Games for Robot-assisted Upper-limb Post-stroke Rehabilitation:

A Participatory Co-Design with Rehabilitation Therapists

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INTRODUCTION

Stroke is one of the leading causes of death, physical disability, and loss of brain functionality each year, especially amongst older adults [1]. Good access to post-stroke rehabilitation exercises is essential for stroke survivors to maximize their potential to regain skills and physical abilities. However, a lack of availability of equipment and therapists can cause challenges in accessing rehabilitation exercises [1,2]. In recent years, there has been substantial research in the use of robotic systems for rehabilitation purposes to augment conventional rehabilitation programs, such as leveraging robots' high precision and endurance [2, 3, 4-5]. Rehabilitation using robot-assisted therapy has been shown to be effective in terms of providing repetitive tasks for stroke patients while reducing therapists' physical engagement and minimizing related costs [6, 7]. Rehabilitation robots can support the clinicians' goal of providing patients with a new way to facilitate recovery as well as providing a more objective way to evaluate patients' progress [6].

During rehabilitation, patients' motivation is considered as one of the major factors affecting rehabilitation efficacy because motivation directly impacts the quality of engagement in physical therapy exercises [8, 9]. Considering the fact that using rehabilitation robots can decrease the patient-therapist interaction, patients may lose motivation during the process if there is no appropriate encouragement and entertainment [10, 11, 12]. Several studies have shown that implementing therapy tasks through engaging games can increase patient motivation, in turn improving their recovery process [13, 14, 15]. These games can be displayed via various methods ranging from ordinary 2D screens to more advanced technologies such as head-mounted virtual reality (VR) or augmented reality headsets [9]. Patients are more engaged in rehabilitation exercises when games are added to robot-assisted therapy; however, the design and development of games for rehabilitation typically follows a linear process, which usually has a minimum involvement of therapists and end-users. As a result of this, while the effectiveness of a game user interface involving the robotic systems can significantly impact the rehabilitation process, the games that are designed for rehabilitation usually are not suitable in terms of therapeutic goals or not very motivating for patients.

The objective of the research presented in this paper is to identify different game design elements that could both motivate patients and support tasks that therapists have identified as having therapeutic value. This paper presents the results of a participatory design process carried out with a group of physical therapists to collect ideas on specific themes for developing VR games for upper limb rehabilitation aided by robotic assistance.

METHODOLOGY

Setup

The manipulandum, an upper-limb rehabilitation planar robot, is used as a robotic system for this research (Fig. 1). In order to measure the force applied by the patient, a force sensor is mounted on the end-effector of the robot [7]. The user interface is a monitor that is installed on top of the robot. Immersive VR or non-immersive 2D (i.e., computer monitor-based) games can be implemented on the robot.

Figure 1. The manipulandum robot with head-mounted VR headset

Participatory Co-Design Procedure

We chose to use a participatory co-design process to directly involve therapists in the game design process to capture therapeutic goals and considerations regarding patients' abilities and game functionalities. To accomplish this, we held a brain-storming session with therapists at a local hospital. The steps were as follows:

- An introductory presentation, showing commercially available VR systems (wired and standalone) was used to familiarize therapists with the equipment. The purpose of showing VR systems was due to VR is novel, and

not everyone would have experienced it before, whereas computer-based games are more common. We also showed therapists videos and pictures of the robotic system since bringing the robot to the ideation session was not possible.

- Therapists were invited to interact with the systems and VR games to allow a better sense of the immersive experience.
- In order to identify games that would be both motivating and effective in the rehabilitation process, a brainstorming session was carried out using the crazy 8's method, where each participant was invited to write down eight ideas in 8 minutes. These ideas included games that could be used by both head-mounted VR and 2D monitor screens.
- After collecting the ideas, we invited therapists to share their ideas with the rest of the participants. In order to encourage participants to listen carefully to each other's ideas and attend the discussion, we asked explicitly to describe similar ideas to the ones being described to make the session more interactive.
- The moderator (one of the authors) grouped ideas into similar categories by placing sticky notes on a large wall in the room. Then, therapists were encouraged to place their ideas in the themes they believe fit the best. For example, making coffee can be described as a category of cooking.
- After completing the clustering of the ideas, a final discussion was used to summarize ideas (e.g., outlining the next steps in research, how to use the ideas to inform game design, etc.) and to thank participants for their active participation.
- Three of the authors met post-session to create an affinity diagram to group ideas and to categorize games based on their affinities such as places, actions, game features, etc.

