topic is to understand the effects of VR user's body position (or bodily involvement), specifically the seated or standing settings, on their experience and task performance in VR [33]. Here, we summarize some of the previous work that investigated how the body configuration contributes to user performance and range of motion in the VR environment.

There have been multiple VR systems based on different user body configurations, including seated and standing [31], leaning while seated and standing [15], and walking in place [27]. Xu et al. used an immersive VR exergame to investigate how being standed vs. seated affects gameplay performance, intrinsic motivation, and motion sickness. Their results showed that compared to standing, being seated could result in higher exertion and provide higher value to players, could lead to participants feeling sicker in the iVR exergame, and could lead to participants missing more gestures in the exergame. This led to the recommendations that full-body gestures for seated exergames need to be designed carefully to help minimize the feeling of motion sickness and to provide more time to perform the gestures [31]. In our study, we will focus on a therapy game for upper-body mobility instead of a full body exercise game with different UX measures.

In the context of PT, gathering data on what body configuration allows for the best range of motion during a VR therapy could lead us to better application designs for patients. However, many prior studies only focused on a certain position configuration, e.g., aforementioned VRT-Home (see Section 2.1) was only used in the seated configuration for their children participants. Gao et al. explored how physical activity in VR experiences could reduce stress while promoting health and well-being in older adults [8]. Given the most immersive VR setting applications in a limited space, a large-scale ground navigation is not the primary action the user has to perform. However, considering the PT context, which could benefit from different position configurations, it is important to investigate the effects of body position in the user's therapy experience and performance.

2.3 Interactive Drawing in Virtual Environments

Among a number of different types of VR applications, interactive drawing is one of the most popular VR use cases. For example, an artistic VR game "Tilt Brush" allows users to change their virtual surroundings and sketch freely [10]. In a work by Laver et al. [17] users reported they enjoyed the virtual art interface, since it allowed them to create accurate drawings. Multiple drawing applications have been proposed while showing the effectiveness of drawing in a positive virtual experience. Nakagawa et al. [21] built a multi-user audiovisual system for interactive mixed reality experience, using an optical see-through head-mounted display (Microsoft HoloLens). In their system, users could draw virtual lines using their fingers while experiencing various visual expressions and audio effects according to the height of real space. Raffle et al. [22] also developed a system named "Jabberstamp," which is a visual and interactive tool to draw and record voices for children to support children's emergent literacy. Gerry [9] pointed out that this kind of drawing/painting activity in immersive VR environments could also promote empathy and creativity in remote multi-user settings.

For therapy applications, virtual art therapy, however, has yet to be further studied. In one of the earliest efforts in this research, McNiff [20] presented the "Virtual Art Therapy Studio" for use of VR drawing/paining art in therapy, and highlighted its advantages for training and accessibility. Such advantages include creating bold and expansive gestures from simple movements, having more precision in a visually diverse way, having better accessibility with drawings easily sent to colleagues all over the world simultaneously, and easing storage of images instead of physical file cabinets. Different uses of the virtual art studio have been shown to possibly be an effective medium for art therapy, especially for physically challenged patients. However, McNiff did not consider how body position can affect the user's experience and the therapeutic applications, which we will explore in our study.

3 EXPERIMENT

In this section, we describe the experiment we conducted to investigate the influence of different VR drawing settings for PT experience.

3.1 Participants

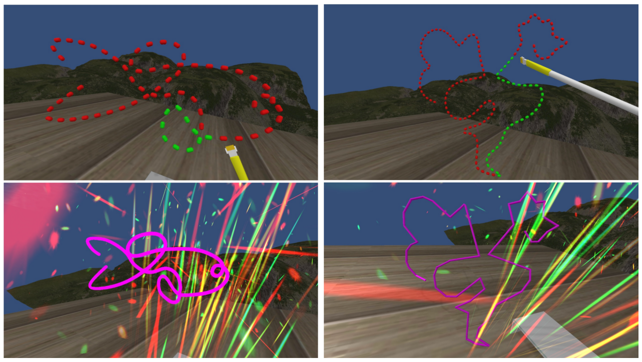
For the experiment, we conducted a priori power analysis to determine our sample size for interaction effects using G*Power for a large effect size (η_p^2: 0.14) with a power of 0.80, resulting in a total sample size of 16 [6]. We recruited a participant pool of 16 non-clinical volunteers enrolled in University of Delaware's undergraduate program (8 male and 8 female; age ranged from 18 to 20, $M = 19.06$, $SD = 0.56$). There was no monetary compensation for the participants.

