Novel Gamified System for Post-Stroke Upper-Limb Rehabilitation using a Social Robot: Focus Groups of Expert Clinicians

Ronit Feingold Polak
Recanati School for Community Health Professions, Department of Physical Therapy
Ben-Gurion University of the Negev
Beer Sheva, Israel

Ariel Bistritsky
Department of Mechanical Engineering
Ben-Gurion University of the Negev
Beer Sheva, Israel

Yair Gozlan
Department of Mechanical Engineering
Ben-Gurion University of the Negev
Beer Sheva, Israel

Shelly Levy-Tzedek
Recanati School for Community Health Professions, Department of Physical Therapy
Zlotowski Center for Neuroscience
Ben-Gurion University of the Negev
Beer Sheva, Israel
Freiburg Institute for Advanced Studies (FRIAS), University of Freiburg, Germany
shelly@bgu.ac.il*

Abstract— **We developed a novel gamified system for stroke upper limb rehabilitation using the humanoid robot Pepper (SoftBank, Aldebaran). In this paper, we present the results of a qualitative study with expert clinicians (n=12) on the compatibility of this system with the needs of post-stroke patients. We conducted three focus groups (3-6 participants in each group) in three rehabilitation centers. The clinicians in the focus groups found both the robot and the gamified system engaging and motivating for stroke patients' rehabilitation, and gave specific recommendations that may be applicable to a wide range of technologies for post-stroke rehabilitation.**

Keywords— focus-group, gamified-system, Socially-Assistive-Robot, stroke, rehabilitation, motivation, personalization.

I. INTRODUCTION

Up to 75% of stroke survivors have persistent upper limb (UL) sensorimotor deficits [1,2], which have a significant effect on the person's ability to be independent in activities of daily living (ADL) and participation, and as a result, on their quality of life [3,4]. Growing evidence indicates that to maximize recovery of a stroke-affected UL, therapists should apply intensive, repetitive task-specific training [5,6], using everyday tasks that are meaningful and already familiar to the person with stroke [7]. In order for the patient to repeat a certain task many times s/he has to be highly motivated and engaged. [8]. In the common practice of clinical rehabilitation, applying a high number of repetitions as part of intensive practice is placing a great challenge on the therapist, due to the limited time available in a therapy session and due to lack of motivation of the patient to train as needed in between sessions with the therapist. The difficulty in producing many repetitions of the desired exercise is even greater when the rehabilitation program ends and the person has to keep on training alone. Therefore, it is imperative to devise feasible, alternative methods for long-term rehabilitation in the rehabilitation center, and in the community that promote and motivate increased use and improved function in the paretic upper extremity [6]. Socially Assistive Robots (SARs) have been offered to serve as a tool for this endeavor [9-12].

SAR was defined by Matarić and colleagues as "a system that employs hands-off interaction strategies, including the use of speech, facial expressions and communicative gestures to provide assistance in accordance with the particular healthcare context" [13]. SARs are being used with healthy older adults, e.g., to enhance their exercise motivation, as described by Fasola and Matarić [13], and in assisting individuals with ADL in order to improve quality of life, as described by Louie et al. [14]. Previous works [9-12] suggest that incorporating SARs into a practice regime that calls for repetitive tasks can increase stroke patient's' motivation. However, it is not yet known whether this motivation lasts during a long-term interaction with the SAR, and whether it can lead to an improvement in the *functional* ability of post-stroke patients. Therefore our ultimate goal is to develop an autonomous robotic system for long-term post-stroke rehabilitation. The system includes a gamified set of functional tasks, which incorporates functional tasks from the everyday life of the person, e.g., reaching to a cup.

