Insights from a Long-Term in-the-Wild Study with Post-Stroke Patients using a Socially Assistive Robot

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Abstract: The growing care gap in rehabilitation calls for ways to help patients perform their exercises in a safe environment, while receiving feedback on their progress. Socially assistive robots have been suggested as potential agents in helping patients in their rehabilitation regimen. Here, we present a set of guidelines that we developed, based on our experience with running a 2-year in-clinic study with 20 stroke patients who used a platform we developed for post-stroke training over a 5-7-week period; 10 of those trained with a socially assistive robot, and 10 with a computer-based system. The guidelines we provide here are aimed to assist researchers who wish to implement a long-term technological intervention program with patients in the wild.

1 INTRODUCTION

Effective, scalable rehabilitation strategies are expected to be in higher demand in the coming decades, with increased patient survival after diseases with severe functional deficits, such as stroke (Kellmeyer et al. 2018). In recent years, many research works studied the applicability of using socially assistive robots (SARs) in different domains such as health, education, and elderly care.

Since March 2020, when the World Health Organization declared COVID-19 a pandemic, the rehabilitation world has been facing new challenges because of the requirement for social distancing, especially in at-risk populations. Khan and Amatya (2020) noted the following two challenges that the realm of rehabilitation faces in light of COVID-19: (1) Providing safe physical environments within rehabilitation wards that comply with social distancing and hygiene; (2) mitigating risk (as able) for a potential COVID-19 exposure to patients and staff. The requirement to keep a social distance and reduce physical contact stresses the need for alternative rehabilitative tools, such as SARs, to enable patients to have an uninterrupted (even if modified) rehabilitation regime. We thus argue that it is now more crucial than ever to develop SARs for healthcare.

We developed a novel gamified system for post-stroke long-term rehabilitation, using the humanoid robot Pepper (SoftBank, Aldebaran). We used the participatory-design approach, and implemented the robotic training platform in a rehabilitation clinic with 10 patients over a 2-year period; another group of 10 patients used the platform we developed using a configuration that does not include the robot, but uses the exact same rehabilitation exercises (Feingold Polak, Barzel, and Levy-Tzedek 2021). We thus conducted the first study (to the best of our knowledge) to evaluate a long-term intervention using a SAR with post-stroke patients in a rehabilitation center, as part of their conventional rehabilitation program.

Though social robots have a great potential to assist patients in the domains of health care and therapy [for examples see (Pulido et al. 2019; Broadbent et al. 2018; Bundea, Bader, and Forbrig 2021), there is still a limited number of works describing longitudinal studies within this domain (Leite, Martinho, and Paiva 2013). Leite, Martinho,

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and Paiva (2013) noted several reasons for this: (1) longitudinal studies are much more laborious and time consuming than short-term studies, especially in ecological environments and in the wild; (2) only in the last few years technology has become robust enough to allow for some degree of autonomy when users interact with robots for extended periods of time. There are thus very limited resourced upon which to draw, when researchers enter this "rough terrain" of longitudinal patient studies. For this reason, based on our experience in this 2-year in-clinic study, as well as on the experience reported by fellow researchers, we constructed a set of guidelines to be used by researchers who wish to run long-term studies with patient populations in the wild.

2 METHODOLOGY

We present the methodology of this study in brief, as it is detailed elsewhere (Feingold Polak, Barzel, and Levy-Tzedek 2021), and is not the focus of the current paper.

Twenty patients post-stroke participated in a long-term study, in which they used a platform we developed for post-stroke rehabilitation. The platform included seven gamified exercise sets, which corresponded to exercise sets that patient need to perform as part of their rehabilitation routine. In those exercise sets, we used everyday objects (such as kitchen items, keys, cards), which were all equipped with RFID tags, so we can track their location and provide feedback to the patients based on it.

Ten of these patients received the instructions for the exercise sets and the feedback on their performance from the Pepper robot (SoftBank Robotics); The other 10 patients used the same platform, and received the instructions for the exercise sets and the feedback on their performance via a standard computer screen.

Each patient came in for 15 sessions with the platform, each lasting 45-60 min, over a 5-7 week period. We thus report here the guidelines we drafted based on a total of 306 sessions.

3 GUIDELINES

3.1 Intensity, Specificity & Engagement

Matarić et al. (2009) suggested that the design of interactions with social robots for rehabilitation should follow two guiding principles: (i) high intensity of task-specific training and (ii) a system that will be engaging and user-friendly.

3.2 Task Variety

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, with different levels of complexity, which can be executed by both low-functioning and high-functioning patients. Users should be able to progress in the task according to their ability and motor performance. The participants in our study highlighted the variety of the tasks this platform offered practice on, which they did not get the opportunity to practice in other therapy sessions they received as part of their standard rehabilitation program.

