Virtual Reality for Post-Stroke Rehabilitation

Tobias Alan Boyd*, Eric Nahe†, Brian A. Cohn‡, and Roghayeh Barmaki§

*†§ Computer and Information Sciences, University of Delaware

‡ Computer Science, University of Southern California

ABSTRACT

Rehabilitation of the upper extremities after stroke aids in patients regaining important functions. After a stroke, a period of neuroplasticity occurs, during which rehabilitative therapy is most effective. However, many patients report feelings of frustration, boredom, and powerlessness during traditional physical therapy. Physicians must also evaluate limb function accurately to tailor rehabilitation to patients. Since existing methods of evaluation can be inaccurate and subjective, we present here a virtual reality simulation designed for upper extremity rehabilitation. Our goals are twofold: to provide patients with therapy that engages their minds as well as their bodies, and to provide therapists with an objective tool with which to evaluate patients' progress. Conducting therapy in a virtual reality environment allows for the inclusion of video game design elements, which engage patients and relieve boredom. Programs for virtual reality therapy can also easily record patient motion as data. These data provide an objective record of patient motion, and can easily be visualized in 3D, allowing physicians to objectively review the patient's upper extremity movements over the course of treatment.

Keywords: Stroke rehabilitation, upper extremity therapy, joint mobility exercise and assessment, virtual reality.

Index Terms: Human-centered computing → Human computer interaction (HCI) → Interaction paradigms → **Virtual reality**; CCS → Applied computing → Life and medical sciences → **Consumer health**

1 INTRODUCTION

After a stroke, the brain's injury responses kick in. Coleman describes this effect as a "plastic window", during which rehabilitation's benefits are increased [2]. For the upper extremities, therapies began no later than two weeks after stroke take advantage of this plastic window [2]. Since this effect occurs for a limited time, providing optimal therapy during the window helps post-stroke patients regain important skills. However, stroke patients describe their experiences with rehabilitation unfavorably. Luker's review of 31 studies on the experiences of stroke patients reveals that patients find physical rehabilitation monotonous and vexing [3]. Patients want to control what happens to them, as well as engage in a greater variety of activities.

Our virtual reality therapy game aims to address the issue of patient boredom while providing an objective measure of patient movement to therapists; virtual reality allows for easy integration of game mechanics into therapy. By using the principles of video games to entertain players, we can make physical therapy entertaining as well. Besides, evaluating a patient's condition is paramount in setting appropriate goals, and selecting the right therapeutic activities. However, the metrics used to measure motor functions after a stroke can be very subjective [1, 4]. It is possible to take more objective measurements of motor function evaluations with commercially-available VR hardware: In virtual reality systems using hand-held controllers, the system works through tracking the location of the controller. Recording the location of tracked hand controllers to a comma-separated values file provides a set of data points describing the exact path taken by the controller, which can then be analysed to understand the agility of hand movements, etc. during the VR therapy session, or across other games in VR. This can allow physicians to objectively review the patient's upper extremity movements and speed in a variety of environments.

2 VR THERAPY

Our simulation was developed using Unity and Autodesk Maya. It is designed to run on any SteamVR-compatible VR system with two controllers. The game requires the user and presenter to each hold one controller. The controller held by the user has a paintbrush that can be used to color dots within the workspace, while the clinician's controller can be used to change the parameters of the task.

2.1 Game

The game requires two participants, a user, and a presenter. In clinical practice, the post-stroke patient is the user and the physician or therapist is the presenter. The patient wears the VR headset and holds one of the controllers, and the physician holds the other controller. While the patient's controller is represented as a brush, the physician's controller is a simple cube in the VR workspace. The environment in the demo is a mountain landscape.

In the final version of the game, there would be multiple options for settings that the patient could choose between. Post-stroke patients frequently report wanting more agency in their rehabilitation [2], and choosing the virtual setting of their therapy could provide that.

*eboyd@udel.edu, †enahe@udel.edu, ‡brianaco@usc.edu, §rlb@udel.edu

The demo starts with the patient making a choice between easy mode and hard mode. The patient's aim is to trace a 3D model with the brush controller, exercising their upper extremity reach. The models started as line drawings of animals, which were replicated in Maya as 3D cylinders forming dotted lines. The demo of the game has two models - a simpler design of a fish, and a more complex design of a chicken.

