Design of an Affordable Socially Assistive Robot for Remote Health and Function Monitoring and Prognostication

Michelle J Johnson PhD[1], Michael J. Sobrepera[1], Enri Kina[1], Rochelle Mendonca, PhD, OTR[2]

[1] *University of Pennsylvania, Philadelpha, PA, 19104, USA*
johnmic@pennmedicine.upenn.edu
mjsobrep@seas.upenn.edu
enrikina@seas.upenn.edu

[2] *Temple University, Philadelpha, PA, 19122, USA*
rochelle.mendonca@temple.edu

ABSTRACT

To address shortages in rehabilitation clinicians and provide for the growing numbers of elder and disabled patients needing rehabilitation, we have been working towards developing an affordable socially assistive robot for remote therapy and health monitoring. Our system is being designed to initially work via remote control, while addressing some of the challenges of traditional telepresence. To understand how to design a system to meet the needs of elders, we created a mobile therapy robot prototype from two commercial robots and demonstrated this system to clinicians in two types of rehabilitation care settings: a daycare setting and a inpatient rehabilitation setting. We propose to introduce the prototype as a social and therapy agent into clinician-patient interactions with the aim of improving the quality of information transfer between the clinician and the patient. This paper describes an investigative effort to understand how clinicians who work with elders accept this prototype. Clinicians from each setting differed in their needs for the robot. Those in daycare settings preferred a more social robot to encourage and motivate elders to exercise as well as monitor their health. Clinicians in the inpatient rehabilitation setting desired a robot with more therapeutic and treatment capabilities. Both groups wanted a robot with some autonomy that was portable, maintainable, affordable, and durable. We discuss these results in detail along with the ethical implications of increasing the robot's autonomy and suggest additional requirements for achieving a smarter robot that can meet the clinicians' social, health monitoring and prognostication desires.

1. INTRODUCTION

In 2030, the shortage of healthcare professionals compared to the aging population in western countries will be critical (Christensen, Doblhammer, Rau, & Vaupel, 2009; Lin, Zhang, & Dixon, 2015; Zimbelman, Juraschek, Zhang, & Lin, 2010; Ovbiagele et al., 2013). As a result, an insufficient number of clinicians will care for people who need rehabilitation and for those who are in nursing care facilities. This shortage of rehabilitation clinicians and experts already exists in rural (Lin et al., 2015; Zimbelman et al., 2010) and developing countries (Jesus, Landry, Dussault, & Fronteira, 2017; Rathore, New, & Iftikhar, 2011; Oyeyemi, 2001). The impending resource strain has led to a growing interest in telemedicine and remote-use devices to connect patients to health care providers. There are different terms which have been coined – telemedicine, telehealth, mobile health (m-health), and electronic health (e-health) – for remote intervention. The term used in any one situation depends on the functionality and application, but the objective is similar, i.e., to provide access to the rural or underserved disabled and elderly populations. How best to provide effective telehealth and to leverage cost-effective technology systems for use within telehealth is still unclear. In a review of 80 tele-medicine studies, only 25% concluded that telemedicine was effective and 23% found telemedicine "promising" at best (Rutledge, Haney, Bordelon, Renaud, & Fowler, 2014; Botsis & Hartvigsen, 2008).

Service robots may present a technological solution to challenges which exist in telehealth and telecare for home and hospital environments (Van Den Berg, Schumann, Kraft, & Hoffmann, 2012; Smarr et al., 2014; Schulz et al., 2015). These robots can function as intelligent assistants and as exercise coaches in rehabilitation and medical environments, and may often be used to direct, monitor, and assist the elderly or patients with motor impairments. *Bandit* (Fasola & Mataric, 2013) and *Care-o-Bot* (Mast et al., 2015) are examples of robot systems used as exercise coaches or helpers for performing daily activities with elderly stroke patients. Evidence suggests that they are effective in motivating stroke survivors to pursue exercise and activities in environments with limited clinical and caregiver oversight (Fasola & Mataric, 2013; Mast et al., 2015). Many of these solutions have been expensive and may not be cost-effective in the long-term. The *NAO* robot (Softbank) is a more cost-effective exercise coaching robot, which has had success with children with motor and cognitive impairments (Miskam et al., 2013; Scassellati, Admoni, & Matarić, 2012; Calderita, Bustos, Suarez Mejias, Fernandez, & Bandera, 2013), and mixed reviews with older adults where many like it as a potential exercise partner, health coach and motivator, although some preferred a human motivator (Torta, Oberzaucher, Werner, Cuijpers, & Juola, 2012). Several studies showed that *NAO* can be successful as an exercise coach with elders (Torta et al., 2012; López Recio, Márquez Segura, Márquez Segura, & Waern, 2013). To optimize its use as an exercise coach, Lopez and colleagues suggest that the system's speed of movement should be closely monitored. Elders' interest waned when the robot moved too slow. They preferred when it moved fast enough to motivate them to increase the speed of their own motion to synchronize and keep pace with it (López Recio et al., 2013).