Prior to introducing the system to stroke patients, we conducted three feasibility studies with healthy young and old adults (n=88, 46 old) users. Two of these experiments are described in [15]. In addition, we conducted a focus-group study of expert clinicians (physical and occupational therapists, and an M.D.) who work with stroke patients in their everyday practice. In this paper, we will describe the results and the conclusions from the focus groups study. Focus groups are 'designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment' [16]. Focus groups are used to explore views on health issues, programs, interventions and research [17]. Interviews and focus groups are the most common methods for data collection in qualitative health research [17]. Focus groups have also been used as a method to evaluate perception of health-care suppliers on the implementation of SAR in rehabilitation [18] and in the elderly [19]. Our aims in this study were as follow:

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1. To evaluate the suitability of the gamified robot-based system we developed for stroke patients by compiling feedback from expert clinicians.
2. To assess, based on the expert opinion, what adaptations are required to obtain the optimal settings for stroke-patient rehabilitation.
3. To generate a set of guidelines that can be used by researchers and engineers when designing technological tools for post-stroke rehabilitation.

II. Materials and Methods

A. The Gamified System

We developed a gamified system for stroke rehabilitation, based on reach-to-grasp movements towards real objects, e.g. cups or jars. The functional games call for both motor and cognitive abilities. In each game there are several levels according to the number of objects the patients interact with at a time, according to their weight (they start from picking and placing objects with low weight and progress to ones with high weight), and according to the height of the platform on which they have to place the objects (they start at a low platform and progress to a high one). The gamified system is planned so the participant can either play with a humanoid robot (Pepper robot, Softbank Robotics Aldebaran), or with a regular computer screen, displaying the game instructions.

We developed five such games, one of them, the "cup game", was already described elsewhere [15]. Due to space constraints, we will describe one example here. In “the kitchen game”, in each of fifteen trials, the player has to organize a set of actual physical jars on shelves at three different heights, according to a picture shown on the robot's chest tablet (see Fig. 1). There are six levels of game difficulty. The difficulty is determined by a combination of: (1) the number of objects to be placed on the shelf; (2) their weight (half full or completely full with actual condiments, e.g., salt, sugar, etc.), and (3) the height of the shelf. The first level has three lightweight jars placed on the lowest shelf (height of a regular table). The sixth level has nine jars, of different weights, placed on three shelves. Prior to the game, the player has two training trials. The instructions and feedback are provided by the robot. There are two modes of game: time un-limited and time limited. In the first mode, the picture stays on the screen until the participant indicates he finished arranging the jars. This allows the clinician to learn the time it takes the participant to complete each trial of the task. In the second mode, the picture with the target order of the jars disappears from the screen after an individually set time, according to the participants' achievements in the first mode. Having completed the task, the player has to press a big push-button, in order to indicate he finished. After each trial, the robot either gives the player feedback on the timing (e.g., “try to do it faster next time”) or on the results (e.g., “you succeeded!”, "you were not right but try again"). The robot’s verbal responses are accompanied with head and arm gestures (e.g., hand clapping, or dancing a victory dance). The robot is autonomous in its function and the player can play without the intervention of a clinician or a caregiver. When the participant is wrong, the robot shows him again the correct order of the jars, so he can see where he went wrong. In each trial, the player collects points for the objects he ordered correctly. In addition, the player can take a break or stop the game at any time, and when he continues playing, the game will start from the same point.

B. Participants

Twelve expert clinicians: eight physical therapists (P1-P8), three occupational therapists (O1-O3) and one medical doctor specializing in physical medicine and rehabilitation (11 females, average age=38.9 yrs, average experience in stroke rehabilitation=13 years) participated in three focus groups. All expert participants work in rehabilitation centers, either in a rehabilitation unit in a hospital (n=6) or in an ambulatory rehabilitation unit (n=6). Participants were recruited to the study via the rehabilitation centers management. The rehabilitation centers were from both urban places and rural places, from both the center of Israel and from the periphery. The focus groups were conducted in the rehabilitation centers, due to convenience restrains, each clinician participated in the group that was conducted in his\her working place. In order to avoid homogeneity in the ideas expressed in the group, the groups included clinicians from different professions (PT, OT, MD). All participants reported that they had former experience with use of technology devices for therapy in their everyday practice, but not with humanoid robots.

