A Computer Game-based Tangible Upper Limb Rehabilitation Device

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ABSTRACT

In order to regain the motor control of upper limbs, stroke patients should go through various exercises to resume finger, hand and arm functions. During such exercises, they need constant assistance, guidance and support from either therapists or caregivers. Due to the increase of aging population, the demand for technology support in home-based stroke recovery has rapidly increased in the last decade. This paper presents an interactive prototype designed to facilitate finger grasping, hand gripping and arm reaching exercises at home. It consists of a portable device with light, audio feedback and a computer game with two scenes and visual guidance. Preliminary usability testing in the community with elderly persons indicates that this device is easy to follow, and enjoyable to play. These trials explore the possibility and feasibility of implementing such tangible interactive training at home or in community rehab centers, inspiring us to improve such designs further to support active rehabilitation.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in interaction design**.

KEYWORDS

Tangible training device, Stroke rehabilitation, Home-based device, Upper limb rehabilitation, Interactive game

ACM Reference Format:
Qinglei Bu, Xiaoyi Cheng, Fan Yang, Jie Sun, Limin Yu, and Ying Hou. 2022. A Computer Game-based Tangible Upper Limb Rehabilitation Device. In *Proceedings of the 10th International Conference on Human-Agent Interaction (HAI '22), December 5–8, 2022, Christchurch, New Zealand.* ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3527188.3563919

HAI '22, December 5–8, 2022, Christchurch, New Zealand

ACM ISBN 978-1-4503-9323-2/22/12…$15.00
https://doi.org/10.1145/3527188.3563919

1 INTRODUCTION

Stroke is one of the main causes of long-term disability in adults, as it destroys nerve cells and systems, impairs body movement function, and affects around 16 million people worldwide every year [4, 8, 17, 20, 21, 23]. Even if most stroke survivors regain the ability to walk, many cannot recover the functional use of the upper limb. For example, merely 11.6% of patients achieved full functional recovery by six months [15], and more than 80% of stroke survivors have different degrees of upper limb impairment [16, 17], which affects the fundamental activities of daily living (ADL) and further reduces the quality of life [2, 17]. Thus, to regain the lost function of the upper limb, such survivors should go through long-term and intensive rehabilitation to enhance the coordination between muscle and brain [8, 12].

Traditionally, patients are encouraged to perform repetitive exercises under the supervision of a healthcare provider or physician in hospitals and rehabilitation centers [23]. Considering the immature development of rehabilitation centers in China, the available facilities are very limited even in big cities [19]. Thus, maintaining such therapeutic hospital-based rehabilitation is often impractical for patients and may incur higher costs.

In contrast, home or community environment-based rehabilitation exercises can reduce the anxiety, depression of patients, and also save hospital resources [6, 23]. As an alternative type, patients and caregivers gradually accept this new mode. While only traditional devices, as shown in Fig. 1 [7], are for repetitive exercise at home or in community centers. The monotonous nature of this device usually leads to passive participation, low motivation and effectiveness [13, 17]. One study by the American Stroke Association also supported that merely 31% of patients can keep following their therapist's plan during the long-term and tedious process [1, 12]. Thus, there are more opportunities and demand for low-cost and intelligent products [23].

Recently, game-based rehabilitation has been introduced to improve upper limb function by integrating recreational elements into training tasks and providing feedback [15, 17, 18, 22]. Advanced technologies in computer entertainment increased the sophistication and realism of games, where device-assisted therapy not only aids the exercise but also creates entertainment [9]. Some generic gaming consoles, such as Nintendo, have been used for rehabilitation with carefully tailored personal training needs. There is still a lack of home-based rehabilitation products in the market.

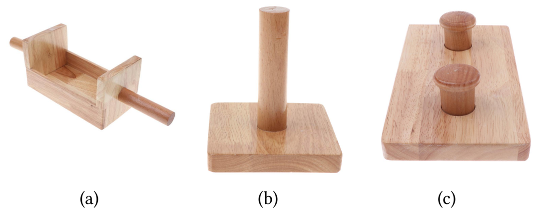

Figure 1: Traditional exercise tools

With the aid of the computer game, we propose a tangible upper limb rehabilitation device to support training exercises actively for finger grasping, hand gripping and arm reaching. It is a simple, space-saving, and low-cost device with visual, audio and tactile feedback for home use.

2 RELATED WORKS

Some traditional tools or devices are used to assist rehabilitation as discussed previously. However, they cannot stimulate the patient's interest [22]. With the help of technological innovations, upper limb training is often integrated with robotic devices and motion sensors [2, 17]. Colombo et al. [5] developed a simple game task that requires patients to grasp and control a robotic handle with sensors to detect and measure the force/torque applied in different directions. Moreover, an arm-sleeve sensor developed by Ploderer et al. [14] served as a detection system with an information visualization function. By assessing patients' rehabilitation habits and conditions, this device helps a lot for the therapists. In terms of home-based rehabilitation devices, Zhang et al. [23] proposed a rehabilitation aid device for patients with lateral asymmetry problems. This device can capture the movements of the dominant upper limb and drive the weaker upper limb for symmetrical movements.