All the participants were asked about their demographics, prior VR and video game experience, and past experience of upper body injuries. Ten of participants (62.5%) have Caucasian or White ethnicity, five (31.25%) came from an Asian or Pacific Islander background, and one (6.25%) was Hispanic or Latino. The majority of participants lacked prior VR/video game experience; 11 (68.75%) have never used VR headsets before and only five (31.25%) reported playing video games weekly. Three participants (18.75%) have previously experienced a severe upper body injury, either due to sports or other incidents, and one (6.25%) needed to participate in rehabilitation sessions to recover from an upper body injury.

3.2 Apparatus

For our study, we developed an interactive VR drawing game using Unity game engine (version 2019.1.0f2). The game was compatible with several VR Head-Mounted Displays (HMDs), but we chose the HP Windows Mixed Reality Headset Developer Edition for our study.

In the drawing game, participants were presented a warm, welcoming home page, in which they could choose one of the drawing contents, either a fish or a chicken (see Figure 2). We developed these drawing contents using Autodesk Maya and Blender. The goal of this game was to connect the dots of an outline drawing of the content using a virtual paint brush (hand controllers). The background was a simple, serene mountain scape with a blue sky and clouds, allowing the user to focus on their task in a relaxing, distraction-free environment. When each dot was hit, it turned from red to green, and a positive and pleasant audio feedback sound was played to the user. When all the dots were green, meaning the user successfully connected all the dots of the drawing, they were celebrated by visual firework animations with sound effects (see Figure 2). The way to perform the game was flexible; participants could switch a controller to draw with either their left or right hand. Another controller that was not drawing could be used to adjust the 3D dots model to the height or position the user felt most comfortable with, which allowed this game to be played in both Seated and Standing settings. No matter where they adjusted the drawing content to be, they were still reaching and moving their body to complete their drawing. We wanted to compare how much



(a) Easy (Fish) (b) Hard (Chicken)

Figure 2: Virtual contents used for the drawing game: (a) Easy and (b) Hard contents. The images on the top show the contents in the middle of drawing exercise with a virtual brush, and the celebration effects after the task completion are shown on the bottom—these positive visual feedback can offer more enjoyable therapeutic experience to users.

the range users could reach and how accurate their movements were while seated or standing.

3.3 Study Design

To address our research questions introduced in Section 1, we used a 2×2 mixed design with the following between-subjects and within-subjects factors.

Content. As a *between-subjects* factor, we prepared two virtual drawing contents, in which we objectively adjusted the content difficulty with different numbers of drawing dots:

- **Easy (Fish)**: the drawing content was a shape of abstract outline fish image with 69 drawing dots, which could be easier to draw.
- **Hard (Chicken)** the content was a shape of abstract outline chicken image with 150 drawing dots, which could be harder to draw.

The difficulty levels of these virtual contents were empirically tested by the experimenter(s) while preparing the experiment.

Position. As a *within-subjects* factor, we had two drawing positions for the participants:

- **Seated**: Participants performed the drawing activity while they were seated on a chair.
- **Standing**: Participants performed the drawing activity while standing.

We chose to use a between-subject design for the drawing contents because it could reduce confounding variables due to the exposure of multiple treatments in the drawing exercise. On the other way, we chose a within-subject design for the drawing positions because it could allow us to see how differently the same person could feel about the VR drawing therapy with respect to their position. The four study conditions following the mixed design were assigned to the participants in a counter-balanced order. The following hypotheses were established with respect to these two factors:

- **H1**: Participants' objective drawing performance and subjective perception of the therapy experience will be influenced by the virtual content.
  - **H1-1**: Participants' drawing performance will be reduced with the Hard Chicken content (more drawing dots), compared to the Easy Fish content.
  - **H1-2**: Participants' perception of easiness and comfort will be improved with the Easy Fish content (fewer drawing dots), compared to the Hard Chicken content.
- **H2**: Participants' therapy experience will be influenced by their position during the drawing exercise.
  - **H2-1**: Participants will perceive that their body is more stretched in the Standing position, compared to the Seated position.
  - **H2-2**: Participants will enjoy the exercise more in the Standing position, compared to the Seated position.