Numerous studies have investigated the use of commercially available telepresence robots as telehealth platforms (Tsui et al., 2014; Reynolds, Grujovski, Wright, Foster, & Reynolds, 2012). The advantage of these robots over the classical research oriented mobile service robots is their cost. Commercially available systems are often semi-autonomous, i.e., able to dock themselves, prevent collisions, and sometimes complete basic navigation tasks, with simple mobile platforms and a screen for internet-based communications. These telepresence robots exist in hospitals 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* (seen in Figure 1), in a situation that required a cardiac nurse to monitor a patient remotely while she was in the birthing facility (Rutledge et al., 2014). Service robots with telepresence capabilities can also aid elderly patients in their homes. The *VGo* telepresence robot has been shown to provide the opportunity to connect elders to their caregivers and family by providing a virtual "in-person" environment (Seelye et al., 2012). Feedback from interviews with healthcare professionals and elder adults were positive and supported the notion that telepresence robots are beneficial in healthcare (Van Den Berg et al., 2012; Vermeersch, Sampsel, & Kleman, 2015). Vermeersch and colleagues found that the technological advantages of using a telepresence robot include time savings, elimination of travel expenses and fewer hospitalizations.

To extend these ideas, we created a first prototype of a mobile therapy assistant, named *Flo* (Figure 1), from a *NAO* humanoid exercise robot in conjunction with a telepresence robot, *VGo* (Wilk & Johnson, 2014). The telepresence robot enables a healthcare professional, family member, or a caregiver to communicate remotely with patients and to use the humanoid robot to direct and/or monitor exercise. *Flo* provides supplemental care and/or therapy to patients. We anticipate that patients would have some type of motor and cognitive impairment (older, or with need for therapy due to stroke, cerebral palsy, etc.). The major vision is that this system would provide health and function monitoring, therapeutic exercise, and learn over time to deliver diagnosis on current function as well as deliver a prognosis on future function.

Telepresence has been combined with humanoid robots in the past, but only in the sense of using telepresence to control the humanoid robot. For example, Kuwamura, Yamazaki, Nishio, Ishiguro (2014) developed a telecommunication robot, *Telenoid*, that is a humanoid torso with a soft outer skin material. The robot has 9 Degrees of Freedom (DOF) and synchronizes the operator's motion to speak, look around and give hugs. Results suggest that the robot can engage elders with and without dementia in conversation and is seen to be more positive, especially after interaction. It does not, however, track patient health status over time (Kuwamura, Yamazaki, Nishio, & Ishiguro, 2014; Sorbello et al., 2014).

Since the settings for the use of *Flo* may vary, it is reasonable to expect that clinicians may have different design requirements which reflect their differing overall mission and available resources. For example, post-acute care of persons with stroke can take place in inpatient rehabilitation facilities (IRF), skilled nursing facilities (SNF), outpatient therapy clinics, or at home with nursing care and therapy from a home health agency (Brown et al., 2006). Patients who go to IRF have better outcomes, fewer readmissions, and lower mortality than those who go to a SNF, though at a greater cost. It is estimated that 45% of hospitalized Medicare recipients who had a stroke are discharged to home directly, with 4 out of 10 not receiving post-acute care (Demaerschalk, Hwang, & Leung, 2010). Patients who go home directly may receive therapy or general care in day care facilities focused on helping elders maintain independence and social interactions.

This paper reports on the deployment of the *Flo* robot prototype in two different clinical settings: **1)** 2 hospital-based rehabilitation settings having inpatient and outpatient rehabilitation facilities and **2)** a daycare setting. We surveyed 42 clinicians at the hospital-based facilities as well as 20 clinicians at the daycare facility. Our goal was to uncover user design requirements, hidden design features that are unanticipated by engineers and product design teams, and barriers to implementation that were unforeseen by the team. We report on clinicians' expectations for this telepresence humanoid robot system with a focus on what would make it 'effective', 'acceptable', and 'usable' in their health care facilities.

2. METHODS

Flo was deployed in an inpatient/outpatient rehabilitation hospital setting and in an adult day care setting for 1 hour. Observers were asked to provide feedback on the potential of the robot after they were shown three pre-defined demonstrations. This section outlines the methods and the parameters of the deployment. We collected patient perspectives as well as clinician perspectives. Patient perspectives are not reported in this paper.

