Humanoid Robotic System for Post-Stroke Upper-Limb Rehabilitation: The Need for Personalization

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 designed a new system for stroke rehabilitation, with the humanoid robot Pepper (SoftBank Aldebaran). In preparation for placement of this system in a stroke-rehabilitation center, for a long-term intervention, we ran a feasibility study with healthy young and old adults (n=28) and performed a series of focus groups with clinicians (n=12). The results from these studies show the need for personalizing the interaction and give specific guidelines for this personalization.**

Keywords—gamified-system, socially assistive robot, stroke, rehabilitation, motivation, focus-groups, personalization.

I. Introduction

Growing evidence indicates that in order to maximize recovery of a stroke-affected upper limb, therapists should apply intensive, repetitive task-specific training [1,2], using everyday tasks that are meaningful and already familiar to the person with stroke [3]. Patient cooperation and satisfaction with a given treatment are essential in achieving successful rehabilitation results [4] and frequently lack of motivation is leading to poor rehabilitation outcome [5]. 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 lack of motivation of the patient to practice as much as needed. The difficulty in producing many repetitions of the desired movement 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 increased use and improved function in the impaired arm [2]. Socially Assistive Robots (SARs) have been offered as a tool for this endeavor [6,7].

SARs have been used with healthy older adults, e.g., to enhance their exercise motivation, as described by Fasola and Mataric [6], and in assisting individuals with activities of daily leaving (ADL) in order to improve quality of life, as described by Louie et al. [7]. In the context of rehabilitation, previous works [8-11] suggest that incorporating SARs into a practice regime that calls for repetitive tasks can increase stroke patients' motivation to practice. 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. The long-term interaction study with stroke patients using the robotic gamified system we developed will start at the end of March 2019.

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 have already been described in [12], and the third experiment will be described here in detail. 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. Our aims were:

1. To test how healthy young and old users perceive the humanoid SAR and what are their preferences when interacting with the SAR.
2. To test the importance of the robot's embodiment, by comparing performance and user satisfaction when completing the gamified tasks with the physically embodied robot, compared to when completing them using a computer screen
3. To evaluate the compatibility of the gamified system we developed to stroke patients by compiling feedback from expert clinicians.
4. To assess, based on the expert opinion, what adaptations are required to obtain the optimal settings for stroke-patient long-term rehabilitation, and to create a set of guidelines based on these recommendations.

II. Materials and Methods

A. The Gamified System

We developed a gamified system for stroke rehabilitation, based on reach-to-grasp movement 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, their weight (they start from picking and placing objects with low weight and progress to ones with high weight), and 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 computer screen

We developed five such games, and, due to space constraints, we will describe one example here. In “the cup game” [12], in each of fifteen trials, a row of colored cups is displayed on the robot’s tablet. The player has to organize a corresponding set of actual physical cups on the table according to the picture shown on the robot's tablet (see Figure 1). There are four levels of game difficulty, according to the number of objects, from three cups in the first level, to six cups in the hardest (4th) level. Prior to the game, the player has two training trials. The instructions and feedback are provided by the robot. The picture with the target order of the cups disappears from the screen after 8 - 10 seconds (for healthy adults; this value will be higher and individually adapted for stroke patients). Having completed the task, the player has to press a big push-button. 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 participants are wrong, the robot shows them the correct order of the cups, so they can see where they went wrong. In each trial, the player collects points for the objects s/he ordered correctly.

B. *Feasibility Study*

B.1.Participants

28 healthy participants (16 old adults, 11 females, average 70.6±3.3yo, and 12 young adults, 7 female, average 23.6±2.3yo) took part in this study. A convenience sample of young participants was recruited from the university's campus using social media and flyers distributed at the university. Older participants were recruited via advertising sent to the mailing lists of retired university workers (academic and non-academic positions) and the university exams inspectors. Older adults were ambulatory and independent in the community. Exclusion criteria were as follows: a vision impairment that would interfere with their ability to see the screen; a neurological or orthopedic impairment that would limit their hand or arm movement; and a Mini-Mental State Examination (MMSE) score below 24 [13] (MMSE was tested in the older adults only). All participants gave their written informed consent to participate in accordance with the requirements of the Ben-Gurion University Ethics Committee, which approved this experimental protocol.