3.4 Measures

For our study, we utilized both objective and subjective measures to assess the perceived difficulty of the drawing activity and other perception related to the VR therapy experience.

Objective Measures. We prepared the following two measures, the task completion time and normalized number of mistakes, to objectively evaluate the drawing performance in the drawing activity.

- **Task Completion Time**: The completion time of the drawing task was calculated based on the starting time when the participants pressed the controller button and the ending time when they released the controller button. The unit is in seconds.
- **Normalized Number of Mistakes**: The number of mistakes, e.g., when the participants missed any drawing dots while performing the exercise, was counted during the study sessions. We normalized the number of mistakes over the task completion time for the fair comparison among the participants; thus, the unit for this measure is the number of mistakes per second.

Subjective Measures. We also collected some perception measures through subjective questionnaires, using Qualtrics survey platform. Most of the measures were in five-point Likert scale (1: strongly disagree, 5: strongly agree), except for the "Willingness to Recommend," which was collected separately in a semantic differential scale (1–10). Here we describe the detailed question for each of the measures.

- **Easiness**: "It was easy to complete the virtual drawing task."
- **Comfort**: "I felt comfortable while completing the task."
- **Body Stretch**: "Using the VR drawing activity, I did stretch my body more than I normally do."
- **Enjoyment**: "I enjoyed playing the creative drawing game."
- **Willingness to Recommend**: "I would recommend this creative therapy game to friends or family members as a therapeutic exercise."

In the end, we also collected the participants' general feedback through text entries, asking for thoughts on how to improve this activity for future use and their preferences for the study conditions.

3.5 Procedure

The experiment was approved by the Institutional Review Board (Protocol #:1658782-1), and was conducted following the University of Delaware COVID-19 safety guidelines. Each participant was required to wear a mask for the entire duration of the study, and only one participant was allowed to be in the room at a time. All equipment was also wiped down with a disinfectant wipe and air-dried for 30 minutes before the new participant was available. Once participants arrived, we received verbal consent after describing the purpose of our study and their right and responsibility. After consent, the participants were randomly assigned to one of the four study conditions based on the 2×2 study design in Section 3.3. They then filled out a pre-questionnaire about their demographics, experience with VR/video games, and experience with physical therapy/exercise. After getting explanation of study directions, participants were guided to a chair or the middle of the room to stand depending on their study conditions. We then gave them the headset to put on, and their hand controllers so that they draw with their dominant hand for the drawing activity. The session was with either the Easy or Hard level content (Figure 2)—each participant experienced only one content as a between-factor. The figure was adjusted to a comfortable height and distance away from the user, depending on their assigned position, e.g., seated or standing, and the user's approval. We recorded how many times they made a mistake in their continuous drawing stroke, e.g., when a dot doesn't turn green because they missed it, and their task completion time. They were then asked to complete the post-questionnaire for the drawing therapy session they just experienced, which we described in Section 3.4. The task was repeated in the other position configuration, either the Seated or Standing setting, which they didn't experience in the previous session. After the second session with a different position setting, participants filled out the post-questionnaire again for the new position configuration. A unique ID was generated by each participant and was repeatedly used in completion of the questionnaires to assist us keep track of their data while preserving their anonymity. The entire experimental session for each participant took 10–15 minutes.

4 RESULTS

We used two-way mixed ANOVA for examining the main and interaction effects. Here, we report the results mainly focusing on the findings with statistical significance (α = .05).

Objective Measures. We present the results of our objective measures, which are related to the user's performance in the VR drawing exercise. The descriptives of the results are shown in Figure 3.

- **Task Completion Time**: We did not find any significant effects in the task completion time for the Content factor ($F(1, 14) = 4.245$, $p = 0.058$). However, the mean of task completion time for the Hard Chicken content ($M = 36.10$, $SD = 5.66$) was larger than the Easy Fish content ($M = 29.67$, $SD = 6.74$) . There was no main effect for the Position factor or the interaction effect.
- **Normalized Number of Mistakes**: We found a main effect of the Content factor for the normalized number of mistakes ($F(1, 14) = 9.047$, $\boldsymbol{p = 0.009}$, $\eta_p^2 = 0.393$; large effect). This indicates that participants made more mistakes with the Hard Chicken content ($M = 0.24$, $SD = 0.09$) than the Easy Fish content ($M = 0.13$, $SD = 0.06$)—the raw numbers of mistakes before normalization: Hard Chicken ($M = 8.38$, $SD = 2.22$) and Easy Fish ($M = 3.81$, $SD = 1.38$). We did not observe a main effect of the Position factor and the interaction between the factors with statistical significance.

