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Usability Feedback of Patients and Therapists on a Conceptual Mobile Service Robot for Inpatient and Home-based Stroke Rehabilitation

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Abstract— **In skilled nursing facilities and nursing homes the number of therapists and nurses is insufficient for the number of residents, affecting the quality of rehabilitation and daily care. This study explores the development of an affordable mobile service robot for therapeutic activities in a health center environment where the number of clinicians is insufficient for clinical demand. Using demonstrations and surveys we solicit users' (clinician and patient) responses to a prototype telepresence robot combined with a NAO humanoid robot trunk to facilitate remote communication between the patient and clinician and to complete supervisory exercising coaching. This paper presents the concept prototype and preliminary survey results of users' reactions in order to demonstrate its potential activities in their healthcare center.**

I. Introduction

AFTER discharge from acute care, more than 40% of stroke survivors will spend considerable time in a skilled nursing facilities and nursing homes [1]. In most of these environments, the number of therapists and nurses is insufficient for the number of residents, affecting the quality of rehabilitation and daily care. Two possible solutions to supplementing care are: 1) clinicians use telepresence robots to virtually monitor and interact with their patients and 2) to use assistive mobile robots or humanoid robots to act as coaches for patients in lieu of therapists.

Telepresence refers to the use of technology which allows a person to feel as if they were present, or to give the appearance of being present at a place different from their location. Typical solutions use mobile robots wirelessly controlled to allow a user to remotely interact with and observe people and their environment via web cameras, microphones, and speakers. Telepresence robots have been used in hospitals in the past as a communication tool between doctors, patients, nurses, and other members of the hospital community. One such hospital, El Camino Hospital, used a telepresence robot, called the VGo robot, in a situation that required a cardiac nurse to monitor patients in remote locations. For example, a pregnant woman with a heart condition needed to be monitored by the cardiac unit, but also needed to be in the hospital maternity ward to prepare for the childbirth. With the help of the VGo robot, a cardiac nurse could remotely monitor the patient while she was in the maternity ward [2]. Telepresence robots have also been used in home environments for elderly patients; they were used as a tool to aid in homecare assistance, which would eventually cut the costs of healthcare. These studies have researched how telepresence robots operate in a home environment, where obstacles and challenges are often encountered, and reported interviews of health professionals and elder adults. In general, feedback from participants were positive and supported the notion that telepresence robots are beneficial in healthcare [3, 4]. Another example is the MantaroBot, which has also been able to allow medical patients to virtually be at home and interact with family [5].

Humanoid robots, such as Aldebaran's NAO robot, have been used in the past for human-robot interactions in the healthcare environment. There have been numerous research efforts to validate the use of the NAO robots as tools in therapy for children living with Autism Spectrum Disorder (ASD). Children with ASD were noted to find humanoid robots appealing, more than typically developing children [6, 7]. Humanoid and mobile robot research efforts with stroke patients and elderly patients have typically been focused on using the humanoid mobile robot such as Care-o-bot [8] or the Bandit [9] as an exercise coach or helper for performing daily activities. These systems have been shown to be effective in motivating stroke survivors to pursue exercise and activities in under-supervised environments with limited care-giver oversight.

This study explores the development of an affordable mobile service robot for therapeutic activities in a health center environment where the number of clinicians are insufficient for clinical demand. Combining a telepresence robot with a humanoid robot was determined to be the best route in order to create a rapid prototype of this concept robot. Telepresence has been combined with humanoid robots in the past, but only in the sense of using telepresence to control the humanoid robot. The NAO was again used for

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this study and an operator used a telepresence system to direct the robot over wireless internet towards a determined location and execute various tasks through the NAO [7].For this current study, however, we desire a social robot model that can both assist and/or direct the patient in exercise and facilitate communication between the patient and the doctor or relatives using telepresence. A robot already equipped with telepresence capabilities was needed in order to fit the criteria of communication between doctor and patient. The humanoid robot was combined with the telepresence robot in order to fulfill the exercise coaching requirements. After the prototypes of the mobile robots were built, the next step was to demonstrate the robot's capabilities in front of clinicians and patients. Surveys were used to evaluate how well patients and potential caregivers responded to the concept and the prototype of the system. We measured users' (clinician and patient) responses to the VGo/NAO robot prototype. This paper presents the concept of the telepresence robot with humanoid coach and the preliminary results of patients' and therapists' reactions to the system and its potential use for their needs.

