Serenity: exploring audio-based gaming for arm-hand rehabilitation after stroke

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ABSTRACT

Recent studies have shown that adding sonification to stroke rehabilitation training is effective. It helps patients achieve better training results by positively affecting motor control, the somatosensory system, and patient engagement. This paper explores the concept of audio-based games in stroke rehabilitation, hypothesizing that the removal of a visual dimension might increase patient focus on the body part being trained. In an expert study with nine therapists we evaluated Serenity, an audio-based rehabilitation game, as a design probe to explore the potential of audio-based games in rehabilitation training. Results show promise for further exploring the concept of audio-based gaming in stroke rehabilitation.

CCS CONCEPTS

• **Human-centered computing** → **Accessibility theory, concepts and paradigms**; **Accessibility technologies**.

KEYWORDS

audio-based gaming, arm-hand rehabilitation, auditory feedback, stroke

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1 INTRODUCTION

Frequent and intense rehabilitation therapy is essential for stroke survivors to restore physical function, especially in the early stages of rehabilitation [13]. The ultimate goal of rehabilitation training is to help patients regain their ability to perform activities of daily living (ADL), such as eating or dressing, thereby helping them reintegrate into family life and back into society.

Completion of ADLs relies on sight, kinesthesia, touch, and hearing cues. Studies have demonstrated that incorporating additional sensory feedback into training can be used to improve motor control [4, 10]. In this regard, auditory feedback is indispensable for providing information about the environment and improving motor performance while increasing body coordination and movement stability [1]. Auditory information can guide the patient's movements during training [7], and this use of non-speech audio to convey information or perceptualize data is also known as "sonification" [11]. Still, the potential of sonification in this area is currently largely underexplored [6]. In particular, sonification is often used as supplementary information for vision, but its impact on rehabilitation as primary sensory information is unknown.

Engagement is another critical factor for patient performance in recovery, ensuring that patients can fully commit themselves to the training for a long time. Numerous studies have shown that game-assisted therapy helps achieve better training outcomes because repeated rehabilitation exercises are more engaging and motivating by completing in-game tasks [2, 3]. Meanwhile, audio feedback has also shown a great impact to help with player engagement. A study on music-supported therapy has shown that incorporating sound into post-stroke upper extremity therapy can increase enjoyability during training sessions [8]. Another study indicated that ambient sound rendering increases the realism and immersion of the virtual environment, resulting in increased user engagement [12].

In this paper, we present an exploratory study into using sonification as part of gamified rehabilitation therapy for post-stroke patients. We explore what value audio-based games can bring to arm-hand rehabilitation training and how to design appropriate interactive audio games for stroke patients. In the remainder of this paper, we briefly discuss the design of Serenity, an audio-based rehabilitation game designed as a probe for discussions with therapists. Finally, we present the results of a preliminary study with nine therapists, and we provide design recommendations for future audio-based games in physical rehabilitation.

2 DESIGN OF SERENITY

To achieve a better understanding of the potential of combining sonification with game-assisted therapy, an interactive audio game named Serenity was designed and implemented. The design of Serenity focuses on the following goals:

- Allowing patients to complete game goals with their eyes closed using only auditory feedback.
- Allowing patients to play with different physical items of daily life, train different hand abilities and restore the ability to complete daily activities.
- A low-cost, low-complexity solution, lowering the bar for clinical use.

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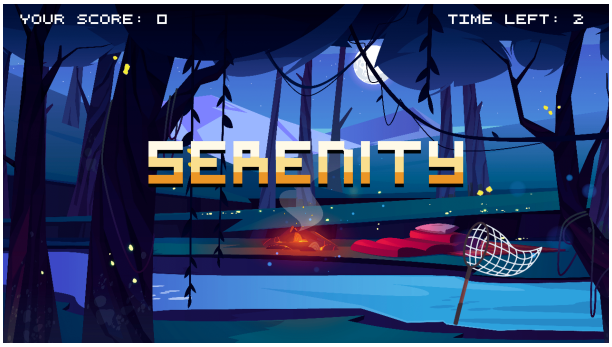

Figure 1: Game screen of Serenity.