Subjective Measures. We present the results of participants' subjective perception of the drawing exercise. The descriptives for the subjective measures are shown in Figure 4.

- **Easiness**: We did not find any main effects and interaction among the study conditions regarding the perceived easiness. Seated position ($M = 4.88$, $SD = 0.34$) and standing ($M = 4.75$, $SD = 0.45$).
- **Comfort**: There was no main effect of the Position factor ($F(1, 14) = 3.611$, $p = 0.078$); however, the mean score of the comfort measure for the Seated position ($M = 4.81$, $SD = 0.40$) was higher than the Standing position ($M = 4.38$, $SD = 0.72$). We did not find a main effect of the Content factor or an interaction effect.
- **Body Stretch**: We found a main effect of the Position factor ($F(1, 14) = 9.800$, $\boldsymbol{p = 0.007}$, $\eta_p^2 = 0.412$; large effect). This means that participants thought they stretched their body more in the Seated position ($M = 3.31$, $SD = 1.14$), compared to the Standing position ($M = 2.44$, $SD = 0.81$). There was no main effect of the Content factor or an interaction effect.
- **Enjoyment**: We found a main effect of the Content factor ($F(1, 14) = 8.000$, $\boldsymbol{p = 0.013}$, $\eta_p^2 = 0.364$; large effect). This indicates that participants enjoyed the VR drawing exercise with the Hard Chicken content ($M = 4.88$, $SD = 0.34$), compared to with the Easy Fish content ($M = 4.38$, $SD = 0.50$). There was no main effect of the Position factor or an interaction effect.
- **Willingness to Recommend**: We did not find any significant effects in this measure, but the mean score for the Seated position ($M = 8.44$, $SD = 1.46$) was higher than the Standing position ($M = 8.25$, $SD = 1.57$), with respect to the Position factor ($F(1, 14) = 4.200$, $p = 0.060$). There was no main effect of the Content factor or an interaction effect.

There were no interaction effects with statistical significance reported; thus, we did not go further for post-hoc tests.

Besides, we conducted a correlation analysis using the Pearson's correlation coefficient. We found the objective *raw* number of mistakes was correlated with the subjective enjoyment with statistical significance ($r(30) = 0.471$, $\boldsymbol{p = 0.007}$). So, we conducted a linear regression (Equation 1) to predict enjoyment based on *raw* number of mistakes ($F(1, 30) = 8.532$, $\boldsymbol{p < 0.001}$, $R^2 = 0.221$). The enjoyment score is relatively high even there is no mistake.

$$enjoyment = 0.079 \times number\ of\ mistakes + 4.146 \quad (1)$$

In addition, there was a statistically significant correlation between the *raw* number of mistakes and the willingness to recommend measures ($r(30) = 0.447$, $\boldsymbol{p = 0.010}$). The linear regression to predict recommendation based on *raw* number of mistakes ($F(1, 30) = 7.493$,

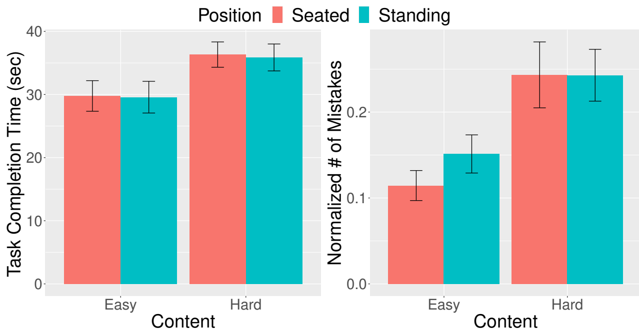


Figure 3: Results of objective measures. Standard error of the mean (SEM) was used for the error bar with the mean. There was a main effect of Content (Easy vs Hard) for the normalized number of mistakes.

$\boldsymbol{p < 0.01}$, $R^2 = 0.200$) results in Equation 2.

$$\textit{willingness to recommend} = 0.227 \times \textit{number of mistakes} + 6.961 \quad (2)$$

These results indicate that participants who drew the hard chicken model tend to enjoy the VR drawing exercise more and also be willing to recommend it to their friends and family.