Combining proximal and distal arm training, Wang et al. [17] designed a tangible game board with 64 RGB-LED rotary encoders evenly distributed on a circuit board to enhance arm-hand function training. The board features a simple and intuitive game interface for exercises at different difficulty levels. However, this expensive system requires the user to stand during operation, which is not friendly for elder people with leg weakness. Yang et al. [22] provided an upper limb rehabilitation device consisting of a tabletop and a colourful map that guides patients through both arm and finger exercises. Compared with traditional training methods, this device enhances the enjoyment of training through interaction with visual feedback and voice commands for patients at different stages. The exercise data can be recorded and sent to a computer via Bluetooth to track rehabilitation progress.

RoBiGAME, a robot-assisted serious game with a sandwich shop scenario for post-stroke cognitive rehabilitation, was developed [10]. The system provides different types of feedback: sound effects, lighting, and client mood to stimulate and encourage the player. In addition, computer games are designed to train practical tasks using fork knives [3] or cups/tennis balls [11] on a multi-touch tabletop screen. However, robotic devices with multi-touch tabletops are often expensive and difficult to implement widely. Sun et al. [12] designed three interactive rehabilitation games (Pig Hole, Rat Fight and Reinforced Grip) for the upper limb rehabilitation device (QikRehab) through the S4A software platform to motivate users. This system is inexpensive and allows for accurate tracking and monitoring of patient improvement during game time.

Inspired by these concepts, we proposed a simple, tangible and interactive device with a game design to support various training exercises on upper limb gross motor and fine hand control. User-friendly tangible objects are applied to help older people quickly become familiar with the training process.

3 DESIGN

3.1 Basket Model Design

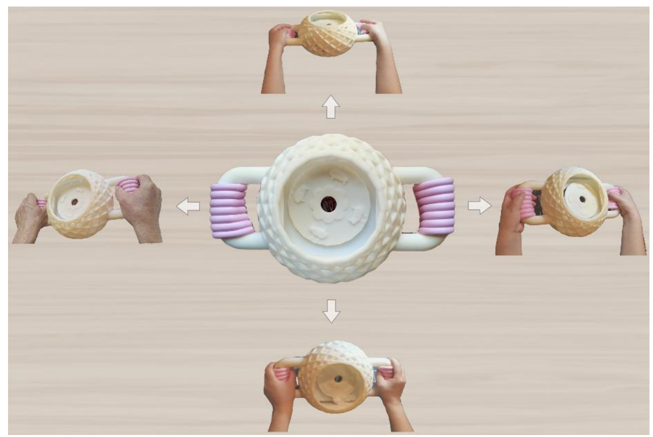

Figure 2: Prototype of seafood catching basket device

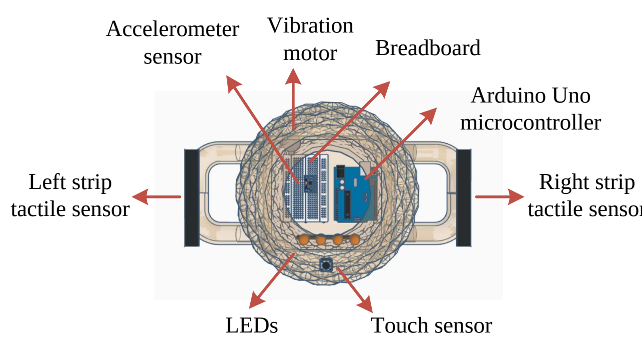

Figure 3: Components placement

The device has been designed as a basket for catching seafood, and the structure is similar to a tumbler toy, so it can stand up on its own, making it easier for the user to perform and increasing the joy, as shown in Fig. 2. Hollow-carved basket reduces the weight of the device and provides good heat dissipation of the embedded electrical components. Meanwhile, the internal LED's light can pass through the basket surface and become visible outside. The strip tactile sensors are placed on the handles for both sides to sense the pressure from the grip or grasp. The acceleration sensor is placed inside the basket, and the tilt angle can be calculated based on the

Table 1: Function of components

Component	Function
LEDs	Provide visual feedback
Touch sensor	Turn on/off the device
Strip tactile sensors	Sense the pressure for actions
Arduino Uno	Microprocessor
Vibration motor	Provide catching feedback
Accelerometer sensor	Calculate tilt actions

acceleration value. The LEDs and vibration modules can provide feedbacks to users. A touch sensor is placed on the surface of the device as a switch.

The specific function of each component is summarized in Table 1, and Fig. 3 shows the placement of components. The device can be exercised by grasping the handles on both sides, tilting backwards, forwards, left and right for seafood catching in the games. Scenes' selection and seafood capture are carried out by pressing the handles on both sides. Simple instructions for basic operation steps will be provided for users.