II. METHODS

A. Telepresence Mobile Robot with Humanoid Coach Prototype

The humanoid NAO T14 and the telepresence robot, VGo were combined, and programmed with some demonstrations of their capabilities.

The VGo robot was chosen because it has the capabilities needed for the telepresence base of the prototype, which were mobility and two-way video/audio communication. It was low cost, commercially available, and had a platform that could be easily modified. The VGo robot allows users to communicate with people through the use of microphones, speakers, a display, and a camera built into the robot. The VGo robot is controlled by the VGo PC App through wireless internet or 4G LTE. The user controls the VGo through the app driving the robot with the arrow keys to move the robot forward, back, left, or right. The VGo's camera can be tilted vertically, either autonomously based on the speed of the robot or manually through up and down arrow buttons in the app. In addition, the user can take snapshots of the local environment with the camera. The VGo utilizes sensors in its base to detect objects and drop-offs, which alert the user through messages in the app, thus assisting the user in avoiding such obstacles.

The NAO T14 (NAO) robot's torso has multiple degrees of freedom in the head and arms. Its key elements are electric motors and actuators. It also has a sensor network, including 2 cameras, 4 microphones, 1 sonar rangefinder, 2 infrared emitters and receivers, 1 inertial board, 9 tactile sensors, and 8 pressure sensors. The NAO has various communication devices as well, including a voice synthesizer, LED lights, and 2 high-fidelity speakers.

A platform was built to secure the NAO to the VGo robot so it would move with the VGo base. This was done by cutting distinct shapes into an acrylic sheet in order to not hinder the range of motion in the arms and to complement the design of the VGo robot. The platform was then attached to the robot using columns braced against the legs and base of the VGo. Figure 1 depicts the NAO robot attached to VGo. This set-up would allow the NAO T14 to interact with users more effectively, because the NAO would be closer to eye level and would be able to turn towards the user.

Figure 1: NAO and VGo Assembly.

B. Demonstration

The robots were programmed to complete a demonstration for clinicians and patients. The demonstration started with an introduction and explanation about the project and a short speech about the Lab. The VGo's telepresence capabilities were shown by driving it towards the participants in the front row of the group and a volunteer communicating with them using the VGo's two-way video/audio communication. The NAO portion of the demonstration followed. The NAO was programmed to wait for feedback from the touch sensors in its head. When it felt feedback for the first time, it was programmed to introduce itself as Flo and say that it will be the exercise coach. It would then move to the starting position and verbally explain the exercise that would be done. The first exercise was to raise the arms to shoulder level, parallel to the ground. The right arm would be raised so it would be perpendicular to the ground, then lowered back to shoulder level. Then the left arm would be raised and lowered in the same manner. This was done a total of five times for each arm. During the exercise, the robot would say preprogrammed words of encouragement to the participants, and when the exercise was completed, the robot would wipe its forehead and congratulate the participants. Then it would wait for feedback from the touch sensors in its head to start the second round of exercises. The format of the exercises was the same, with a verbal description of the exercise, encouragement during the exercise, and congratulation at the end. The NAO portion of the demonstration was strictly an automated program, with little feedback; there was no two-way communication. After the demonstrations were completed, surveys were passed out amongst the participants. There were two different types, one geared towards clinicians and the other towards patients.

C. Subjects

A demonstration was completed at an adult day care center, the Milwaukee Center for Independence (MCFI). Nine patients and seven caregivers participated in the demonstration at MCFI. The caregivers described the general patient population of the facility as elderly, with physical, cognitive, and developmental disabilities. The patient population included two stroke survivors, one with an impaired arm. There was also a patient with an impaired arm who did not suffer a stroke. Over half of the patient population was over the age of 50 and female (56%). The health professional population consisted of three therapists, two nurses, and a social worker (SW). There was an even distribution of ages amongst the population as well. The majority (86%) were female.