5 DISCUSSION

Here, we summarize our main findings with respect to the hypotheses established in Section 3.3, based on the results reported in previous section. We discuss implications behind the findings considering the physical therapy context.

Effects of Drawing Content. Our results about the objective measures support the **H1-1**, showing that the participants actually made more mistakes when they drew the Hard content than the Easy content. In contrast, the results of the subjective measures related to the perceived easiness and comfort did not show any differences among the study conditions, resulting in no evidence for the **H1-2**. These contrary observations about objective and subjective measures are particularly interesting in an aspect that one may eventually moderate the duration and intensity of a therapy session objectively through the simple adjustment of the virtual drawing content. More work need to be done to explore the most challenging level of the game without compromising patients' sense of comfort during the game.

Our findings are further interesting when it comes to the participant's enjoyment during the drawing exercise. We initially set a hypothesis expecting a higher level of enjoyment for the Standing setting compared to the Seated setting, with respect to the Position factor (**H2-2**), considering the higher level of bodily involvement in the Standing setting. However, what we actually found was a main effect of the Content factor instead. We observed that the small change of content to the chicken model (the Hard content) could increase the enjoyment score. It is noteworthy that this effect was found when each participants experienced only one of the virtual contents, either the Easy or the Hard content, as a between-subjects factor even without comparing the contents directly through the repeated measures. Knowing that there is low adherence to therapeutic exercise in typical PT settings, this observation can be useful to design more engaging and enjoyable therapy interventions. Many of participants' feedback after the experiment also supported the validness of the interactive VR drawing game for the enjoyable PT exercise, including the comment below.

> Participant #13: *"When I broke my arm from hockey and got my cast off, I had to do several exercises like bending/straightening my arms, rotating my wrists, and other things to regain my strength. I could see how this game could be helpful and fun at the same time."*

Effects of Drawing Position. We had established a hypothesis that participants would feel they stretched their body more in the Standing setting than the Seated setting (**H2-1**), due to the potential increase of movement in the Standing setting. On the contrary, however, we found that they thought they stretched more in the Seated setting. The reason could be because the restriction of movement on the chair encouraged the body stretch, which is also reported by several participants as below.

> Participant #4: *"When I was sitting I had to reach more and wanted to lift myself off the chair a bit to get to the highest parts of the chicken. But since I couldn't I had to really stretch my arm and controller out to hit the dots."*

This finding has implications for PT exercises for patients who have severe restrictions of lower-body movement, such as rehabilitation for post-stroke patients in seated settings. The Seated setting could also strengthen the compatibility/accessibility of our therapy game for a limited space, e.g., for remote at-home therapy interventions. Although we need a further investigation to examine the participants' bodily movement objectively, this benefit of the seated setting for the sense (or intent) of body stretch is promising for effective VR-based PT interventions, especially considering the simplicity of the proposed line art drawing game together.

Correlations. Our correlation analysis revealed that there are positive correlations between the number of mistakes, and the enjoyment and the willingness to recommend measures. More investigations will certainly be required to make more personalized therapy experience possible with appropriate difficulty levels in the virtual contents for individual PT patients. However, considering mental frustrations of patients during the PT exercises [26], our finding is interesting and important. Ideally, PT patients could enjoy more and be satisfied with the VR therapy experience when they make more mistakes, based on the results from our healthy participants in our correlation and regression analysis. Further research with more representative group of PT patients will be conducted to also validate this.

Study Limitations. As with the majority of studies, the design of the current study is subject to limitations. Our research motivation was drawn from post-stroke rehabilitation, but the conducted study was based on a convenience sampling, which involved young, healthy students selected from our university community. The study sample was also relatively small ($n = 16$) which may influence the generalizability of the results.