3.3 Integration with Patients' Rehabilitation Program

In our experiment (Feingold Polak and Levy-Tzedek 2020; Feingold Polak, Barzel, and Levy-Tzedek 2021), we placed the SAR in a rehabilitation center as part of patients' scheduled rehabilitation program, which we believe was a facilitator to the success of the implementation of the system. We recommend that, if possible, the SAR will be situated in a familiar location, which the patient visits on a regular basis, so that travelling to train with the robot is not an added hurdle – for the patients or for the family members who drive them. In addition, scheduling sessions with the robot in the same day as other rehabilitative activities and having a single point-of-contact for both can facilitate the maintenance of a regular schedule for training.

3.4 Communication

The instructions given to the user should be simple, gradually increasing in difficulty, and spoken slowly and clearly. However, the response time of the robot should be as fast as in human-human interaction (Feingold Polak et al. 2018). From the experience from the current study and from previous ones (Feingold Polak et al. 2018; Feingold Polak and Levy-Tzedek 2020), when the response time of the system is longer than 4-5 sec participants experience it as slow, which causes frustration. We added to the robot a reaction of "I'm checking" if it took it longer than four seconds to examine whether the order matched the displayed image, so the participant will not experience the robots' response time as too long (for more on the effect of timing on users' perception of HRI, see (Langer and Levy-Tzedek 2020).

3.5 Fatigue Management

Since stroke patients experience frequent fatigue (Acciarresi, Bogousslavsky, and Paciaroni 2014; Cumming et al. 2016) and muscle weakness, patients should have the ability to rest when needed. When the patient is fatigued and cannot complete the task without using undesirable compensatory movements (Kashi et al. 2020), either the patient should rest, or the session should end. In our system, in addition to enabling the participant to rest or to pause when desired, we also added built-in stretching breaks.

3.6 Safety without Direct Contact

In our study, a clinician was always present in the room, to offer assistance if needed. Future studies on SAR interaction should strive to use a room with one-way mirror, so that the participant will be able to interact safely with the system without the presence of a research assistance, who will be sitting on the other side of the glass and will be able to see the participant and to intervene in case of a technical failure or if other assistance is required.

3.7 Multidisciplinarity and Participatory Design

Our multidisciplinary lab team built and developed the rehabilitation platform we used. It included a physical therapist who specialized in post-stroke rehabilitation, and engineering students. During the process we interviewed clinicians (Feingold Polak et al. 2019; Feingold Polak and Levy-Tzedek 2020; Feingold Polak, Barzel, and Levy-Tzedek 2021), patients and their family members (submitted for publication). We believe that a multidisciplinary team, and the participatory-design approach are central components in the success of this platform.

3.8 Feedback and Reward

Users need to receive feedback on their performance and on their results, as this is an essential component of their motor learning (Cirstea and Levin 2007). However, as the participants in our study noted, the feedback should be given in a manner and at a frequency that will not negatively affect their compliance to keep on training. Some of the participants in our study, especially the younger ones (<45 yo) mentioned they do not wish to receive verbal feedback on their performance after each trial, but would rather receive verbal feedback after several trials and visual feedback (like the sign of raised thumb for "like") following the other trials. In addition, they mentioned they would like to receive feedback on their motor performance. That is, they sought feedback on their body movements as they performed the task, whether they involved any compensatory movements, in addition to their task performance. We are currently in the process of developing this capability (Kashi et al. 2020).

3.9 Real-Time Technical Support

During the 2-year in-clinic study we faced several technical challenges; software and hardware malfunctions, which, at times, were not solved on the spot, and led to frustration on the part of the experimenters and patients alike. In the context of rehabilitation, it is advantageous to have clinicians run the study; the clinicians may not have a strong technical background, and thus their ability to resolve technical problems that arise may be limited. Technical problems are part of any technology implementation, specifically of novel prototype devices. Therefore, having quick-responding technical support, and training the clinician to solve basic technical problems which may occur, is essential for the success of technology implementation in a rehabilitation setting.

3.10 Personalization

The value in adapting the rehabilitation program to the personal needs of the patient was also stressed by the participants in our study, who mentioned the importance of personalizing the design of HRI and Human-Computer Interaction (HCI) and tailoring it to the specific task and patient needs. They mentioned they would like the system to be able to adapt to their personal performance, e.g. by adapting the feedback to their movement patterns, and by automatically progressing through the exercise game levels based on their success rates.

Importantly, personalization of human-robot interactions in the context of rehabilitation is multi-layered, and needs to be frequently updated, as opposed to a single setting that might suffice in other context. For example, personalization should include adaptive responses to the patient's motor ability, or physiological state (Feingold-Polak and Levy-Tzedek 2021) In rehabilitation, personalization is not only important in order to establish engagement, but it is an essential component for the recovery of motor and cognitive abilities over a long-term interaction, and is an essential part of establishing trust between the patient and the SAR.

4 CONCLUSIONS

During our experience in running an in-the-wild long-term study with patients, we identified several factors that can support the success of such an implementation of novel technology. The factors are related to the system itself (e.g., task variety), to the technical aspects of running the experiment (e.g., technical support), and to user-related factors (e.g., personalization). We anticipate that the insights we collected will be useful to researchers who wish to run a study with patients using novel technology, and most particularly to those who wish to run a long-term study in the wild.