B.2. Procedure

Each participant played one of the five games, both with the Pepper robot and with a computer screen. In the “screen” condition, participants played the same game, but the instructions were given by a video of the Pepper robot, displayed on a standard computer screen. Half of the participants in each age group first played with the robot, and half played with the screen first. When finished, each participant answered a short custom-built questionnaire regarding their experience with the games, and their preferences.

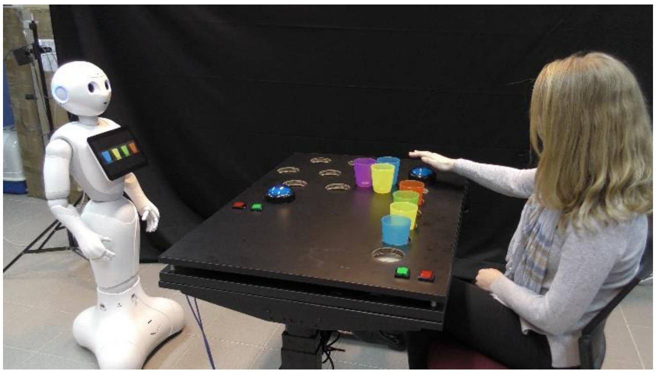

Figure 1: The experimental set up. *The participant sits near a height-adjustable table, in front of the Pepper robot. The participant has to order the cups on the table according to the picture displayed on the robot's tablet. When finished, she has to press the blue button on her right.*

C. Focus Group Study

C. 1. Participants

Twelve expert clinicians: eight physical therapists, three occupational therapists and one medical doctor specializing in physical medicine and rehabilitation (average age 38.9, average experience in rehabilitation 13 years), as well as two physical therapy students in their last year of studies (total of 14 participants, 13 females, 1 male), 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 focus groups were conducted in the rehabilitation centers, each clinician participated in the group that was conducted in his\her working place. All participants reported that they had former experience with use of technology devices for therapy in their everyday practice, but not with humanoid robots.

C.2. Procedure

We conducted three focus groups [14] in three rehabilitation centers. The number of participants in each group was 3-8 clinicians. 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 for further analysis. The research was approved by the Ben-Gurion University of the Negev’s ethical committee and all the participants signed an informed consent Form.

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 with healthy old and young individuals, showing the participants playing each of the five games with the Pepper robot. Prior to watching the video, participants received written questions to consider 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 according to the questions the participants received in writing. The mediator asked 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. The questions are summarized in Table 1.

D. Data Analysis

D.1. Feasibility Study

Data from the feasibility study was analyzed using the SPSS Statistics toolbox (version 25).

D.2. Focus Groups qualitative data analysis

The audio recordings of the focus group sessions were transcribed and coded according to techniques used for qualitative data analysis [15]. Two members of the research team, both are physical therapists specializing in rehabilitation, independently categorized the comments and suggestions of the participants into themes that were common and spanned over the three sessions. The results were then discussed, and a final coding scheme was generated.

Table 1: Questions presented at the focus-group sessions

Is the game suitable for stroke patients?
What do you like about the game?
What difficulties can a stroke patient 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.

III. Results

A. Feasibility Study

A.1 Robot presence and embodiment

In order to analyze the data from the feasibility study we performed the Chi squared test. Both old and young participants found the robot engaging. 46.4% preferred the robot condition, 25% preferred the screen condition and 28.6% had no preference. No statistical difference was found between the age groups (χ^2 (2, N=28)=4.235, p=0.12). In the young group, 58.4% preferred the robot condition, 33.3% preferred the screen condition and 8.3% had no preference. In the old group, 37.5% preferred the robot, 18.7% preferred the screen and 43.8% had no preference. Participants mentioned the interaction with the robot was more interesting, "human-like", responsive, and motivating than with the screen. Those who preferred the screen condition mentioned it was more familiar to them from former interactions with technology and some of them found the gestures the robot was making during the task to be confusing. Those who had no preference mentioned they enjoyed the game and the interaction in both conditions. Participants indicated that the starting condition (robot/screen first) affected their preferences, as it took them time to "get" the games. In the old group, 62.5% of those who started with the screen condition preferred the robot condition, and 37.5% had no preference. From those who started with the robot condition 37.5% preferred the screen, 12.5% preferred the robot and 50% had no preference (χ^2 (2, N=16)=5.81, p=0.055). In the between groups analysis there was no significant difference between the two age groups (χ^2 (2, N=28)=5.353, p=0.069). In the old group, 43.8% preferred the robot, 31.2% preferred the screen and 25% had no preference. In the young group, 83.3% preferred the robot and 16.7% preferred the screen.