Broader Implications and Future Work. We presented a simple, creative, and portable VR drawing game as an effective tool for PT,

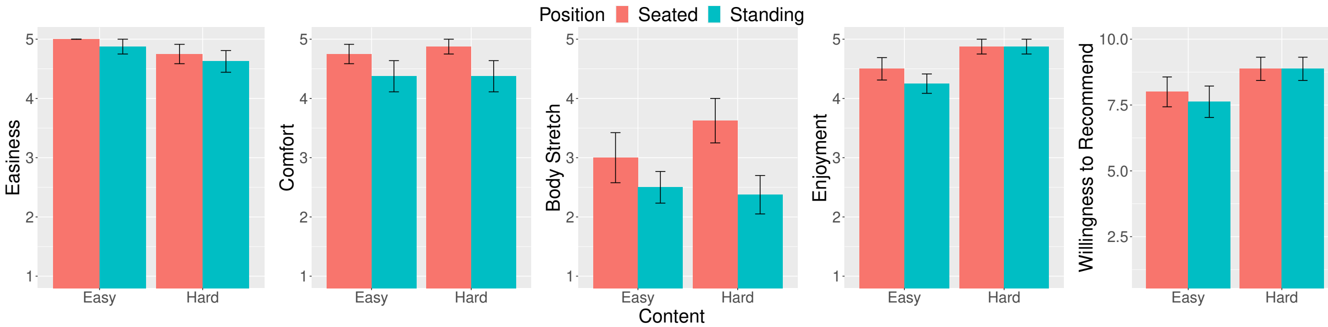


Figure 4: Results of subjective measures. Standard error of the mean (SEM) was used for the error bar with the mean. There were a main effect of Position (Seated vs Standing) for the perception of body stretch, and a main effect of Content (Easy vs Hard) for the enjoyment.

which can be useful for at-home, remote therapy interventions. Our proposed VR drawing game can allow patients to perform their therapy sessions at the comfort of their homes, helping both physical and emotional health of the individuals. The scope of the VR drawing game is currently focused to the upper extremity conditions; but the implications of the work can be extended to different disciplines in PT interventions, e.g., for lower-body or any different body parts rehabilitation exercise. Beyond the physical rehabilitation, VR experience has been implemented for enhancement of cognitive skills [4, 13], and is considered as an effective tool for the prevention and treatment of stress-related psychopathological symptoms and PTSD, with therapeutic benefits [3, 5]. While the importance of mental health is growing and emphasized during/after the COVID-19 pandemic and for *shelter at home*, we consider how our therapy game can be received as a remote therapy tool, similar to "The Secret Garden" by Imperatori et al. [12]—a 10-minute self-help VR protocol made to reduce the burden of the coronavirus.

While the drawing experience that the participants had was short and happened only a couple of times per participant, our study was conducted with non-clinical participants as convenience sampling due to restrictions in the past year for conducting more structured studies. We plan to extend our work with a larger sample for repeating measures and representative participant pools, with upper extremity injuries, or post-stroke patients to further validate our findings. We will also use objective measures to examine the participants' movement and the level of body stretch. From a technical point of view, it would be beneficial for patients to receive real-time or after-action feedback on their performance to check their rehabilitation progress. While the current system can provide various positive feedback in different stages of the game to user during or after completion of the drawing, a variety of interactive VR interventions and a dashboard to summarize user's progress in different levels of the game would be desired. Research on the effects of immersive VR interventions comparing with augmented/mixed reality (AR/MR) interventions could be interesting in terms of the patient's distraction from the therapy by real-world occurrences.

6 CONCLUSIONS

In this paper, we presented a creative VR therapy game using line drawing activities, and investigated how the drawing content and the user's position could influence the user's performance and perception in the drawing exercise. Our results showed that the proposed VR drawing game is an effective tool for enjoyable physical therapy, which has a lot of potential for customized therapy experience. While taking into account the broader use cases of this interactive VR drawing intervention for various types of PT exercise, we will extend our study and further investigate the effectiveness of VR therapy in the future.

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REFERENCES

[1] Sergei V. Adamovich, Alma S. Merians, Rares Boian, Jeffrey A. Lewis, Marilyn Tremaine, Grigore S. Burdea, Michael Recce, and Howard Poizner. 2005. A Virtual Reality—Based Exercise System for Hand Rehabilitation Post-Stroke. *Presence* 14, 2 (2005), 161–174.

[2] Rares Boian, A Sharma, C Han, A Merians, Grigore Burdea, Sergei Adamovich, Michael Recce, Marilyn Tremaine, and Howard Poizner. 2002. Virtual Reality-Based Post-Stroke Hand Rehabilitation. *Studies in health technology and informatics* 85 (2002), 64–70.

