Evaluation of a Stroke Rehabilitative Sonification System for AI-based Gamification of Neuromotor Therapy

Vaibhav Mishra
Georgia Institute of Technology
College of Computing
Atlanta, GA 30332
+1 (478)-484-7202
vmishra48@gatech.edu

ABSTRACT

Currently, stroke rehabilitation faces numerous problems in the effectiveness of therapy and the lack of engaging, at-home, and accessible rehabilitation techniques that can increase patient motivation. With the importance that stroke rehabilitation plays in in restoring motor functions for individuals with a history of stroke, it is imperative to create a solution to battle common challenges in the field including diminished audio-visual feedback, attention deficits, and lack of motivation during exercises. This study proposes a novel sonification system using AI-based gamification of neuromotor therapy that takes in real-time input from patients and provides sonification to therapy exercises to increase user engagement and motivation. Research questions of the study explored whether the sonification system was effective in improving participants' engagement as well as measuring the usability of the overall system using a NASA TLX survey as well as qualitative feedback from the participants. The participants in the user study included five adults (who did not have a history of stroke which is a limitation of the study). The results from the user study showed a statistically significant increase in user engagement and motivation while using the sonification system compared to not using the sonification system. Common limitations faced by the sonification system include the tasks being a little bit overwhelming to use and the need for more audio-visual elements to enhance the overall system.

CCS Concepts

• Human-computer interaction (HCI) → Gamification of AI-powered Sonification Systems • Computing evaluation methodologies → Assessment of a stroke rehabilitative sonification system for AI-based gamification of neuromotor therapy.

Keywords

Human-centered computing; AI-based gamification; Sonification Systems; OpenCV; Mediapipe; Rehabilitative technology; Stroke Technology

1. INTRODUCTION

In the United States, nearly 800,000 individuals have a stroke each year resulting in more than $50 billion in healthcare costs [1]. Moreover, the effects of having a stroke can lead to individuals with severe forms of motor dysfunction causing difficulties with mobility and requiring long-term rehabilitative care [1].

To regain mobility and neuromotor functions individuals who have had strokes practice a wide range of stroke rehabilitation exercises which includes various motion exercises, muscle strengthening exercises, and balance training exercises with their hands, elbows, shoulders, and feet to increase strength, balance, fine motor skills, and coordination [2].

While these exercises are effective methods for improving an individual's neuromotor functions there are significant problems and barriers that a person faces while doing these tasks leading to poor training outcomes. According to a paper published in the Journal of Functional Morphology and Kinesiology, stroke patients often feel many barriers to their recovery including attentional deficits, diminished processing of visual stimuli, and lack of motivation while performing stroke rehabilitation exercises [3]. These barriers not only lead to lower clinical improvements but also leave the patients with depression and anxiety feeling that they will not make any meaningful improvement to their mobility over time [3].

Thus, specific user needs identified include providing a motivating and engaging method of performing stroke rehabilitation exercises (with improved attention and multiple modalities of stimuli) and providing feedback and progress tracking to help stroke patients see their overall progress.

Some strategies that people are currently employing to overcome these problems include collaboratively setting up realistic goals and setting up a rehabilitation timeline to improve motivation [4], improving practitioner engagement to help build a positive relationship between therapists and patients for better engagement [5], and implementing wearable technology like a passive haptic feedback glove for improved attentional sensory feedback [6]. However, these methods still lack multiple modalities of stimuli including auditory and visual output as well as have limited amounts of engagement for patients.

Therefore, this project aims to solve this problem by enhancing stroke rehabilitation exercises using support from audio-based interfaces. Specifically, this project aims to use an integration of multiple technologies including computer vision, audio, and interactive games to create music-based gamification of stroke rehabilitation exercises. By using music as a form of gamification, the rehabilitation process can be transformed into an enjoyable experience while still focusing on therapeutic goals. The project would aim to build an app or wearable device where users' video would be an input to a camera system that would perform machine learning-based pose and hand gesture detection. As the user's movement changes, the components on the game screen will change providing real-time audio output in the form of musical melodies.