B. Focus Group Study

Six different categories that were common to all the focus groups were identified from the transcripts. The categories were as follows:

1. ***Robot presence and embodiment:*** The participants thought the robot could be engaging and motivating for stroke patients more than a non-embodied training program.
2. ***The Task:*** The participants thought that the functionality of the task, the gradual increase in the difficulty of the games, and the demands of the task made the games adjustable and adaptable to a variety of patients.
3. ***Engagement and Motivation:*** Participants high-lighted that in stroke rehabilitation, it is important for the task to be interesting and engaging for long time. Some stroke patients have difficulty to concentrate and to persist in one task for long time. They noted that the progress in the games could be either in the game or between the variety of games, which could increase the patients' engagement.
4. ***Motor control:*** participants related to different aspects of motor control that they found in the game and marked their importance: bilateral or unilateral use of hand and arm, the variability of the required movement (the height, the features of the objects etc.)
5. ***Feedback and Reward to the user:*** The participants related to what reward and feedback should the patient receive when completing the task, either correctly or wrong, in order to motivate him to keep on training.
6. ***Adaptability to different populations:*** Participants found the system adaptable to different populations, for example variable native language speaking patients, patients who suffer from motor aphasia, and different ages.

IV. Discussion

We developed a gamified robotic system for stroke upper-limb rehabilitation. Our studies showed that both healthy old and young adults as well as the clinicians in the focus groups found the robot engaging and motivating. Based on our work with healthy young and old participants, and based on the focus groups with expert clinicians, we designed specific guidelines for the design and implementation of such assistive social robot systems in therapy and care.

Mataric et al. [11] 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 is the personalization of the system. Feingold-Polak et al. [12], Eizicovits et al. [16], Kashi & Levy-Tzedek [17], and Clabaugh and Matarić [18] already highlighted the importance of personalizing the design of HRI and tailoring it to the specific task. This is highly important in vulnerable populations such as older adults or 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 important [19]. 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 designated for sensorimotor rehabilitation should be adaptable so they can be adjusted to each patient in person. 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, structured, gradually increasing in difficulty, and spoken slowly and clearly. The response time of the robot, however, should be fast. Patients should have the ability to rest when needed, but not for too long. However, when the patient is fatigued and cannot complete the task in a good quality of movement, the session should end. Reward, motivation and adequate feedback are very important. Users need to receive feedback on their performance and results as this is important for their motor learning [20]. However, the feedback should be given in a manner and at a frequency that will not negatively affect their motivation to keep on training.

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. In conclusion, the developing teams of robotic systems for rehabilitation should be interdisciplinary, and include both engineers and clinicians in order to address all aspects of such systems and to make them feasible and usable.

Acknowledgment

The research was partially supported by the Helmsley Charitable Trust through the Agricultural, Biological and Cognitive Robotics Initiative and by the Marcus Endowment Fund, both at the Ben-Gurion University of the Negev. Financial support was provided by the Promobilia Foundation and the Borten Family Foundation grants. This research was also supported by the Israel Science Foundation (grants No. 535/16 and 2166/16) and received funding from the European Union's Horizon 2020 research and innovation programme under the A. Marie Skłodowska-Curie grant agreement No 754340.

We would like to thank Ms. Inbal Paran, Ms. Anna Yelkin and Ms. Allison Langer for their help in this research.

References

[1] Brackenridge J, et al. (2016) A Review of Rehabilitation Devices to Promote Upper Limb Function Following Stroke. *Neuroscience and Biomedical Engineering* 4: 25-42.

[2] Combs SA, et al., (2012) Effects of a repetitive gaming intervention on upper extremity impairments and function in persons with chronic stroke: a preliminary study. *Disability and Rehabilitation*, 34:15, 1291-1298.

[3] Hubbard IJ, Parsons MW, Neilsen C, Carrey LM (2015) Task-specific training: evidence for and translation to clinical practice. *Occup. Ther. Int*. 22: 28–35.