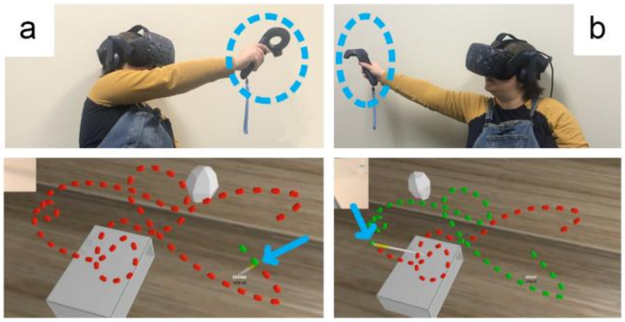

Figure 1: (a), and (b) Demo setup for VR Therapy game showing different positions of the user and the corresponding location in the VR drawing task (the fish model in this example). The blue arrows show the location of the virtual drawing brush held on hand.

We intend for the final version of the game to have a greater variety of drawing models, as well as simple shapes like circles and squares. The goal is for the user to progress through multiple levels, with the model in each consecutive level becoming more complex. Changing the image traced will keep the task from being monotonous. Increasing levels of difficulty will keep the patient's mind engaged as well as the body. At the game start, all of the model's dots are red. Touching a dot with the 'brush' controller colors it green. Once all of the dots are green, the model animates - the fish swims, and the chicken pecks the ground and waves its tail. This adds visual interest and variation. In addition, wanting to see the animation can provide more motivation to the player beyond finishing the level.

2.2 Evaluation

Virtual reality systems using handheld controllers function by tracking the exact position of the controllers in space. Because of this functionality, a VR program can easily create a track record of user motion by recording the position of the controller at equal increments of time. We created a data analysis pipeline to take advantage of this. First, we automatically generate a .csv file containing the motion data. We then visualize the data as an interactive 3D walk model using RStudio and Plotly's R graphing library (see Figure 2). The output data from the controller can be used as-is or cleaned by removing portions when the user's controller was not touching the model. The result is a 3D model of the exact path the controller took through space, optionally with changing colors along its length to show motion speed. Both the numerical data and the visualization provide objective measurements of user motion. Physicians may use this information to evaluate patient progress and identify problem areas.

3 Demo Scenario

In our demo, users will play the role of the patient and the presenter will play the role of the physician. The user will wear a HTC Vive™ and hold one of its controllers. (see Figure 1). The user will select the desired game mode, after which the presenter will position the model within the user's reach. The user will trace the model with their controller. For extra stretch and mobility

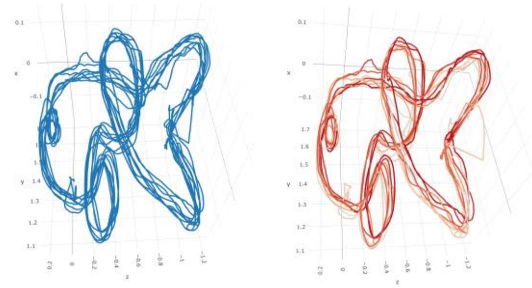

Figure 2: An example outcome of the data analysis pipeline: tracings of the fish model are captured from the hand controller. The right image has colors changing over time for each trial.

challenges of the user, the 3D model could be repositioned by the presenter. Afterwards, the visualization of the tracking data using the aforementioned data analysis pipeline will be presented to the user (similar to Figure 2) for evaluating the user's drawing accuracy and speed of motion.

4 Conclusion

Providing the best possible rehabilitative care for post-stroke patients is critical in their recovery. Virtual reality offers new possibilities for improving the experience for both patients and physicians. Incorporating gameplay elements into virtual reality therapy provides a reward system that keeps patients engaged—alleviating boredom. In this work, we introduced a VR therapy game. Using our system, patients can enjoy completing their rehabilitation sessions with a drawing task. Therapists, on the other hand, can track patient motion, and create digital models, which to evaluate patient conditions such as hand shakiness more objectively. As a next step, we plan to study the effects of our game with post-stroke patients in clinical settings.

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