2.1. The Prototype: A Mobile Telepresence Robot with a Humanoid Rehabilitation Coach

The mobile telepresence robot, *VGo*, was combined and programmed to work with the *NAO T14* (*NAO*) humanoid robot (Figure 1). The *VGo* robot was chosen because it was low cost, less than USD 6,000, commercially available, and could easily be modified to build the conceptualized prototype. Additionally, its capabilities as a mobile telepresence robot, already in use in the healthcare setting, were proven and well-documented (Rutledge et al., 2014; Van Den Berg et al., 2012). *VGo* (VGo Communication, 2011) stands 4-feet high and features an integrated 2-megapixel camera, 6-inch LCD touch screen, 4 microphones, and upper and lower speakers, enabling telepresence communication among users. Both its mobile and telepresence features are controlled through the *VGo Client App* (PC or Mac App) that is installed on the remote user's computer. *VGo*'s capabilities are contingent upon wireless internet; in our case we used a *Verizon JetPack 4G LTE* mobile router. By means of the *VGo Client App*, the remote user can control the robot using a mouse pointer or laptop touchpad. Once the user positions the mouse pointer on the screen, the driving controls appear and the *VGo* can be moved forward, backward, left, or right. The *VGo*'s camera can be adjusted along the vertical axis through arrow buttons found within the *VGo* Client app and can take snapshots of the local environment; however, to pan a room or move closer or farther away from a patient, the robot must be moved by the remote user. *VGo* also utilizes sensors in its base to detect and warn users when its approaching large objects, drop-offs, and reaching the edge of the Wi-Fi network.

The *NAO T14*, torso only model, was selected by the research team due to its ubiquity as the most popular humanoid robot for research and education and relative affordability at less than USD 7,000. The *NAOQi Framework* is used to run and control the *NAO*. The framework is cross-platform (it can run on Windows, Linux or Mac) and cross-language (with an identical API for Python or C++). The best part of this framework is the ease of use for end users. The interface software (*Choreographe*) utilizes a drag-and-drop interface

Figure 1. *Flo* – our *NAO* and *VGo* Assembly. The mobile robot base with the mounted screen is the *VGo*. The humanoid torso mounted upon the base is the *NAO*. Both robots are commercially available, although the coupling between them is custom.

making *NAO* easily programmable to experienced programmers and novices alike. The *NAO* has 14 degrees of freedom in the head and arms. It includes a robust sensor network, 2 HD cameras, 4 microphones, 1 sonar rangefinder, 2 infrared emitters and receivers, 1 inertial board, 9 tactile sensors, and 8 pressure sensors. *NAO* contains two processors, an Intel Atom 1.6 GHz and an ARM-9 processor in its chest. Additionally, *NAO* has various communication devices, including a voice synthesizer, LED lights, and 2 high-fidelity speakers. These capabilities made *NAO* the ideal test platform for the conceptualized model.

A custom base was built to secure the *NAO* to the *VGo* robot. This was accomplished by cutting distinctive shapes into acrylic sheets to complement the design of the *VGo* robot and take full advantage of *NAO*'s capabilities. This set-up maximized the efficacy of the prototype by permitting *NAO* to interact with seated users close to eye level and move in the same direction as the *VGo*.

2.2. Demonstrations

The robots were programmed to complete a demonstration for the various healthcare professionals. Prior to the demonstration, a short presentation was given to the healthcare professionals participating in the study, which included the following: an introduction to the lab's body of work, an explanation about the research being conducted, the capabilities of the *NAO*/*VGo* prototype, and its potential importance in the healthcare arena. After the presentation, the *VGo*'s mobile capabilities were demonstrated by driving it around in front of the volunteers; its telepresence capabilities were then explained by pointing out that the research team member controlling *VGo* via the laptop in the room could be dialing in from any location. 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 the combined system as Flo and say that it will be the "exercise coach today." It would then move to the starting position and verbally explain the exercise that it would be performing. The first exercise was meant to engage the group of participants. The humanoid robot raised both of its arms to shoulder level, parallel to the ground. The right arm would then be raised so it would be perpendicular to the ground – the left arm stayed in its parallel position – then lowered itself back to shoulder level. The left arm would then be raised and lowered in the same manner. This was done a total of 4 times for each arm. During the exercise, the robot would encourage the participant and when the exercise was completed, the robot would wipe its forehead and congratulate the participants on a job well done. A second and third round of exercises were then demonstrated. Once again, the humanoid robot would first wait for feedback from the touch sensors in its head prior to commencing the exercise. The format of the second and third exercises that were demonstrated was the same: a verbal description of the exercise provided by the robot, encouragement given during the exercise, and congratulations provided at the end. After the demonstrations were completed, surveys were distributed to the participants.