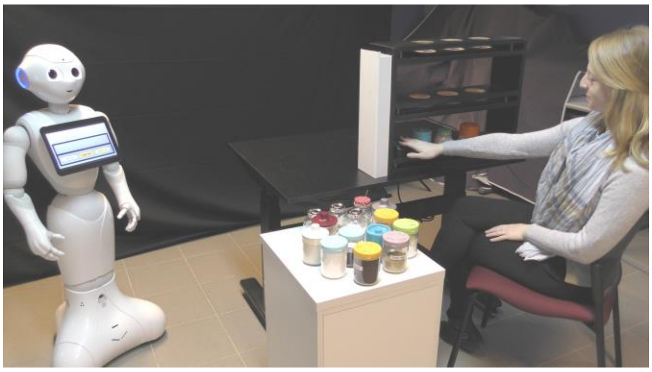

Figure 1: The experimental set up. *The participant sits facing a height-adjustable table. She has to order the jars on the shelves according to the picture displayed on the robot's tablet. When finished, she has to press the blue button on the bottom-left side of the custom-built shelf unit.*

C. Procedure

We conducted three focus groups [16] in three rehabilitation centers. The number of participants in each group was 3-6 clinicians (group 1 n=3, group 2 n=6, group 3 n=3) . Each group meeting lasted between 60-90 minutes. The first author (a physical therapist specializing in stroke rehabilitation) was the mediator of the group discussions. All the sessions were video-taped and audio-taped for further analysis. The research was approved by the Ben-Gurion University of the Negev ethical committee, and all the participants signed an informed consent to participate in the study.

At the beginning of each session, the mediator presented the aims of the long-term intervention with stroke survivors, the methods and the designated population, inclusion and exclusion criteria. In addition, she presented the aims of the focus group study. After the introduction, the participants viewed a 9.5-min video of participants from the feasibility study - healthy old and young individuals - playing each of the five games with the Pepper robot. We chose to show the participants a video of the interaction for two reasons: 1. We wanted the clinicians to experience and to assess how real users of different ages interact with the system. 2. Transporting the robot and the system between the locations of the focus groups was not feasible. Since our main goal was to assess the compatibility of the interaction and of the games to stroke patients, showing a video didn't diminish from the ability of the participants in the focus groups to appraise it. Prior to watching the video, participants received written questions to consider for each game specifically while observing the video. During the focus-group discussion, the video was shown in a loop, so the participants could identify specific points during the discussion. The guided discussion in the group was structured based on the questions the participants received in writing (see table 1), but was elaborated and generalized for the common theme of the games (see table 2). The mediator guided the participants to consider specific patients they are currently treating, or have treated in the past, when responding to the questions. They were asked to think of the compatibility and adaptability of the gamified system in relation to these patients. All questions are summarized in tables 1 and 2. The questions for the discussion were developed to follow the aims of the study.

D. Data Analysis

The audio recordings of the focus group sessions were transcribed and coded according to techniques used for qualitative data analysis [20]. Data were coded for key results using a combined deductive and inductive approach to coding [20]. This approach consisted of initial codes being generated based on the literature review and research questions. Two members of the research team, both are physical therapists specializing in stroke rehabilitation, independently read the transcripts. They independently and separately coded and categorized the impressions and suggestions of the participants from the different groups discussions into common themes that were common and span over the different sessions and participants. Following that, the results were discussed in the research team and a final coding scheme was generated. After two focus groups were conducted, there was a repetition of the ideas and the information obtained, and therefore the study stopped after three focus-group discussions [16]. In the third group, no major new data were collected, but mainly repetition of ideas that were already raised in the first two groups. As was noted by Hollis et al., much new information is generated in the first two interviews but subsequent interviews tend to elicit similar material [16].

Table 1: Questions presented at the focus-group sessions, while participants watched the videos

Is the game suitable for stroke patients?
What do you like about the game?
What are the difficulties that a stroke patient can experience while playing the game?
What changes should be made in the game to maximize its applicability for stroke patients?
Would you play the games with your patients?

Table 1: The questions relate to each one of the five games. Participants were asked to consider the questions while watching the video and to invoke patients they are either currently treating or had treated in the past.