Figure 2. Participatory co-design session with physical therapists

RESULT

A total of fourteen participants, including physiotherapists (x5), occupational therapists (x2), a physician (x1), a nurse (x1), therapy assistants (x2), engineers (x2) and a game designer (x1), carried out the brainstorming session. The experience of healthcare professionals regarding stroke rehabilitation ranked from 3 to 20 years. The proposed games from the participatory co-design session were categorized through the affinity diagram (Fig.3) into three categories: activities of daily living (ADL), fun and fictional Games, and Music and Art. Fig.3 shows the number of ideas per each category and per each sub-category. The main cluster is for simulation of ADL (53 activities), happening in five different places (kitchen, bedroom, living room, bathroom, and outdoors). ADL games simulate real-life activities, such as activities in the kitchen (e.g., cooking, cleaning, reaching). For example, the user is asked to cook with different utensils and get the ingredients needed to make a dish or to carve meat.

The second cluster is fun and fictional games (36 ideas), divided into two subcategories (sport and specific games) that can represent imagined games that can be as simple as a puzzle game. For instance, in the fun and fictional game category, the user can be in a flight simulator environment avoiding or reaching specific objects like imaginary rocks. Finally, the last group is for activities involving music and arts (6 ideas). Therapists mentioned how some patients enjoy exploring their creative side as well as having background music during the rehabilitation sessions.

The researchers were interested in creating a game that maps to a real-life task as well as a fictional game; therefore, both these categories were selected to discuss further with therapists. Therapists stated that although fictional games can be more appealing compared to ADL games, they did not think they are necessarily more effective, and patients usually do not see a clear benefit of playing them. Therapists also discussed that these two categories might represent different results in terms of enjoyment, engagement, and short/long term improvement. It was mentioned that games should be functional and represent the activities of daily living. Therefore, fun and fictional games were less popular with the therapists we met. In addition, patients' ability to live independently is dependent on their ability to perform ADL by themselves. These activities include toileting, dressing, cooking, washing, bathing, eating, and functional mobility [16]. While reaching for a balloon can have the same movement as reaching for an item in a refrigerator, therapists wondered if patients might be discouraged if they do not see the functional correlation to everyday tasks. Therapists further stated that designed games should represent some movements like grasping, catching objects, reaching to a pre-defined point or region, and staying at that point or

region for an allocated time; however, these movements can vary in terms of technology used, i.e. head-mounted VR, 2D monitor screen, etc. As a result, based on their opinions and experience with stroke patients, therapists stated that ADL games that mimic real-life activities could be potentially more aligned in terms of rehabilitation and therapeutic goals.