[3] Cristina Botella, Berenice Serrano, Rosa M Baños, and Azucena Garcia-Palacios. 2015. Virtual reality exposure-based therapy for the treatment of post-traumatic stress disorder: a review of its efficacy, the adequacy of the treatment protocol, and its acceptability. *Neuropsychiatric Disease and Treatment* 11 (2015), 2533–2545.

[4] B.M. Brooks, F.D. Rose, J Potter, S Jayawardena, and A Morling. 2004. Assessing stroke patients' prospective memory using virtual reality. *Brain injury: [BI]* 18 (2004), 391–401.

[5] Błażej Cieślik, Justyna Mazurek, Sebastian Rutkowski, Paweł Kiper, Andrea Turolla, and Joanna Szczepańska-Gieracha. 2020. Virtual reality in psychiatric disorders: A systematic review of reviews. *Complementary Therapies in Medicine* 52 (2020), 102480.

[6] Franz Faul, Edgar Erdfelder, Albert-Georg Lang, and Axel Buchner. 2007. G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behaviour Research Methods* 39, 2 (2007), 175–191.

[7] Hao Feng, Cuiyun Li, Jiayu Liu, Liang Wang, Jing Ma, Guanglei Li, Lu Gan, Xiaoying Shang, and Zhixuan Wu. 2019. Virtual Reality Rehabilitation Versus Conventional Physical Therapy for Improving Balance and Gait in Parkinson's Disease Patients: A Randomized Controlled Trial. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research* 25 (2019), 4186–4192.

[8] Zan Gao, Jung Eun Lee, Daniel J. McDonough, and Callie Albers. 2020. Virtual Reality Exercise as a Coping Strategy for Health and Wellness Promotion in Older Adults during the COVID-19 Pandemic. *Journal of Clinical Medicine* 9, 6 (2020), 1986:1–10.

[9] Lynda Joy Gerry. 2017. Paint with Me: Stimulating Creativity and Empathy while Painting with a Painter in Virtual Reality. *IEEE Transactions on Visualization and Computer Graphics* 23, 4 (2017), 1418–1426.

[10] Google. [n.d.]. Tilt Brush. https://www.tiltbrush.com/. [Accessed 2021-05-23].

[11] Amy Henderson, Nicol Korner-Bitensky, and Mindy Levin. 2007. Virtual Reality in Stroke Rehabilitation: A Systematic Review of Its Effectiveness for Upper Limb Motor Recovery. *Topics in Stroke Rehabilitation* 14, 2 (2007), 52–61.

[12] Claudio Imperatori, Antonios Dakanalis, Benedetto Farina, Federica Pallavicini, Fabrizia Colmegna, Fabrizia Mantovani, and Massimo Clerici. 2020. Global Storm of Stress-Related Psychopathological Symptoms: A Brief Overview on the Usefulness of Virtual Reality in Facing the Mental Health Impact of COVID-19. *Cyberpsychology, Behavior, and Social Networking* (2020).

[13] D Jack, Rares Boian, A.S. Merians, Marilyn Tremaine, Grigore Burdea, Sergei Adamovich, Michael Recce, and Howard Poizner. 2001. Virtual Reality-Enhanced Stroke Rehabilitation. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 9 (2001), 308–318.

[14] Yong Kim, Min Chun, Gi Yun, Young Song, and Han Young. 2011. The Effect of Virtual Reality Training on Unilateral Spatial Neglect in Stroke Patients. *Annals of Rehabilitation Medicine* 35 (2011), 309–15.

[15] Ernst Kruijff, Bernhard Riecke, Christina Trekowski, and Alexandra Kitson. 2015. Upper Body Leaning Can Affect Forward Self-Motion Perception in Virtual Environments. In *Proceedings of the 3rd ACM Symposium on Spatial User Interaction*. 103–112.

[16] Peter Langhorne, Fiona Coupar, and Alex Pollock. 2009. Motor recovery after stroke: a systematic review. *Lancet Neurology* 8 (2009), 741–754.

[17] KE Laver, B Lange, S George, JE Deutsch, G Saposnik, and M Crotty. 2017. Virtual reality for stroke rehabilitation. *Cochrane Database of Systematic Reviews* 11 (2017).

[18] Angela Li, Zorash Montaño, Vincent J Chen, and Jeffrey I Gold. 2011. Virtual reality and pain management: current trends and future directions. *Pain management* 1, 2 (2011), 147–157.