3.2 Gamification

To make the tangible device more attractive to stroke patients, a serious "catching seafood" game was developed based on the S4A platform, a modification of the scratch developed by MIT, that helps patients exercise their upper limbs. The device is connected as a controller for the users to play the game, which will help them exercise and receive feedback from both hardware and software. The game's background is based on a traditional Chinese story, which is about the mysterious origin of seafood on the beach in China. This story is familiar to the elderly persons, and gathering seafood activity is a typical daily routine for communities living near the sea. Two scenes in the storyline can be chosen: beach and underwater. The specific instruction will be explained in the following description.

The preparation for game is shown in Fig. 4. Setting up the device with the computer's communication is the first step. A welcome page is displayed. After pressing the touch sensor, the game starts. In this scene, an animated basket appears, giving a subconscious idea of moving the device by lifting different angles of its arms with the help of the accelerometer sensor. There is no specific instruction except for some basic operation descriptions before the game. Instead, we hope the users can learn how they can control the character "basket".

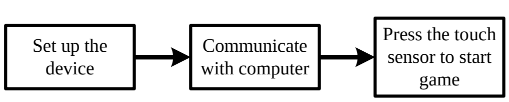

Figure 4: Pre-game preparation

There are two scenes currently for the user to choose, "Beach" or "Underwater" are shown in Fig. 5(a) and (b), respectively. More scenes can be designed based on the user's needs. The confirmation operation is the same logic as the later catching activity, which is

(a)

(b)

Figure 5: Examples of game interface, (a) Beach scene, (b) Underwater scene

gripping the device handle with the integrated strip tactile sensor. Two movement patterns differentiate from each other in the difficulty of catching the "seafood". Specifically, there are 4 crabs, 2 lobsters and 2 starfishes on the beach rotating from their original position at a slight angle, which is easier to locate than the fishes that continuously do the shutter swimming with a relatively fast speed. When the user moves the character role, touches any seafood, and grips the two handles, the character and seafood will enter a compulsive preset shaking, indicating the catching process. This procedure is to simulate the real-life fishing and catching procedure. After the user catches a creature, the device will broadcast a voice message to inform the success of a specific creature type.

We designed for elderly stroke patients who have difficulty understanding the rules for games, operations and interface, and try to maintain only the essential information and components and avoid obscure descriptions in the interface. The playing procedure is straightforward and patients can play independently after practicing several times. By designing multiple scenes, we hope to prolong the total game playtime and maintain the interest of the patients. The visual animation and audio guidance feedback from the computer are aligned well with the LEDs' light, vibration and light feedback from the interactive devices. There are two levels of coordination that can be found in this design: the fingers, hands and arms' muscles coordination; cognition and the visual system coordination.

4 PRELIMINARY USER TESTING

User tests and interviews were conducted to understand the prototype's usability and explore further improvements. Due to the pandemic prevention, we are not allowed to conduct the test in hospitals or rehabilitation centers. Instead, six elderly persons living in different communities are engaged, containing five males and one female, aged between 62 and 83. Some of them are with the muscle-controlled problem in a stage of physical inactivity. The user study was conducted in the following sequence.

- Introduction to the background and purpose
- Explain the operation of the prototype
- Record data from participants and collect their feedbacks

The set-up for the game was prepared in advance for them to play, as shown in Fig. 6. The researchers acted as the family members of the stroke patients and assisted them with their rehabilitation. User feedback covers three aspects: 3D model design, user interface, and the prototype. The feedbacks are summarized as follows.

The design has an interesting outlook, is lightweight, and the device is feasible for them to exercise for longer time. As for the user interface, some patients think the scenes are interesting, and the animation is easy to understand. The information given in the interface is straightforward and instructive. The difficulty of the different game scenes was also rated as a distinguishing feature with a strong immersion experience. Participants can reach an over 20-minute playtime.

Figure 6: User testing for interaction with device and game

We also collected the feedback from a physiotherapist at the Rehabilitation Centre of Dushu Lake Hospital, Affiliated with Soochow University (SDLH). He believed that the adjustable difficulty design could accommodate diverse patients' situations. He commended the design of this device for achieving the pronation and supination test, which is normally ignored in traditional rehabilitation. The attractive device is sufficient to maintain 20-40 minutes of training at home, which is similar to the exercise load in the hospital.

In general, all participants did not show obvious resistance in the user testing. They are all interested in playing with a 30 minutes training duration.

5 CONCLUSION

To summarize, the proposed seafood catching basket design is the combination of a hardware device and a serious software game, which provides a promising solution to post-stroke upper limb rehabilitation. The preliminary user testing shows that participants are enthusiastic about playing. This design also has the potential to save healthcare resources due to its home-based characteristic. We plan to collect more user testing data and improve the design to prompt the experience for stroke patients.

ACKNOWLEDGMENTS

This work was supported in part by the Teaching Development Fund of Xi'an Jiaotong-Liverpool University (XJTLU) under Grant TDF20/21-R22-144.

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