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REFERENCES

Acciarresi, Monica, Julien Bogousslavsky, and Maurizio Paciaroni. 2014. 'Post-stroke fatigue: epidemiology, clinical characteristics and treatment', *J European neurology*, 72: 255-61.

Broadbent, Elizabeth, Jeff Garrett, Nicola Jepsen, Vickie Li Ogilvie, Ho Seok Ahn, Hayley Robinson, Kathryn Peri, Ngaire Kerse, Paul Rouse, and Avinesh Pillai. 2018. 'Using robots at home to support patients with chronic obstructive pulmonary disease: pilot randomized controlled trial', *Journal of medical Internet research*, 20: e45.

Bundea, Alexandru, Sebastian Bader, and Peter Forbrig. 2021. "Interaction and Dialogue Design of a Humanoid Social Robot in an Analogue Neurorehabilitation Application." In *International Conference on Human-Centered Intelligent Systems*, 76-85. Springer.

Cirstea, MC, and Mindy F Levin. 2007. 'Improvement of arm movement patterns and endpoint control depends on type of feedback during practice in stroke survivors', *Neurorehabilitation neural repair*, 21: 398-411.

Cumming, Toby B, Marcie Packer, Sharon F Kramer, and Coralie English. 2016. 'The prevalence of fatigue after stroke: a systematic review and meta-analysis', *International Journal of stroke*, 11: 968-77.

Feingold-Polak, Ronit, and Shelly Levy-Tzedek. 2021. "Personalized Human Robot Interaction in the Unique Context of Rehabilitation." In *Adjunct Proceedings of the 29th ACM Conference on User Modeling, Adaptation and Personalization*, 126-27.

Feingold Polak, Ronit , Ariel Bistritsky, Yair Gozlan, and Shelly Levy-Tzedek. 2019. "Novel gamified system for post-stroke upper-limb rehabilitation using a social robot: focus groups of expert clinicians." In *2019 International Conference on Virtual Rehabilitation (ICVR)*, 1-7. IEEE.

Feingold Polak, Ronit, Oren Barzel, and Shelly Levy-Tzedek. 2021. 'A robot goes to rehab: a novel gamified system for long-term stroke rehabilitation using a socially assistive robot-methodology and usability testing', *Journal of neuroengineering rehabilitation*, 18.

Feingold Polak, Ronit, Avital Elishay, Yonat Shahar, Maayan Stein, Yael Edan, and Shelly Levy-Tzedek. 2018. 'Differences between young and old users when interacting with a humanoid robot: A qualitative usability study', *Paladyn, Journal of Behavioral Robotics*, 9: 183-92.

Feingold Polak, Ronit, and Shelly Levy-Tzedek. 2020. "Social Robot for Rehabilitation: Expert Clinicians and Post-Stroke Patients' Evaluation Following a Long-Term Intervention." In *Proceedings of the 2020 ACM/IEEE International Conference on Human-Robot Interaction*, 151-60.

Kashi, Shir, Ronit Feingold Polak, Boaz Lerner, Lior Rokach, and Shelly Levy-Tzedek. 2020. 'A machine-learning model for automatic detection of movement compensations in stroke patients', *IEEE Transactions on Emerging Topics in Computing*.

Kellmeyer, Philipp, Oliver Mueller, Ronit Feingold Polak, and Shelly Levy-Tzedek. 2018. 'Social robots in rehabilitation: A question of trust', *Science Robotics*, 3: eaat1587.

Khan, Fary, and Bhasker Amatya. 2020. 'Medical rehabilitation in pandemics: towards a new perspective', *Journal of Rehabilitation Medicine*, 52: 5-8.

Langer, Allison, and Shelly Levy-Tzedek. 2020. 'Priming and Timing in Human-Robot Interactions.' in, *Modelling Human Motion* (Springer).

Leite, Iolanda, Carlos Martinho, and Ana Paiva. 2013. 'Social robots for long-term interaction: a survey', *International Journal of Social Robotics*, 5: 291-308.

Matarić, Maja, Adriana Tapus, Carolee Winstein, and Jon Eriksson. 2009. 'Socially assistive robotics for stroke and mild TBI rehabilitation', *Advanced technologies in rehabilitation*, 145: 249-62.

Pulido, Jose Carlos, Cristina Suarez-Mejias, Jose Carlos Gonzalez, Alvaro Duenas Ruiz, Patricia Ferrand Ferri, Maria Encarnacion Martinez Sahuquillo, Carmen Echevarria Ruiz De Vargas, Pedro Infante-Cossio, Carlos Luis Parra Calderon, and Fernando Fernandez. 2019. 'A socially assistive robotic platform for upper-limb rehabilitation: a longitudinal study with pediatric patients', *IEEE Robotics Automation Magazine*, 26: 24-39.