2.1 Conceptual design

The context of Serenity is set in the jungle on a peaceful night with fireflies flying (Figure 1). In order to catch these fireflies, players need to move their arms to control a net. If the player catches a firefly within 15 seconds or times out, the firefly will change to another random position and the score will increase or decrease accordingly.

Serenity can be played with different physical items of daily life under open-eyes or closed-eyes conditions.

2.2 Implementation

In order to achieve the second and third design goals, Serenity was designed as a hardware-independent computer game, using the computer camera as motion sensor for tracking the color of an item held by the player, so that the movement of the hand can be mapped on the game screen as the movement of the net.

In order to achieve the first design goal, three kinds of audio were designed in the game. The first audio is ambient sound, including the sound of bonfires and birdsong, which shapes the scene of camping in the jungle on a summer night and enhances the immersive qualities of the game. Although this is an audio game, the visuals are still designed to provide the player with the first impression and bring the player quickly into the game scene. The second audio is a repeated beep sound that guides the movement, the pitch and speed of the sound vary with the distance between the hand and the target (both are higher when closer to the target), guiding the player to achieve the target with their eyes closed. Additional situational awareness is provided by shifting this audio stream between the left and right audio channels. Finally, two sound effects of notify the player of hitting or missing the target, giving the player feedback on the results of their movements.

Processing 4 [5] was used as the development environment for building Serenity.

3 EVALUATION

3.1 Method & procedure

We performed an expert review with Serenity as a design probe for audio-based rehabilitation games using a mixed-methods approach. Nine therapists from a rehabilitation center in Hoensbroek, The Netherlands (1 physiotherapist (P1), 6 occupational therapists (P2-7) and 2 physiotherapist interns (P8-9)) participated, all of which had at least basic professional knowledge about stroke rehabilitation.

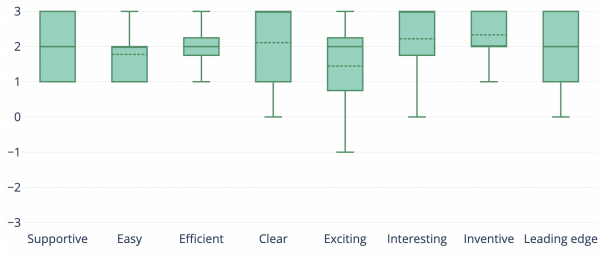

Figure 2: UEQ-S scores for Serenity.

Participants were first given an introduction video about Serenity and then five minutes to experience the game by themselves, both with their eyes open and closed. After that, an interview about audio-based rehabilitation games was conducted. Finally, a shortened version of the User Experience Questionnaire (UEQ-S) [9] was used to evaluate the user experience of Serenity. Interview data was transcribed and analyzed using an inductive coding approach, followed by iterative clustering into themes.

3.2 Results

Overall user experience - UEQ-S results (Figure 2) revealed that Serenity fulfills the general expectations concerning user experience, especially on inventiveness (Avg=2.33, Med=2, IQR=1). On the other hand, exciting rated lowest (Avg=1.44, Med=2, IQR=2). Several therapists (P1, P3, P8) pointed out that although they felt thrilled when they were playing for the first time, they could foresee the boredom after playing multiple times repetitively, as a therapy session usually lasts ten to fifteen minutes.

Eye-closed experience - Compared to video-based games, most therapists found that closing the eyes and using sound as a form of feedback brought a very different, but positive experience. For instance, P1 thought she was more focused and more sensitive: "*I think I was more concentrated. I was feeling more when my eyes were closed, I felt everything was more 'on'.*" P3 also stated that she focused more on the feeling of her arm: "*I noticed that if you have your eyes open, you're more focused on the screen. When you have your eyes closed, you are more focused on what you are feeling.*"

However, two out of nine therapists (P5&P6) made opposite points, arguing that they were distracted by the sound. As P6 explained: "*When I closed my eyes, I think I was too busy with the sound but not with my arm. My movement had no purpose. I have no idea what I did with my arm.*"