D. Surveys

The surveys sought information on demographic of the audience, overall impressions, human robot interactions and design (Table 1). Patients and clinicians were asked similar categories of questions.

The patient demographic questions determined the gender and age range of the patients, as well as if they had a stroke and an impaired arm. The first eleven demonstration questions, which determined the patients' opinions of the robot's features and characteristics, were answered on a scale of 1 to 5 (1 being the lowest score and 5 being the highest). The health professional demographic questions determined the gender and age range of the clinicians, as well as their job title. The clinicians were also asked to describe the patient population at the facility. The first eleven demonstration questions, which determined the clinicians' opinions of the robot's features and characteristics, were answered on a scale of 1 to 5, (1 being the lowest score and 5 being the highest).

On each survey, there were 5 questions pertaining to the participants' impressions of the robot. The questions asked the clinicians and the patients to rate the likelihood of them recommending the robot to friends, their willingness to exercise with the robot again, whether the robot was interesting, whether it was a good companion, and the overall impression of the robot's performance. On each survey, there were also 5 questions pertaining to human-robot interactions (HRI). The questions asked the clinicians and the patients to rate their perception of the robot as an intelligent, helpful, useful, and social being that is able to communicate with them. These HRI questions were similar to those asked in a previous study [9]; here the humanoid robot, Bandit, was evaluated for its ability to successfully coach elderly patients through therapy. The NAO demonstration was modeled after the work-out portion of the therapy sessions performed by Bandit. These five questions were regarding the intelligence, helpfulness, usefulness, social presence, and companionship of the robot. In that previous study, the participants rated the robot's intelligence and helpfulness high (averaging at 4.0 out of 5.0 or above), and the usefulness, social presence, and companionship moderately high (averaging above 7.0 out of 10.0). If the participants from MCFI rated similarly, if not better than the participants in the other study, it would indicate that the prototype could potentially be an assistive robot that successfully meets the criteria for social robotics set forth in the introduction.

On the patient survey three questions, which determined the patients' emotional responses during the demonstration, were answered on a Self-Assessment Manikin (SAM) scale [10]. The SAM scale is a non-verbal pictorial assessment technique that directly measures the pleasure, arousal, and dominance associated with a person's affective reaction to a wide variety of stimuli. The arousal scale is used to rate the perceived alertness and excitement as a physiological and psychological condition of the participants. The dominance scale is used to rate the participants' feeling of control in the situation. The pleasure scale is used to rate the positive (happiness) or negative (sadness) feeling caused by the situation. The SAM scales were recorded and analyzed in a range from -4 to +4, with 0 representing the center picture.

On the clinician survey, there were design questions. These questions were also on a scale of 1 to 5 (1 being the lowest and 5 being the highest). The design questions were modeled after the questions asked in the surveys distributed in *Design Requirements for a Tendon Rehabilitation Robot: Results from a Survey of Engineers and Health Professionals* [11]. These survey questions were created for health professionals and engineers that would be utilizing the robot in question. These questions asked the clinicians to give their opinions on design requirements by rating the importance of certain characteristics of the robot, such as the portability, ease of set-up, weight, cost, maintainability, durability, comfort, appearance, and operation noise level. Their opinions would be useful for insight into which design requirements would be prioritized in future design changes.

E. Data Analysis:

The data was analyzed using descriptive statistics where patient responses were compared to their caregivers. The surveys were divided into 4 main themes (Table 1). Patient and Clinician responses were compared for two themes: their impression about the robot and their perception of the interaction with the robot. Only patients' responses on the motivation and overall emotional response on the robot were assessed and discussed. Only clinicians' design recommendations were sought and assessed.