Table 2: Questions presented at the focus-group discussion

What do you think of the role of the robot in the games?
What are the difficulties that a stroke patient can experience while playing the games?
What changes should be made in the games to maximize their applicability for stroke patients?
What patients do you think will benefit from the system and from the games?-think of patients you are currently treating or treated in the past
What do you think of the feedback the robot is giving? What feedback would you, as a clinician, like the robot to give?
In your opinion, what should and what must a technology system for stroke rehabilitation include?

Table 2: The questions in the focus group discussion.

III. RESULTS

Six different categories that were common to all the focus groups were identified from the transcripts.

A.1. Robot presence and embodiment

The participants found the presence of the robot engaging and mentioned its gestures as an added value of a humanoid robot, compared to when playing with instructions displayed on a computer screen.

"I'm really impressed by the multidimensional movement of the robot" (P2)

"His movements, his kindness are the main added value of the robot" (P2)

"The robot itself is very nice and very motivating for training" (P6)

Some of them thought the response time of the robot in some of the games was too slow, but agreed that the response time of the robot is suitable for the designated population of stroke survivors, especially the older ones.

"I think its pace would suit the older population" (O1)

"I'm afraid a slow response time may cause a lack of compliance of the young patients" (P1)

A.2. The Task

There was an overall agreement among all participants in the different groups that the various tasks in the five games are functional and represent tasks from the everyday life of the patients. They highlighted that this was a main novelty and added value of these games.

"I really like the functionality of the task and the use of actual everyday objects" (P1)

"The games are functional and simulate real functions, like a real kitchen" (P6)

The participants also commented on the comprehensive dimension of the task and the games, which integrate motor, cognitive, visual, and perceptual aspects.

"One of the nice things here is that the task incorporates so many things: motor, cognition, vision, hearing, perception and memory (P5).

"I really like the integration of motor and cognitive demands" (P2)

However, some of them thought this could be an impediment for some of the stroke patients because of their significant cognitive impairment:

"The cognitive aspect adds interest to the game and makes it more engaging, it is wonderful. But it could also exclude patients who could have benefited from the motor task but don't have enough working memory to accomplish the task, for example" (O1).

A.3. Engagement and Motivation

Participants stressed that in stroke rehabilitation, it is important for the task to be interesting and engaging over a long period, especially since some stroke patients have difficulty concentrating and persisting in one task for a long time.

"We know how difficult it is for patients to persist in one task during training, even with the use of technology, they lose interest quickly" (P1)

"Actually the older patients are really excited about new technology and from what I see, they can keep on training for forty minutes if it's interesting" (O1)

"There are patients who have difficulty persisting in the same task. By changing the environment of the game I allow them to keep on training reaching, which this is the goal."(O2).

The participants noted that, the progression in the game could be either in a specific game or between the various games, which could increase the patients' engagement.

"There is hierarchy in the game but also hierarchy between the games" (P8)

A.4. Motor Control

A.4.1 Bilateral or Unilateral use of hand

A great deal of discussion in all the groups revolved around the question of which of the two arms should be most engaged in performing the task: whether the task should be performed by the impaired arm, the non-impaired arm, or both. Participants agreed that in tasks that a person can complete with one hand (e.g. reach to a cup), participants should be instructed to use only their impaired arm. But in tasks that naturally involve both arms/hands (e.g. open a wallet), the patient should be instructed to use both arms and to make sure they do not use only their unimpaired arm.

"There are games that I would ask them to work bilaterally….the coordination and the bilateral use of the hands is also of great importance" (O1)

"One of the things I see with patients is that they have difficulty in coordinating both hands, so this is something I do want to work on and practice with my patients" (O2)

A.4.2 Variability of movement

Another theme of discussion in all the groups was on the way the patients will reach and grasp the objects. Specifically, the size of the object, its location, its weight, and what they are asked to do with the object (e.g. place a jar on the shelf or keys on a hanger) changes the way a person will reach, grasp and manipulate an object [21].