Benefits for particular symptoms - Therapists believed that sound can be used to help improve different symptoms of stroke patients, such as neglect and proprioception impairment. P9 gave an example of proprioception impairment in stroke patients: "*It's really a problem for patients sometimes because they don't know where their body is. They cannot catch a bottle without looking, they always have to look and then try to catch it. So it's a great thing to train their proprioception with sound.*" P4 thought it is worth trying this game with patients with neglect: "*...they ignore half of their space and body, and that is with their eyes open. And I think with the eyes closed, that feedback is difficult, they can catch things in their difficult side.*"

With regards to training proprioception P4 mentioned: "*Not every patient can feel how their hands move without seeing them. We*

practice it by having patients hold a knife in one hand and a fork in the other hand, and try to put them together with their eyes closed." After experiencing Serenity, she indicated that the way of playing Serenity is very similar to this training method.

P3 talked about some patients being unable to play video-based games because of their cognitive problems. "*Some of my patients cannot pay attention to the screen for long. Maybe with this game, they can play longer, because the sound is everywhere, they can't ignore it.*" In general, P2 believed that moving with the sound helps the motor system, stating: "*When you listen to the sound and then do the movement, you can have a strong connection between your neurological system and your motor system.*"

Patient-centered rehabilitation - Therapists requested the need for Serenity being customizable. For instance, P6 raised the need to set the position of fireflies rather than generate them randomly: "*I think I would make it more task-specific for my patients. Like, if I want my patients to stretch their arms, I can make a string of fireflies that are getting higher and higher, so it will stimulate patients to go there.*" Also, the game needs to be able to work with assistive tools for people with limited arm or hand capability, as P4 said: "*But there are also people who cannot lift their arm up like this. You have to think about how to do it in another way, maybe help them with some support tools.*"

Six out of nine therapists appreciated that Serenity can be played with different objects. As P1 is now participating in a study evaluating new devices for arm-hand rehabilitation, she shared her experience measuring patient performance: "*I really like that you can play the game with different kinds of objects. Because I test people with how they pick up stuff, like with five fingers or just with two fingers, some people find holding things difficult, some find pinching difficult. So it's really good to play with different gestures.*" Meanwhile, P9 proposed that she is looking for systems to support fine motor skills: "*I think it's a good game to train your proximal muscles. And it's good that you can use different objects from daily life. But I think maybe it would be nice if fine manipulation could be included, so you use your fingers separately when you really manipulate an object.*"

Real-world deployment - P6 thought Serenity can be well adapted to group therapy as it can be installed easily, leaving room for the therapist to take care of other patients: "*If you have a computer, you can say it's [ed. Serenity] ready, just go in front of it and start with your exercise, then that patient can already start. I think this game has great potential for group therapy.*"

All the therapists in the interview agreed that Serenity was suitable for home therapy. Normally people don't have expensive equipment at home like those in the rehabilitation centers, which highlights the fact that Serenity doesn't require any hardware other than a computer, as P7 stated: "*I think people can use it at home, especially because you can do it just on your laptop. That's really cool that you don't need any equipment.*"

4 DISCUSSION & CONCLUSION

This study pioneers the concept of integrating audio-based interaction into game-assisted therapy for arm-hand rehabilitation after stroke. Findings from our exploratory expert review show that the overall impression of Serenity was positive. We also found that therapists believe audio-based games enable the gamification of closed-eye training, leveraging an opportunity to have patients focus more on the subject of the training. Therapists recognized that interaction with sound in the game may help with different symptoms of stroke patients, such as impaired attention, spatial neglect, and proprioception deficits, as well as in improving motor control.

Naturally, this study presents but a first step in exploring the potential of audio-based games in rehabilitation. Further studies should emphasize on exploring together with the target patient group strategies for the application of audio-based games, and sketch the boundaries of the design space for such games. For example, the nature of the sound being used (e.g., pitch, rhythm, etc.), but also to what extent (and how) customization should be implemented to accommodate for varying patient needs.

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