Table 1: Survey categories

	Themes	Patient Questions	Clinical Questions
A	Overall Impression of Robot	Demonstration Questions 1, 2, 9-11	Demonstration Questions 1, 2, 9-11
B	Human Robot Interaction	Demonstration Questions 4-8	Demonstration Questions 4-8
C	Motivation and Emotional	Demonstration Questions	N/A

	Response	12-14	
D	Design Recommendations	N/A	Design Questions 1-14

III. RESULTS

A. Overall Impression of New Robot

Figure 2 compares patients and clinicians overall impressions. Most of the mean ratings for these questions were greater than or equal to 4, which are considered high ratings. The patients tended to be more willing to recommend the robot to friends ($M_P = 4.11\pm0.39$ versus $M_H = 4.00\pm0.31$), and had a greater overall impression ($M_P = 4.5\pm0.28$ versus $M_H = 3.86\pm0.40$) than the clinicians. In contrast, the health professionals were more willing to use the robot for exercises in the future ($M_P = 4.11\pm0.35$ versus $M_H = 4.67\pm0.20$), and rated it higher as a companion ($M_P = 3.89\pm0.51$ versus $M_H = 4.00\pm0.22$) than the patients. The patients and health professionals equally thought that the robot was interesting ($M_P = 4.56\pm0.24$ versus $M_H = 4.57\pm0.20$).

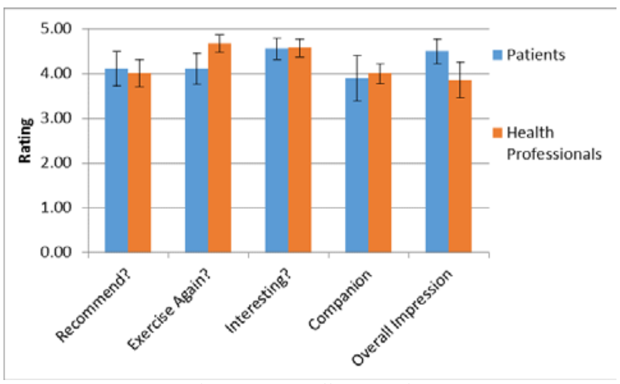

Figure 2. Overall Impression

B. Human-Robot Interaction

Figure 3 compares patients and clinicians responses to a previous survey results in [10]. Patients tended to rate the robot as more intelligent (3.67/5.00±0.44 versus 3.57/5.00±0.37), helpful (4.11/5.00±0.31 versus 4.00/5.00±0.34), useful (4.56/5.00±0.24 versus 4.00/5.00±0.34) and social (4.22/5.00±0.36 versus 3.50/5.00±0.21) than clinicians. In contrast, the health professionals believed the robot communicated more effectively (3.67/5.00±0.55 versus 4.17/5.00±0.75) than the patients. The data was normalized by maximum response. Note there was no communication data for literature. The results were relatively comparable and suggest that our system was successfully able to function as a mobile exercise robot agent and were able to elicit similar perceptions of intelligence, helpfulness, usefulness and social ability as the Bandit robot.

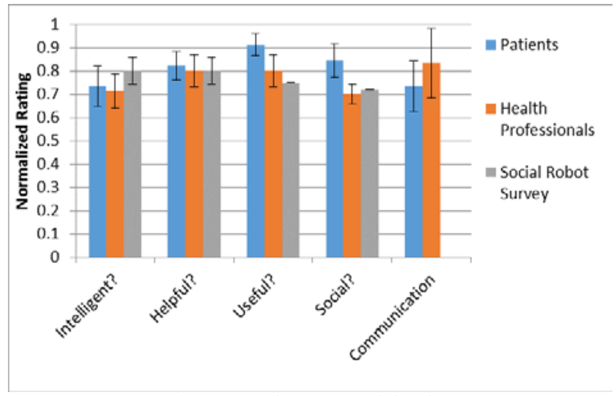

Figure 3. Robot as a Social Being

C. Motivation and Emotional Response

The SAM scale was recorded and analyzed in a range from -4 to +4, with 0 representing the center picture. The mean ratings of the scales are 2.00±0.87 for the dominance scale, 2.33±0.62 for the arousal scale, and 2.67±0.50 for the pleasure scale. These results suggest the robot elicited moderately positive responses. The mobile robot prototype elicited positive feelings of engagement and pleasure. The dominance score suggested that subjects were not intimidated by the system. The emotional response measures engagement and may indicate the patients' willingness to participate in exercising.