2.3. Setting and Subjects

The demonstrations were given to various rehabilitation healthcare professionals at a large rehabilitation hospital in Philadelphia, PA and one in Allentown, PA. These rehabilitation hospitals offer both inpatient and outpatient therapy services where the standard of care is 2-3 times per week for 10 sessions and more if the patient is progressing. These sites treat patients with a wide range of functional abilities. The patient population is 60% female and 21% black, with an average age of 45. The healthcare professionals surveyed administer care to sub-acute inpatients or recently discharged outpatients. Of the total 42 healthcare professionals surveyed, 16 were MDs (38%), 18 therapists (43%), 2 PsyD (5%), 1 PhD (2%), 1 nurse practitioner (2%), 1 home health aide (2%), 1 manager of assistive technology procurement (2%), and 2 unreported (5%). Nearly 29 % of the surveyed population was under the age of 30; 48 % between the ages of 30 and 50; and just less than 24 % was over the age of 50. 63.4% of the surveyed population were female.

Additional demonstrations were given at an adult day care facility, which follows the Program of All-Inclusive Care for the Elderly (PACE) model (Eng, Pedulla, Eleazer, McCann, & Fox, 1997; Hirth, Baskins, & Dever-Bumba, 2009) in Philadelphia, PA. The facility cares for patients during the day, while they live independently in their own home, retirement or senior housing, or in independent- and assisted-living housing settings. This community-based rehabilitation (CBR) center with 8 rehabilitation (PT/OT) clinicians provides comprehensive community-based care to 500 older adults of whom approximately 30% have had a stroke. The center serves a population that is 76% female and 88% African American. Demonstrations at this site were given to healthcare professionals who described the patient population as geriatric, frail, nursing-home eligible, with many of them having cognitive deficits. Data and feedback were captured from a total of 20 healthcare professionals. Of the 20 healthcare professionals, 4 were nurses (20%), 3 therapists (15%), 1 social worker (5%), 4 certified nursing assistants (20%), 1 nurse practitioner (5%), 1 administrator (5%), 1 procurement specialist (5%), 1 activities director (5%), 1 medical records administrator (5%), and 3 unreported (15%). Five % of the population was under the age of 30; 45 % between the ages of 30 and 50; and half of the population was over the age of 50. 85% of the surveyed population was female.

Although the populations between the two centers differ in exact training, the participants are experts in their fields and are all focused on the rehabilitation and care of elders. The difference in title represents the different needs of the two types of centers. As primary users of any robotic system in their facilities, gaining an understanding of the opinions of these subjects is critical.

2.4. Surveys

The surveys sought information on demographics of the audience, overall impressions, human robot interactions, and design (Table 1). The complete survey can be found in the Appendix. 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 (reported in Section 2.3).

2.4.1. Demonstration Questions

After demonstration of *Flo*, the clinicians were given eleven demonstration questions, which determined the clinicians' opinions of the robot's features and characteristics, answered on a Likert scale of 1 to 5 (1 being the lowest score and 5 being the highest).

Impressions: There were 5 questions pertaining to the participants' impressions of the robot. The questions asked the clinicians 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.

HRI: There were 5 questions pertaining to human-robot interactions (HRI). The questions asked the clinicians to rate their perception of the robot as an intelligent, helpful, useful, and social being that can communicate with them. These HRI questions were like those asked in a previous study (Fasola & Mataric, 2013); where the humanoid robot, *Bandit*, was evaluated for its ability to successfully coach elderly patients through therapy.

2.4.2. Design Questions

The design questions were also on a Likert 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 (Fasola & Mataric, 2013; Wilk & Johnson, 2014; Patoglu, Ertek, Oz, Zoroglu, & Kremer, 2010). 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 operational noise level. In addition to providing feedback based on a 1-5 scoring system, both groups of health care professionals were asked to provide suggestions for additional robot capabilities that they would like to see offered by the prototype.

Table 1. Survey categories for the survey which was administered to clinicians. The complete survey can be found in the Appendix.

	Themes	**Clinical Questions**
A	Demographic Information	Intake Questions 1-7
B	Overall Impression of Robot	Demonstration Questions 1-5
C	Human Robot Interaction	Demonstration Questions 6-11
D	Design Recommendations	Design Questions 1-12

2.5. Data Analysis

The data were analyzed using descriptive statistics where the responses of clinicians who worked in inpatient/outpatient facilities were compared with those clinicians who worked with elders at the adult day care facility. Responses were compared across three themes: impression about the robot; perception of the interaction with the robot; and design recommendations. An unpaired t-test was performed to determine significant differences, where $p < 0.05$ was set as the significance threshold. The feedback from the clinicians was processed. The information was used to create a comprehensive design requirement document.

3. USER FEEDBACK

Clinicians were generally positive, scoring all but one variable with 3 or above. Responses did tend to differ across setting, but the results were not significant for all variables. We describe the results for each major survey section below.