[19] William Li, Sophie Lam-Damji, Tom Chau, and Darcy Fehlings. 2009. The development of a home-based virtual reality therapy system to promote upper extremity movement for children with hemiplegic cerebral palsy. *Technology and Disability* 21, 3 (2009), 107–113.

[20] Shaun McNiff. 1999. The Virtual Art Therapy Studio. *Art Therapy* 16, 4 (1999), 197–200.

[21] Ryu Nakagawa, Ryo Komatsubara, Taku Ota, and Takahisa Mitsumori. 2018. Drawing Sound in MR Space: A Multi-User Audiovisual Experience in Mixed Reality Space. In *Proceedings of the Virtual Reality International Conference - Laval Virtual*. 20:1–4.

[22] Hayes Raffle, Cati Vaucelle, Ruibing Wang, and Hiroshi Ishii. 2007. Jabberstamp: Embedding Sound and Voice in Traditional Drawings. In *Proceedings of the 6th International Conference on Interaction Design and Children*. 137–144.

[23] American Academy of Orthopaedic Surgeons. 2016. One in two Americans have a musculoskeletal condition. https://www.sciencedaily.com/releases/2016/03/160301114116.htm. [Accessed 2021-05-16].

[24] National Institutes of Health. 2020. National Institute of Neurological Disorders and Stroke: Post-Stroke Rehabilitation Fact Sheet. https://www.ninds.nih.gov/Disorders/Patient-Caregiver-Education/Fact-Sheets/Post-Stroke-Rehabilitation-Fact-Sheet. [Accessed 2021-05-26].

[25] World Health Organization. 2021. WHO Fact sheets: Musculoskeletal conditions. https://www.who.int/news-room/fact-sheets/detail/musculoskeletal-conditions. [Accessed 2021-05-16].

[26] Jenny Röding, Britta Lindström, Jan Malm, and Ann Öhman. 2003. Frustrated and invisible - Younger stroke patients' experiences of the rehabilitation process. *Disability and Rehabilitation* 25, 15 (2003), 867–874.

[27] Mel Slater, Martin Usoh, Anthony Steed, Queen Mary, and Westfield College. 1995. Taking Steps: The Influence of a Walking Technique on Presence in Virtual Reality. *ACM Transactions on Computer-Human Interaction* (1995), 201–219.

[28] Robert Teasell, Matthew J. Meyer, Andrew McClure, Cheng Pan, Manuel Murie-Fernandez, Norine Foley, and Katherine Salter. 2009. Stroke Rehabilitation: An International Perspective. *Topics in Stroke Rehabilitation* 16, 1 (2009), 44–56.

[29] Daria Tsoupikova, Nikolay Stoykov, Molly Corrigan, Kelly Thielbar, Randy Vick, Yu Li, Kristen Triandafilou, Fabian Preuss, and Derek Kamper. 2015. Virtual Immersion for Post-Stroke Hand Rehabilitation Therapy. *Annals of Biomedical Engineering* 43 (2015).

[30] Andrea Turolla, Mauro Dam, Laura Ventura, Paolo Tonin, Michela Agostini, Carla Zucconi, Pawel Kiper, Annachiara Cagnin, and Lamberto Piron. 2013. Virtual reality for the rehabilitation of the upper limb motor function after stroke: A prospective controlled trial. *Journal of NeuroEngineering and Rehabilitation* 10, 1 (2013), 1–9.

[31] Wenge Xu, Hai-Ning Liang, Qiuyu He, Xiang Li, Kangyou Yu, and Yuzheng Chen. 2020. Results and Guidelines From a Repeated-Measures Design Experiment Comparing Standing and Seated Full-Body Gesture-Based Immersive Virtual Reality Exergames: Within-Subjects Evaluation. *JMIR Serious Games* 8, 3 (2020), e17972.

[32] Kevin Yu, Roghayeh Barmaki, Mathias Unberath, Albert Mears, Joseph Brey, Tae Hwan Chung, and Nassir Navab. 2018. On the accuracy of low-cost motion capture systems for range of motion measurements. In *Medical Imaging 2018: Imaging Informatics for Healthcare, Research, and Applications*, Vol. 10579. International Society for Optics and Photonics, 105790G.

[33] Daniel Zielasko and Bernhard E. Riecke. 2020. Sitting vs. Standing in VR: Towards a Systematic Classification of Challenges and (Dis)Advantages. In *Proceedings of the IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*. 297–298.