D. Design Recommendations

The results of the design questions can be seen in Figure 4 and Table 2. It is apparent that all the design requirements, except for appearance, were rated 4.0 or higher in terms of importance. Two requirements, ease of set-up and maintainability, were consistently rated 5.0. Portability, ease of set-up, maintainability and durability were seen as the most important features. The clinicians also rated higher than the participants in the tendon rehabilitation robot survey on all design features, except for weight and comfort, but only by a small margin [11]. The comparison can be seen below in Table 2. Differences in the actual survey could be explained by considering the differences in purpose of these systems. Overall, a mobile robot system for rehabilitation must enable clinicians to use it quickly and effectively without frequent repairs.

Along with the design questions, the health professionals discussed activities that the robot could be permitted to do. Suggestions for additional robot capabilities offered by the health professionals included:

- performing interactive exercises
- performing exercises along the lines of physical therapy and occupational therapy
- memory exercises
- incorporating music into the exercises
- setting up reminders for the patients to take their medication, go to doctor appointments, and check their blood sugar
- Assisting/directing during emergency situations

The health professionals also made comments on where the design of the robot could be improved. They noted that the Wi-Fi network that was being used was faulty, and transferring between the programs that controlled the robots seemed to be difficult. They also noted that the trigger being used to start the NAO's exercise program (tapping the head) could be difficult for certain patients. These results indicate that the clinicians were able to see the potential use of this system.

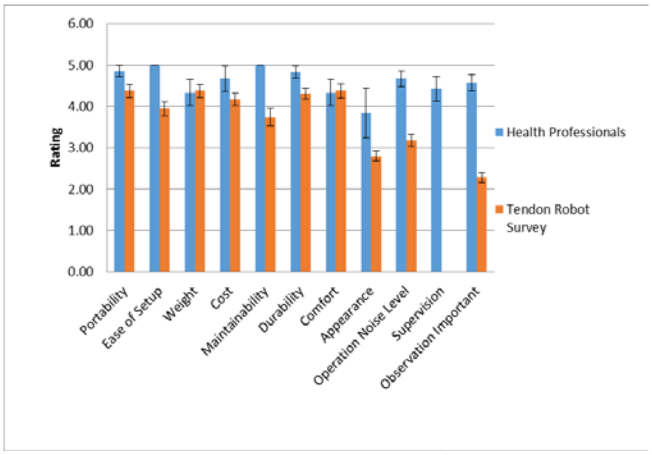

Figure 4. Design Recommendations

Table 2: Comparing Survey Results with *Design Requirements for a Tendon Rehabilitation Robot: Results from a Survey of Engineers and Health Professionals*

Design	Tendon Robot Survey		Health Professionals	
Question	Mean	Std. Dev	Mean	Std. Error
Portability	4.37	0.16	4.86	0.14
Ease of Setup	3.94	0.16	5.00	0.00
Weight	4.37	0.15	4.33	0.31
Cost	4.17	0.16	4.67	0.31
Maintainability	3.74	0.21	5.00	0.00
Durability	4.31	0.14	4.83	0.15
Comfort	4.37	0.17	4.33	0.31
Appearance	2.8	0.12	3.83	0.61
Operation Noise Level	3.17	0.14	4.67	0.20
Supervision	N/A	N/A	4.43	0.30
Observation Important	2.28	0.13	4.57	0.20

IV. Discussion and Conclusions

The questions regarding the participants' interest level in the robot, their willingness to recommend the robot to friends, and their willingness to exercise with the robot again describe the participants' enjoyment while working with the robot. Since both the patients and clinicians rated the robot as highly interesting, with mean ratings of 4.56 and 4.57, it is evident that the robot has the potential to be beneficial in rehabilitation.