3.1. Overall Impressions of the Robot

The clinicians were asked to respond to five questions regarding the intelligence, helpfulness, usefulness, social presence, and companionship of the robot. Table 2 and Figure 2 compare the clinicians' overall impressions. Without exception, healthcare professionals surveyed at the senior day care facility (SDC) rated each category higher than did their peer clinicians working with inpatient and outpatient populations (I/O). However, the numbers were not significantly different from each other. For the senior day care clinicians, the mean ratings of the questions ranged from 3.84 to 4.47, all of which are considered high ratings. The mean ratings provided by the inpatient/outpatient clinicians ranged from 3.48 to 4.14. Notably, both cohorts of rehabilitation professionals provided the highest rating to the question: "The robot was interesting?" ($\mu_{\text{SDC}} = 4.47 \pm 1.04$ versus $\mu_{\text{I/O}} = 4.14 \pm 0.97$). The largest divergence among the mean scores occurred in categories of "Recommend" ($\mu_{\text{SDC}} = 3.9 \pm 0.24$ versus $\mu_{\text{I/O}} = 3.5 \pm 0.16$), "Companion" ($\mu_{\text{SDC}} = 3.84 \pm 0.26$ versus $\mu_{\text{I/O}} = 3.45 \pm 0.15$), and "Overall Impression" ($\mu_{\text{SDC}} = 3.95 \pm 0.25$ versus $\mu_{\text{I/O}} = 3.48 \pm 0.14$).

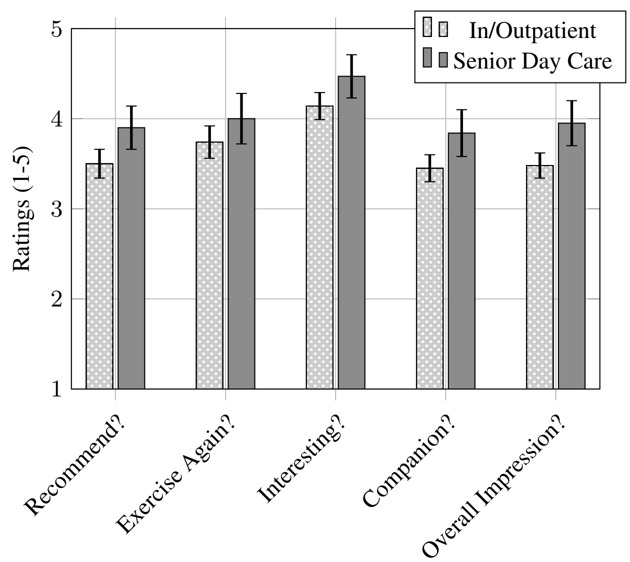

Figure 2. Overall impression ratings of the robot at the hospital-based rehabilitation facilities having inpatient and outpatient rehabilitation facilities and the senior day care. Mean values are shown with standard error (I). The category of "Overall Impression" shows the greatest difference between the groups with a p-value of 0.11. Raw data with significance can be seen in Table 2.

3.2. Human-Robot Interaction

Table 3 and Figure 3 describe the results of the HRI interaction questions. Once again, each question asked was rated higher by the senior day care clinicians. Significant differences occurred in the 'Intelligent' ($\mu_{\text{SDC}} = 3.55 \pm 0.18$ versus

Table 2. Responses from the overall impressions section of the survey on a 1-5 Likert scale.

	Inpatient/Outpatient		Senior Day Care		
	Average	Std. Error	Average	Std. Error	P-Value
Recommend?	3.50	0.16	3.90	0.24	0.18
Exercise Again?	3.74	0.18	4.00	0.28	0.44
Interesting?	4.14	0.15	4.47	0.24	0.25
Companion?	3.45	0.15	3.84	0.26	0.20
Overall Impression?	3.48	0.14	3.95	0.25	0.11

$\mu_{\text{I/O}} = 2.98 \pm 0.17$, p=0.03) and 'Communication' categories ($\mu_{\text{SDC}} = 3.89 \pm 0.19$ versus $\mu_{\text{I/O}} = 3.36 \pm 0.15$, p=0.01). Communication, or more particularly, when asked the question, "Did you feel the robot was talking with you?" represented the largest difference among reported means of any category. The remaining categories – 'Helpful', 'Social', and 'Useful' – all received relatively high scores with each question receiving a mean rating of at least 3.0. However, differences were not significant across clinicians.