The research questions explored in this study included: Will the patient understand and be able to differentiate between the different hand gestures they perform with their left hand and the changes they hear/see from the instrument auditory and visual cues

changing from the system? Can the patient correlate the range of motion they perform with their right hand and the dynamics of the auditory feedback (that the volume and pitch increases as their hands reach a bigger angle)? Will using the sonification make stroke patients feel more engaged and motivated with their stroke rehabilitation therapy exercises? Is the sonification of three different types of hand movements too overwhelming for participants? Is the range of sonification accurate? Does the auditory cue have enough differences to be detectable by the user?

2. METHODS

During the protocol, the participant is first given a tutorial on how to use the audio-centric rehabilitation system after which they are asked to demonstrate how to interact with the system to make sure that they understand the overall sonification system. After which participants are asked to perform a therapeutic exercise without the sonification system for five minutes. Next, the participant is asked to perform the therapeutic exercise with the sonification system specifically a hand extension exercise, a fine motor movement, and an object grasping exercise (the same ones as previously done without the sonification system) for five minutes. Here the controls of the sonification system are controlled by the evaluator to simulate the sonification system. After the evaluation tasks, post-study assessments include a NASA TLX Survey to measure user satisfaction with the sonification system, ratings of completing rehabilitation exercises with and without sonification systems, and a qualitative feedback session.

Some shortcomings of the method included that the system was intended for stroke rehab patients, but the user evaluation study was done on a different population that didn't include this target population due to difficulties in finding the target population. Further shortcomings included the fact that the user evaluation study had a smaller sample size through which a greater number of participants would have enhanced the overall user study.

3. RESULTS

The user evaluation study was run on five participants giving them three rehabilitation exercise tasks both with and without the sonification systems and running three post-hoc user evaluation tests on each of the five participants.

The first evaluation test run on the participants included the NASA TLX Survey of the sonification system. The ratings were scaled to a 0-100 scale where 0 indicates "Very Low" and 100 indicates "Very High" for each of the six categories of user engagement and system usability.

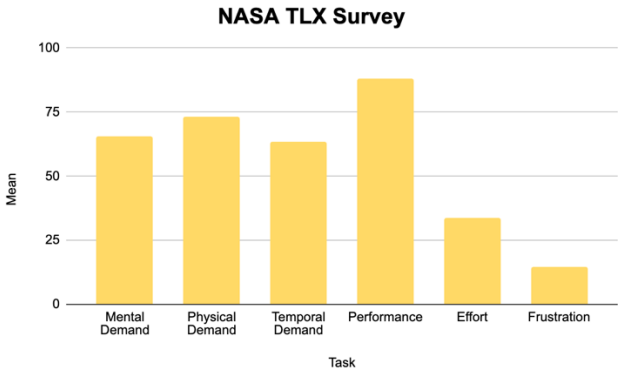

Figure 1. NASA TLX Survey of Sonification System

The overall results from the NASA TLX Survey included the following: mental demand (mean = 65.5), physical demand (mean = 73.4), temporal demand (mean = 63.4), performance (mean = 87.9), effort (mean = 33.7), frustration (mean = 14.6).

The second evaluation test run on the participants included the user motivation rating scale of each exercise both with and without the sonification systems. Each participant was asked to rate each of the three performed exercises on a scale of 1-10.

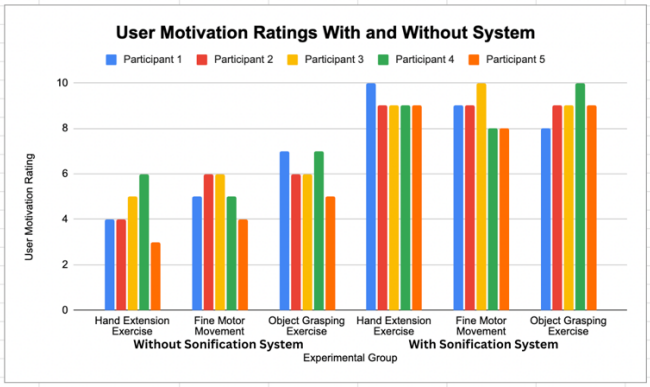

Figure 2. User Motivation Ratings of Rehabilitation Exercises With and Without Sonification System

Performing a paired samples t-test on the user motivation ratings with and without the sonification system yields a p-value of 0.0234, a mean difference between with sonification and without sonification equaling 3.733 with 95% CI [1.233, 6.234] and t-value of 6.4236 and a standard error of difference = 0.581.