It should be noted that the patients rated their willingness to exercise with the robot again and their willingness to recommend the robot to friends consistently high with a mean rating of 4.11. This was expected, because it shows that the patients enjoyed their experience with the robot, and the robot's features are desirable for the patients. The health professionals' ratings of their willingness to work with the robot again and their willingness to recommend the robot to friends were slightly less expected, with mean ratings of 4.67 and 4.00 respectively. Although both ratings are considered high, the difference should be noted. It is unknown as to exactly why there is a difference. One possibility could be that the clinicians interpreted the question as whether they would recommend the robot immediately, and would not do so until the robot was further developed.

When looking at the patients' and clinicians' overall impression rating, it is interesting that the patients' rated their impressions higher than the health professionals by 0.64 points. This difference was not expected. Although the health professionals' rating of 3.86 is considered to be moderately high, it should be noted that one of the health professionals gave a rating of 2 for their overall impression of the robot while the other clinicians rated their overall impression 3, 4, and 5. The clinician's rating of 2 significantly decreased the mean rating from a possible 4.17 to 3.86. This is the cause of the large difference in ratings. If the low rating was taken out, the difference would be halved, but the patients' rating would still be higher. This could be due to the clinicians having higher expectations than the patients.

Human robotic interaction ratings suggested that the VGO/NAO combination was believed to be a social being with intelligence and adequate communication. The patients' and clinicians' ratings of the robot's intelligence, at 3.67 and 3.57 respectively, are not ideal, due to the fact that they are lower than the rating of 4.00 in the social robot demonstration, but also not surprising. This is because the robot's program did not allow it to be aware of its environment and the participants took notice of that almost immediately. The participants could tell that the robot was basically performing a routine, rather than truly interacting with them.

The patients' and clinicians' ratings of the robot's helpfulness, at 4.11 and 4.00 respectively, are ideal, because they are greater than/equal to the social robot demonstration rating of 4.00. The patients' and clinicians' ratings of the robot's usefulness, at 4.56 and 4.00 respectively, are ideal, because they are high ratings. When comparing a being's ability to be social and communicate effectively, one would think that the abilities are synonymous. However, this is not the case in this survey, because the health professionals rated the robot's ability to communicate high, with a rating of 4.17, and its ability to be social only moderately high, with a rating of 3.50. Also, the patients rated the robot's ability to be social high, with a rating of 4.22, and its ability to communicate moderately high, with a rating of 3.67. This outcome could be due to several different possibilities. The health professionals could have rated the robot's ability to communicate higher than the patients, because they understood the instructions given by the robot more than the patients. At the same time, the patients could have rated the robot's ability to be social higher than the clinicians, because they responded to the robot's encouragement more positively than the clinicians.

Motivation and emotional ratings were moderately positive and were not as enthusiastic as desired. These ratings could be due to several different factors, such as the fact that the patients were following a routine, and not performing interactive exercises with the robot, which could make the patients feel more in control, excited, and happy during the exercises. Despite this, the motivation and emotional ratings from patients suggest that the VGO/NAO has the potential to be an exercise assistant that is capable of keeping them connected with caregivers and relatives. If the robot's autonomous and feedback capabilities were utilized more at the time, the patients' motivational and emotional ratings may have been closer to the desirable rating.

The preliminary data suggest that a mobile service robot of this nature would be of interest to the clinical community. At this time, the study provides insight into the potential acceptability of this system and provides guidelines for future development. For example, in the future, the humanoid robot should be programmed to have bi-directional communication with patients and therapists. The system would then have the capability to be more interactive with the patients while conducting the exercises. In addition, the real system should be more autonomous with the capacity to assist in a larger variety of physical exercises. Besides physical exercises, the robot may be able to assist cognitive and speech rehabilitation. In order to gather a more representative data set, a larger survey of patients and clinicians is underway.

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