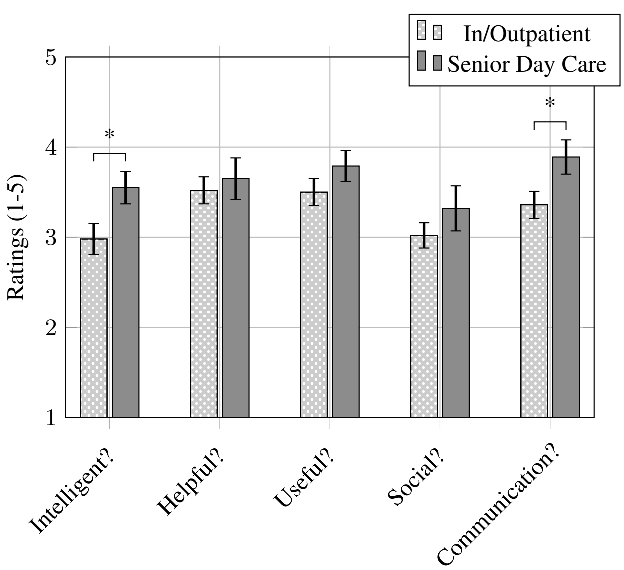

Figure 3. Ratings on the robot as a social being at the hospital-based rehabilitation facilities having inpatient and outpatient rehabilitation facilities and the senior day care. Mean values are shown with standard error (I). The categories of "Intelligent" and "Communication" are significant with p-values of 0.03 and 0.01 respectively. Raw data with significance can be seen in Table 2.

3.3. Design Recommendations

The results of the design questions can be seen in Table 4 and Figure 4. Both the users at the inpatient/outpatient and senior day care rated all 11 design features as important, with all scoring close to 4.0 and above. There were no significant differences between the two groups on each. The mean scores did suggest priority and ranking of features. Maintainability, Durability, and Portability were the top three features for both clinician cohorts, scoring 4.5/5 and higher. Ease of Set-up and Cost was ranked #2 and #4 by the hospital-based clinicians, while Supervision and Cost were ranked #4 and #5 by the day care clinicians. Appearance was given the lowest rating by the inpatient/outpatient clinicians (3.86 ± 0.13). Weight was rated the lowest by the senior day care professionals (3.86 ± 0.26).

Both groups gave suggestions for additional robot capabilities that they would like to see offered by the prototype. The suggestions are detailed in Table 5. The comments were distilled into emergent themes. In general, clinicians at the senior day care center wanted the robot to assist patients with reminders, e.g., reminding them to take medications and encouraging them to do exercise. Other suggestions were for the robot to act as a companion and take elders for a walk or touch/hug them. In contrast, the clinicians in the hospital-based rehabilitation settings, wanted the assistive robot to be more useful for therapy. They wanted the system to provide real-time feedback during mobility exercises, help with range of motion, coordination, fine motor manipulation, and vision exercises, and assist with more cognitive exercises including language practice and memory/executive function re-training.

4. DISCUSSION

4.1. Interpretation of Results

Responses to the overall impressions section of the survey (Section 3.1) suggest that our prototype has potential with both groups, however, in its current iteration it may be slightly better suited in a senior day care facility.

In the design questions, we saw that both groups desired maintainability, durability, portability and cost, which could be formalized as desiring an affordable robot system that is long-lasting, easy to maintain and easy to move around within their settings. Senior day care professionals valued comfort, and appearance much higher than their counterparts in the hospital-based settings.

In general, day care communities may desire a more socially-focused robot to act as a companion, provide reminders and fill a supervisory role rather than just monitor patients. On the

Table 3. Responses to the survey to determine whether the robot is a social being, responses were given on a 1-5 Likert scale. *indicates significance

	Inpatient/Outpatient		Senior Day Care		
	Average	Std. Error	Average	Std. Error	P-Value
Intelligent?	2.98	0.17	3.55	0.18	0.03*
Helpful?	3.52	0.15	3.65	0.23	0.64
Useful?	3.50	0.15	3.79	0.17	0.39
Social?	3.02	0.14	3.32	0.25	0.31
Communication?	3.36	0.15	3.89	0.19	0.01*

Table 4. Design recommendations from the survey where subjects were asked the importance of each category on a 1-5 Likert scale.

	Inpatient/Outpatient		Senior Day Care		
	Average	Std. Error	Average	Std. Error	P-Value
Portability	4.54	0.09	4.50	0.21	0.87
Ease of Setup	4.60	0.11	4.24	0.26	0.21
Weight	4.20	0.13	3.89	0.26	0.41
Cost	4.39	0.13	4.42	0.21	0.90
Maintainability	4.66	0.09	4.67	0.19	0.97
Durability	4.60	0.10	4.67	0.19	0.74
Comfort	4.05	0.12	4.39	0.28	0.28
Appearance	3.86	0.13	4.26	0.22	0.12
Operational Noise Level	4.29	0.10	4.28	0.25	0.98
Supervision	4.10	0.13	4.45	0.21	0.16
Observation	4.30	0.13	4.19	0.30	0.74

other hand, hospital-based professionals ranked ease-of-use and monitoring (observation) as much more important. These choices may reflect the reality of treating patients in hospital settings. Therapy sessions are time-limited and observing and providing real-time feedback is a priority in these settings. In a study of 972 patients across 6 rehabilitation facilities in the US, Jette and colleagues (Jette et al., 2005) found that the average time for a physical therapy session for a stroke patient in an inpatient rehabilitation facility was 38.1 minutes. Given this already highly limited time, it is important that setting up the device does not reduce therapy time. The fact that clinicians in the IRF rated Ease of set-up as #2 further support this observation. This is especially important because we do not see the robots as a replacement for therapists, but rather as smart assistants that enable more efficient therapeutic actions. In order for this to be feasible, the robot must not be overly burdensome for the clinician, so that they can continue to focus their time on patients.