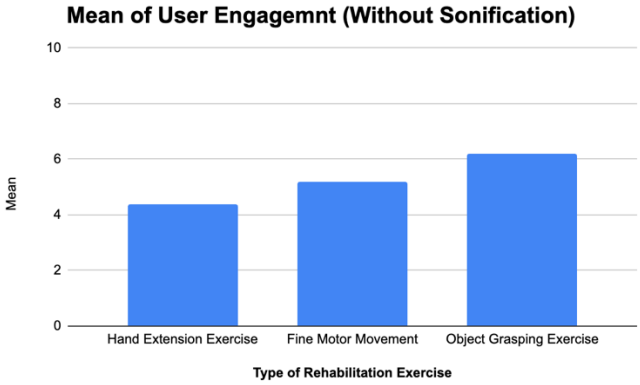

Figure 3. Exercise User Engagement Means Without Sonification

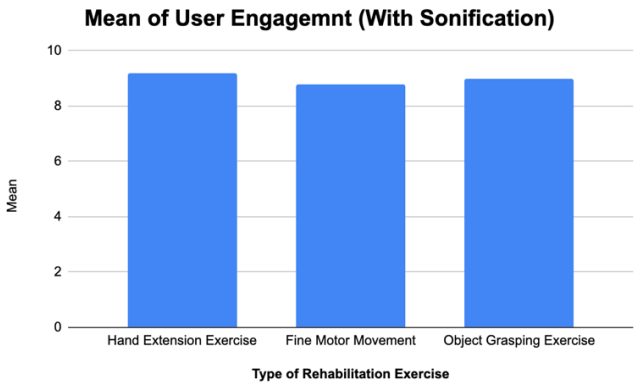

Figure 4. Exercise User Engagement Means With Sonification

Qualitative feedback included adding more interactive elements like additional visual elements to the overall sonification system and displaying both the hand tracking-based gesture detection and the visual elements on a split screen setting.

Another qualitative feedback point included adding more complex sounds like adding more types of instruments, adding particular symphonies or musical pieces, and adding more rhythmic sounds on top of the synthesized sounds.

4. DISCUSSION

The first user test of the NASA TLX Survey indicates that the system has great usability for the effort and frustration categories with very low user ratings indicating the system requiring low effort and causing low frustration. The category of performance was rated the highest showcasing that the participants felt that the system enabled them to achieve great performance in the required task of neurorehabilitation. Finally, the categories of mental demand, physical demand, and temporal demand were also rated higher which were some of the more negative attributes in the NASA TLX Survey and show the points on which the system can be improved upon to make it less demanding both physically and mentally for users to use.

The second user test of the user motivation rating indicated that the motivational ratings using the sonification system were statistically significant and higher than the motivational ratings without using the sonification system. This is highlighted by the statistics of the p-value being less than 0.05, the test statistic being greater than the observed test statistic and the mean difference between the sonification system and no sonification system being a difference of 37.33% increase in user engagement.

Furthermore, Figure 3 and Figure 4 show the increase in exercise user engagement rating from without the sonification system to with the sonification system. Specifically, the greatest increase in user engagement was in hand extension exercises which could be attributed to the fact that hand extension usually requires the greatest range of hand movement and is the most physically demanding compared to the other two categories of exercises. Thus, adding the sonification system to hand extension exercises creates greater user engagement and motivation to pursue the exercises with more focus and greater enthusiasm.