"In my opinion. As long as they can hold the object, according to their ability, it is good. The games call for a variety of movement types and different grasping motions" (P1)

A.4.3 Range of Motion

Participants stressed the importance of adjusting the required range of motion (ROM) of the arm in the game according to the ability of the participant. There are patients who post-stroke suffer from pain in their shoulder when making arm movements. With these patients, it is important not to go into a painful range, so that their pain sensation will not be exacerbated. In addition, demanding a motion beyond the ability of the patient may cause him to make un-desired compensatory movements.

"Patients who suffer from pain in the shoulder won't be able to practice in the high ROM, when the table is high or when they have to place the objects on the higher shelfs" (P7)

"There are patients who have better distal movement than a proximal one, the task should be adjusted to their ROM" (P2)

A.4.4 Motor control of the hand

Participants in the different groups mentioned the difficulty of some stroke patients to release their hand while holding an object and placing it on the surface. In addition, they anticipated that the cognitive load associated with the tasks could raise the patients' muscle tone and make it difficult for them to release the object from their hand.

"The cognitive load can raise the muscle tone in the hand and make it hard for them to release the hand" (P8)

"If the patients will have more time to complete the task, the load will diminish, so this could be a solution for them" (O3, P8)

A.4.5 Compensatory Movements

Stroke patients use compensatory movements of the trunk, the scapula and the shoulder when reaching to an object, due to the weakness of the arm, lack of coordination, and lack of proper motor control. The participants in the focus groups noted that the adaptability of the games make it possible to adjust the setup of the gamified system to the ability of the patient in order to avoid undesired compensatory movements, while encouraging the use of the impaired arm.

"In the kitchen games the initial location of the jars to the side of the shelves requires them to make trunk rotation to the paretic side which is very good." (P3)

"There are patients who may be high functioning, but they use a lot of undesired compensatory movements in order to complete the task…… Those who experience difficulty can stay on the lower shelves and not progress to the higher shelves if they use compensatory movements" (P7)

A.5. Feedback and Reward to the user

The participants commented on what reward and feedback the patient should receive when completing the task, either correctly or incorrectly, in order to motivate him to keep on training.

"It could be frustrating to keep on failing…Perhaps they should be given more feedback when they succeed and less feedback when they fail, so they won't be frustrated from their failures" (P8)

A.6. Adaptability to different populations

There was an agreement that the variety of games, and the multiple levels in each game, make the system adaptable for different levels of post-stroke impairment. Participants found some of the games more suitable for the moderately cognitive- or motor-impaired patients (but not severe), and some more suitable for the high-functioning patients.

In addition, they raised the option of making adjustments for different populations. For example, to include patients speaking native languages other than Hebrew, patients who suffer from motor aphasia, and patients of different ages. They found the instructions clear, and mentioned that most of the games do not depend on speaking Hebrew as a native language, in order to follow instructions. However, they offered to add an option to repeat the instructions or to add a video, in order to make it clearer for patients who are having difficulties understanding the instructions.

"In my opinion adding a demonstration video will make it easier for patients who are not native Hebrew-speaking, or have difficulties understanding the instructions" (P2)

IV. Discussion

We developed a gamified robotic system for stroke upper-limb rehabilitation using objects of everyday life. We used focus groups of expert clinicians, experienced in stroke rehabilitation, in order to evaluate the compatibility of the gamified system we developed with the process of post-stroke rehabilitation. In addition, we assessed, based on the expert opinion, what adaptations are required to obtain the optimal settings for stroke-patient rehabilitation. Our study showed that the clinicians in the focus groups found both the robot and the gamified system engaging and motivating for stroke patients' rehabilitation.

As was already stressed by [5] in a review of various robotic devices for rehabilitation, the goal is for the SAR to augment the work of the clinician, not replace it. It is designed to complement the one-on-one session with the clinician and to help the clinician and the patient to achieve repetitive task-specific training in an engaging and motivating manner.

Two main limitations of our work were the small size of two of the focus groups (n=3), and the fact that the participants in each group were from the same working place. In order to overcome these two limitations, and in order to minimize their effect on the variability of the group's discussion, we recruited to each group clinicians from variable professions (i.e. PTs, OTs and MD). Only one MD joined the discussion. However, from a clinical point of view, PTs and OTs are the clinicians who, in the everyday practice of rehabilitation, work with the patients to maximize the potential of UL recovery.