4.2. Prioritizing Design Requirements

We set out to gain feedback from health professionals who serve the needs of aging adults in diverse care settings to guide the design of a custom and affordable socially assistive robot with telepresence. The literature that addresses robotics intended for the elderly is ever-growing, but with respect to what clinicians expect out of a system, a gap in knowledge still exists. A variety of rehabilitation settings exist – inpatient, outpatient, nursing home, skilled nursing facilities, adult day rehab care, and assisted living. Each setting must be treated differently since each setting cares for patients at different stage in their recovery cycle, independence and rehabilitation needs (Freedman & Spillman, 2014). The setting often drives the needs of the patients and the treatment goals of the clinicians. The findings of this study support the notion that healthcare professionals have expectations contingent upon their work environment.

Scores in the inpatient/outpatient therapy space were generally lower than those from the day care facility, potentially indicating that expectations were higher in the inpatient/outpatient therapy space. Although the clinicians in each site are experts in their fields, they varied in their patient experiences and clinical needs. Lower enthusiasm by the therapists suggests that the Flo prototype in its current iteration needs to be better tailored for neurorehabilitation. Given the complexity of neurorehabilitation, the desire of the hospital-based health professionals for motor, cognitive, and speech support in the assistive robot is not surprising. Real-time feedback must be incorporated, and a degree of individualization should be in-

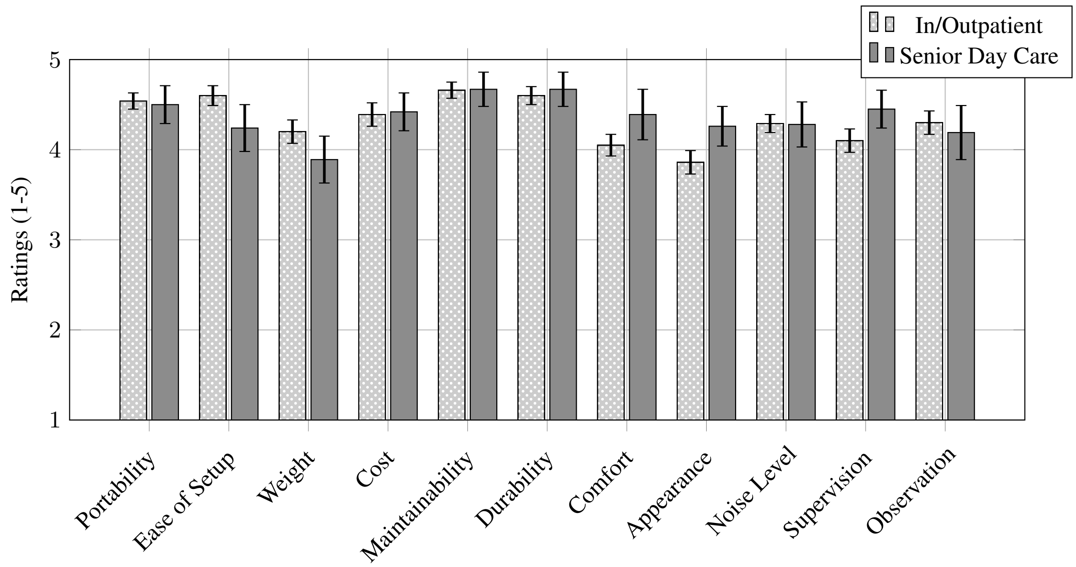

Figure 4. Ratings on design recommendation questions at the hospital-based rehabilitation facilities having inpatient and outpatient rehabilitation facilities and the senior day care. Mean values are shown with standard error (I). The category of "Appearance" shows the greatest difference between the groups with a p-value of 0.12. Raw data with significance can be seen in Table 2.

Table 5. Emergent themes from the survey comments section for each of the two groups. These open format responses allowed subjects to express their needs beyond what the survey was able to capture.

Senior Day Care	**Inpatient/Outpatient**
• Instruct elders to take meds • Provide reminders • Encourage elders to do exercise • Take elders on a walk • Touch hand / give someone a hug	• Real-time feedback • Cognitive exercises and retraining • Ability to do fine motor manipulation tasks • Range of motion, coordination exercises • Vision exercises • Speech practice • Memory/executive function training

voked to meet the unique and varied needs of each facility and each patient.