[4] Popovic MD, Kostic MD, Rodic SZ and Konstantinovic LM (2014) Feedback-Mediated Upper Extremities Exercise: Increasing Patient Motivation in Poststroke Rehabilitation. Hindawi Publishing Corporation BioMed Research International, Article ID 520374, 11 pages http://dx.doi.org/10.1155/2014/520374..

[5] Goršič M, Cikajlo I, Novak D (2017) Competitive and cooperative arm rehabilitation games played by a patient and unimpaired person: effects on motivation and exercise intensity. *Journal of neuroengineering and rehabilitation* 14, 23.

[6] Fasola J & Matarić MJ (2012) Using Socially Assistive Human-Robot Interaction to Motivate Physical Exercise for Older Adults. Proceedings of the IEEE vol. 100 No. 8 pp. 2512-2526.

[7] Louie GWY, McColl D, Nejat G (2014) Acceptance and Attitudes Toward a Human-like Socially Assistive Robot by Older Adults. *Assistive Technology* 26, 140–150.

[8] Matarić MJ, Eriksson J, Feil-Seifer DJ, Winstein CJ (2007) Socially assistive robotics for post-stroke rehabilitation. *Journal of NeuroEngineering and Rehabilitation*, 4 (5), https://doi.org/10.1186/1743-0003-4-5

[9] Swift-Spong K, Short E, Wade E, Matarić MJ (2015) Effects of Comparative Feedback from a Socially Assistive Robot on Self-Efficacy in Post-Stroke Rehabilitation. IEEE International Conference on Rehabilitation Robotics (ICORR).

[10] Tapus A, Tapus C, Matarić MJ (2008) "User-Robot Personality Matching and Assistive Robot Behavior Adaptation for Post-Stroke Rehabilitation Therapy." Intelligent Service Robotics Journal, Special Issue on Multidisciplinary Collaboration for Socially Assistive Robotics, A. Tapus, ed., Apr 2008, 169-183.

[11] Matarić MJ, Tapus A, Winstein C and Eriksson J (2009) Socially assistive robotics for stroke and mild TBI rehabilitation. *Stud Health Technol Inform*;145:249-62.

[12] Feingold-Polak R, Elishay A, Shahar Y, Stein M, Edan Y, and Levy-Tzedek S (2018) Differences between young and old users when interacting with a humanoid robot: a qualitative usability study. *Paladyn, J. Behav. Robot*. 9:183–192.

[13] Mitchell AJ (2009) A meta-analysis of the accuracy of the mini-mental state examination in the detection of dementia and mild cognitive impairment, *Journal of Psychiatric Research*, 43(4), 411-431

[14] Hollis V, Openshaw S, and Globe R (2002) Conducting Focus Groups: Purpose and Practicalities. *British Journal of Occupational Therapy*, 65(1), 2-8. doi.org/10.1177/030802260206500102.

[15] Gale NK, Heath G, Cameron E, Rashid S, Redwood S (2013) Using the framework method for the analysis of qualitative data in multi-disciplinary health research. *BMC Med Res Methodol*. 13:117. doi: 10.1186/1471-2288-13-117.

[16] Eizicovits D, Edan Y, Tabak I and Levy-Tzedek S (2018) Robotic gaming prototype for upper limb exercise: Effects of age and embodiment on user preferences and movement, *Restorative Neurology and Neuroscience*, 36(2), 261-274, DOI:10.3233/RNN-170802

[17] Kashi S & Levy-Tzedek S (2018) Smooth leader or sharp follower? Playing the mirror game with a robot, *Restorative Neurology and Neuroscience*, 36(2), 147-159, DOI 10.3233/RNN-170756

[18] Clabaugh C, Matarić MJ (2018) Robots for the people, by the people: Personalizing human-machine interaction. *Sci. Robot*. 3, eaat7451 DOI: 10.1126/scirobotics.aat7451 S.

[19] Kellmeyer P, Mueller O, Feingold-Polak R and Levy-Tzedek S (2018) Social robots in rehabilitation: A question of trust. *Sci. Robot.* 3, eaat1587.

[20] Cirstea MC & Levin MF (2007) Improvement of Arm Movement Patterns and Endpoint Control Depends on Type of Feedback During Practice in Stroke Survivors. *Neurorehabilitation and Neural Repair* 21 (5): 398-411.