Using the NASA TLX Survey, the research question regarding whether the sonification of the three different types of hand movements was too overwhelming for participants was answered by the physical, mental, and temporal demands of the software system which also happened to be a weakness of the system because the users thought that the sonification system might be too overwhelming to use the first time a participant tried to use it. Furthermore, a strength of the system was found through the user engagement and motivational ratings which showcased that the participants felt more engaged and motivated with the rehabilitation exercises with the sonification system rather than without the system.

Qualitative feedback answered some of the research questions about whether the auditory cues had large enough detectable differences, whether the range of sonification was accurate, and whether patients were able to differentiate between the different hand gestures for different hands.

Some parts of the study design that might have been inadequate to fully answer the research questions might have been adding more quantitative metrics to the research questions that were supported more by qualitative methods as well as increasing the sample size and the addition of more types of exercises to see if the results transfer over in increasing user engagement for a variety of both upper extremity and full body exercises.

5. CONCLUSIONS

In conclusion, this study proposes the creation of a novel sonification-based gamification system of neuromotor rehabilitation for stroke patients to enhance user experience and increase the effectiveness and motivation of common stroke rehabilitation exercises. This system creates a novel integration of core technologies like computer vision, audio feedback, and interactive elements through which the key challenges posed in neurorehabilitation by stroke patients are solved.

The user evaluation tasks revealed that the sonification system significantly increased user engagement and motivation compared to traditional methods of no sonification. The tasks also revealed the fact participants faced higher levels of mental and temporal demand while completing the exercise tasks which can be a limitation of the sonification system. These findings suggest that audio-based interfaces offer a promising approach to overcoming barriers to effective stroke rehabilitation, including attention deficits and lack of motivation.

The next steps for this project would be to work on specific clinical metrics that can more accurately measure rehabilitative exercises, adding a feature to track progress over time, and enhancing the overall simulator design to include more sonification with a variety of music tones.

Overall, this study contributes to the growing body of literature on innovative approaches to stroke rehabilitation and underscores the importance of considering user engagement and motivation in the design of rehabilitation interventions. With further development and product iterations, audio-based interfaces have the potential to revolutionize stroke rehabilitation practices and improve outcomes for individuals recovering from strokes.

6. ACKNOWLEDGMENTS

The author would like to thank the participants of the research study as well as Dr. Maribeth Coleman and Dr. Scott Robertson for their valuable feedback.

7. REFERENCES

[1] Centers for Disease Control and Prevention. (2023, May 4). *Stroke facts*. Centers for Disease Control and Prevention. https://www.cdc.gov/stroke/facts.htm#:~:text=Stroke%20stat

istics&text=Every%20year%2C%20more%20than%20795%2C000,are%20first%20or%20new%20strokes.

[2] *Post-stroke exercise videos*. www.stroke.org. (n.d.). https://www.stroke.org/en/life-after-stroke/stroke-rehab/post-stroke-exercise-videos

[3] Tavares, E., Coelho, J., Rogado, P., Correia, R., Castro, C., & Fernandes, J. B. (2022, October 13). *Barriers to gait training among stroke survivors: An integrative review.* MDPI. https://www.mdpi.com/2411-5142/7/4/85

[4] Van De Weyer RC;Ballinger C;Playford ED; (n.d.). *Goal setting in neurological rehabilitation: Staff perspectives.* Disability and rehabilitation. https://pubmed.ncbi.nlm.nih.gov/20624106/

[5] Bright, F. A., Kayes, N. M., Cummins, C., Worrall, L. M., & McPherson, K. M. (2017, October). *Co-constructing engagement in stroke rehabilitation: A qualitative study exploring how practitioner engagement can influence patient engagement.* Clinical rehabilitation. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5613802/

[6] Maceira-Elvira, P., Popa, T., Schmid, A.-C., & Hummel, F. C. (2019, November 19). *Wearable Technology in stroke rehabilitation: Towards improved diagnosis and treatment of upper-limb motor impairment - journal of Neuroengineering and Rehabilitation.* BioMed Central. https://jneuroengrehab.biomedcentral.com/articles/10.1186/s12984-019-0612-y