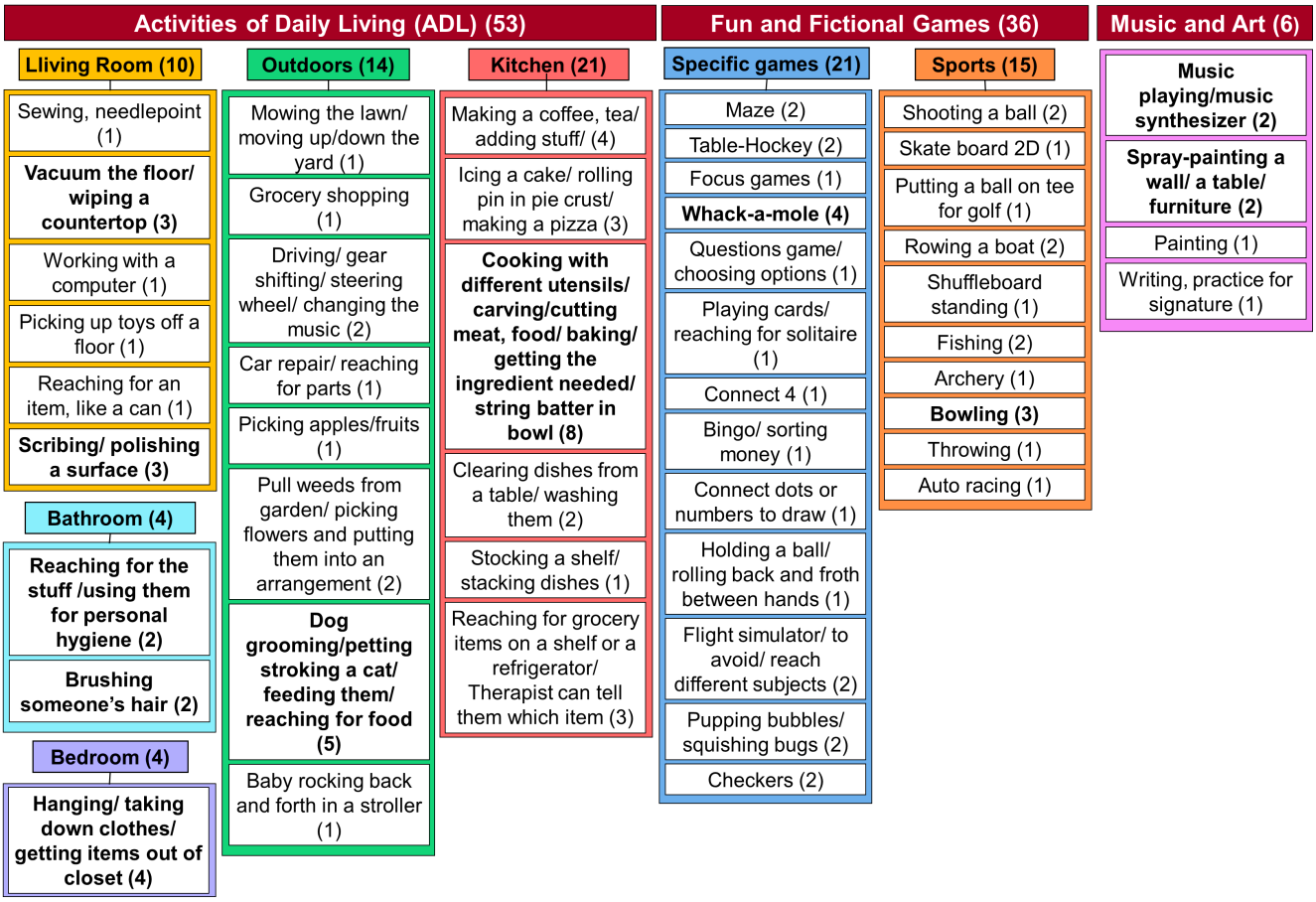

Figure 3. Affinity diagram for the game ideas from participatory design session. The number of ideas identified per each game/category is indicated in brackets. The bolded font game ideas are the ideas that have the most popularity in each sub-category among therapists.

DISCUSSION

One of the essential factors in designing games for rehabilitation is allowing a more participatory process, which includes physical therapists, as they understand the therapeutic goals and are the facilitators for technology adoption. The results of the brainstorming session indicate that, while fictional games may be more entertaining and appealing than other game categories, rehabilitation games that simulate more real-life events or environments seemed to be more attractive for rehabilitation therapists. It has been mentioned in the literature that designing rehabilitation exercises around ADLs can enhance the independence and quality of life among the patients [17, 18].

Among the games suggested by therapists, some games require robots with 3D motion, but some of them are implementable using both robots with 3D motion or planar (2D) motion. For example, cooking or personal hygiene games are best suited to robot-assisted therapy with a 3D moving pattern, since users should reach to different spaces and areas, whereas cleaning a surface or navigating a maze can be implemented using both types of robots.

For our rehabilitation robot, the games need to be compatible with the robot's restriction to planar movements. To further test the games with stroke survivors, we decided to create one game from each category of the ADL and fun and fictional categories for the 2D monitor screen attached to the manipulandum robot shown in Fig. 1. The decision to design a game in a computer instead of a VR headset was due to difficulties in obtaining ethics through both institutions, (i.e., the University of Waterloo and Grand River Hospital) within the timeframe that the research has to be executed.

Specific activities such as “scribing or polishing a surface” and “wiping a counter-top,” were chosen due to the simplicity of the activity as well as its frequent use in ADL for older adults. Among the fun and fictional games, we decided to choose a maze game where stroke patients can reach specific objects to get points. This game can accomplish the criteria of reaching, grasping, and staying at a point for an allocated time. The games have been selected based on the criteria such as the feasibility of being used together with the robot that only includes a planar range of motion, being engaging and fun and being popular among therapists as found in the affinity diagram. Future work encompasses the development of initial prototypes of the games and the evaluation of the impact on stroke patients.

CONCLUSION

Novel immersive or non-immersive VR games that are created for rehabilitation purposes should consider design criteria that are aligned with the therapeutic needs described by therapists. In the past, some researchers attempted to include criteria for designing rehabilitation games, such as the interactive technology they used (i.e., head-mounted VR or 2D monitor screen), game genres (i.e., movement evaluation, simulation games, etc.) meaningfulness of the games, level of difficulty, progress feedback, application area, and range of motions for therapy tasks [19, 20]. While these criteria are important for designing rehabilitation games aided with robotic systems, to the best knowledge of the authors, the current paper is the first paper to examine different game categories based on brainstorming sessions with physical therapists. This can be important in terms of providing patients and therapists with a balance of functionality, acceptance, and enjoyment. This study provides a basis for future work that will explore some of the design ideas introduced here, which need to be tested with patients and therapists in real-world rehabilitation scenarios.

ACKNOWLEDGMENT

We would like to thank the physical therapists, nurses, occupational therapists, and doctors at Freeport-Grand River Hospital for their dedicated support of this research. We also acknowledge funding from Dr. McPhee's Canada Research Chair in Biomechatronic System Dynamics and from Dr. Boger’s Schlegel Research Chair in Technology for Independent Living.

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