Six main themes of discussion were identified from the focus groups: 1. the role of the SAR and its embodiment 2. The functionality of the task and its grading. 3. Engagement and motivation 4. Motor control aspects 5. Feedback and reward 6. Adaptability to different populations.

Matarić et al. [12] highlighted that robots for stroke rehabilitation should include two guiding principles: (1) intensity of task-specific training and (2) engagement and self-management of goal-directed actions. In the robot-based system that we developed, we followed these guidelines with the addition of the guidelines that we will elaborate on here. One of the most notable requirements of SAR for rehabilitation, that was stressed in the focus groups discussion, is the need for personalization of the system. Feingold-Polak et al. [15], Eizicovits et al. [22], Kashi & Levy-Tzedek [23], and Clabaugh and Matarić [24] also highlighted the importance of personalizing the design of HRI and tailoring it to the specific task. This is of high significance in vulnerable populations such as neurological impaired patients, where robots can assist in maintaining a training regime and establishment of long-term trust between the user and the robot is essential [25]. Stroke patients often depend on reliable and effective relationships with their therapists. They are often older and multi-morbid and suffer from psychological distress because of their disability [25]. Thus, in order for the robotic device to be effective for therapy and accepted by both the patient and the clinician, it has to be flexible and adjustable, taking into account the complexity of the specific impairment. For the experience of the user to be positive, and to achieve engagement in the task, it is important to personalize the interaction according to the age, the needs of the user and the characteristics of the task. Robots that are designed for sensorimotor rehabilitation should be adaptable so they can be adjusted to each patient individually. For a system to be applicable to a wide variety of patients and different levels of impairments, and in order for it to engage patients in the long-term, there should be a variety of tasks, at different levels, applicable for both low-functioning and high-functioning patients. Users should be able to progress in the task according to their ability and performance. The instructions given to the user should be simple, gradually increasing in difficulty, and spoken slowly and clearly. The response time of the robot, however, should be fast [15]. Patients should have the ability to rest when needed, but not for too long. When the patient is fatigued and cannot complete the task without using undesired compensatory movements, the session should end. The participants in the focus groups stressed the importance of the reward, the motivation, and the adequate feedback to the user. Users need to receive feedback on their performance and on their results, as this is an essential component of their motor learning [26]. However, the feedback should be given in a manner and at a frequency that will not negatively affect their motivation to keep on training.

One of the main contributions of our novel gamified system is the use of genuine objects from the everyday life of the patients (e.g. jars or cups). Task-specific training is recommended internationally in stroke rehabilitation guidelines [27]. We integrated the use of real objects in a gamified way, and used the SAR as a means to motivate stroke patients. The clinicians in the focus groups appreciated this integration of real everyday objects with a physically embodied social robot, and stressed the potential it has for stroke UL rehabilitation.

Following this study, we performed several adaptations and changes in the system. In order to address the dilemma of unilateral or bilateral use of the hand we added to each game an instruction guiding the users whether they should use their impaired hand or both hands according to the natural requirements of the task. In order to adjust the cognitive load of the task to the ability of the participant we added an adjustable time for the image to be displayed on the screen (that is, the image on the robot's chest screen will not disappear after a uniform amount of time for all patients, but will be set by the clinician per patient). Specifically, in the first mode of game the image will be displayed on the screen without disappearing. In the second mode, the image can be displayed according to a defined time. In order to enable adaptability to different languages speaking participants and to make the instructions clearer, we added a demonstrating video of the task. In addition to the ability of the participant to rest whenever needed, we added to each game built-in breaks.

Robotic systems for stroke rehabilitation should be adapted both to the needs of the patients and to those of the clinicians, who are expected to introduce the system to their patients [5]. In the focus groups we conducted, the clinicians raised from their experience, interesting and essential points to consider, before introducing the system to stroke patients. Their insights can be also used when designing and implementing other technological tools for post-stroke rehabilitation.

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