Clinicians are key stakeholders and as such their needs must be taken into account since they are key gatekeepers to robots being accepted and used in rehabilitation and medical settings. If convinced, clinicians could be the chief advocates for robot use in their respective environments. Johnson and colleagues indicate that the needs of the clinicians are often different from the patient needs (Johnson et al., 2017). They examined the needs of elders, clinicians and caregivers for a low-cost mobile service robot in the same all-inclusive senior care community in Philadelphia. Via surveys and focus groups, elders, caregivers, and clinicians identified 36 high priority needs for a social robot (Sefcik et al., 2018; Johnson et al., 2017). The elders perceived that a social robot should meet their needs for assistance with instrumental activities of daily living, their desires to have their preferences known, their desires for more leisure activities, and their desires for increased opportunities for socialization. The clinicians and caregivers believed that a social robot should help elders to create personal connections and maintain mental health and provide cognitive interventions such as reminders to do such activities as stay hydrated, active, and nourished. Many of the desires expressed in Table 5 agreed with this study which further highlight the need for companion social robots within day care environments that are capable of being smart and multi-functional.

In general, our findings agreed with past literature and our own preliminary work in Wilk and Johnson (2014), where a Flo demonstration was completed at an adult day care center, the Milwaukee Center for Independence (MCFI). Nine patients and seven caregivers (three therapists, two nurses, and a social worker) participated in the demonstration at MCFI. The general patient population of the facility was over the age of 50 and predominantly female (56%) with physical, cognitive, and developmental disabilities. When we compared overall impressions of the robot's usefulness and sociability we saw a positive correlation with our results. Table 6 compares the desired design features across the cohorts. The top design requirements were also similar. Ease of Set-up, Durability, Portability, Maintainability, and Cost were also the most desired five design features at MCFI. In Milwaukee, the health professionals desired an assistive robot that was able to observe and monitor, as well as supervise the patients. Observation and Supervision were ranked #5 and #6. Based on Table 6, the top five design needs were portability, maintainability, durability and ease of set-up. Ease of set-up has less agreement with the Elder daycare suggesting this is not as high a priority as those centers that do therapy.

Table 6. Comparing score-based ranking of design features, i.e. how important clinicians believed each design requirement is at the inpatient rehab facilities in Philadelphia, elder daycare in Philadelphia, and elder/child daycare in Milwaukee. The top five design requirements are bolded.

	Flo (Philadelphia)		Flo (Milwaukee)
	IRF	Elder Daycare	Elder/Child Daycare
Portability	**3**	**3**	**2**
Ease of Setup	**2**	**9**	**1**
Weight	7	11	7
Cost	**4**	**5**	**4**
Maintainability	**1**	**1**	**1**
Durability	**2**	**2**	**3**
Comfort	9	6	7
Appearance	10	7	8
Noise Level	6	8	4
Supervision	8	4	6
Observation	5	10	5

The *Flo* robot was successfully received by clinicians as a potential companion and exercise coach. The literature supports the idea that social robots improve engagement and elicit social interactions that keep patients and elders engaged (Fasola & Mataric, 2013; Scassellati et al., 2012). In stroke rehab, motivation is highly linked to motor function improvement and so we believe that the use of robots with the ability to interact and exercise will be highly beneficial for the patient population. Ensuring that the robot is interesting, intelligent, sociable, able to communicate, and helpful are important. Defining these terms is a challenge as each user perceives them differently. In general (Breazeal, 2003), perception of the robot as interesting occurs when the robot can stand out from the rest of the environment; intelligence comes from reacting in ways that can be interpreted by the human; sociable comes from engaging in empathy like interactions; ability to communicate comes from being able to understand the users vocalization and/or gestures; and being helpful is driven by an ability to aid in the task at hand. Engineers therefore must consider what parameters are needed to ensure these features are realized.

Table 5 does highlight dissatisfaction with the perceived autonomy and function of the *Flo* robot in its current form and further supports the notion that clinicians viewed the robot as being more of a social entity than a therapy assistant or helper. Unfortunately, most of the desired activities in Table 5 would not be delivered with the current commercial robots used for *Flo*. We found that although the *NAO* (seen in Figure 1) is highly programmable and easy to use, it is hard to modify and when it breaks, hard to maintain. The *VGo* (also in Figure 1) is user friendly in its default configuration but offers no programmatic interface to extend its capabilities. Finally, the *NAO/VGo* combination is high cost. As a result, future directions dictate developing a custom *Flo* robot that is able to be more affordable and more of an intelligent therapy and service companion.

4.2.1. Monitoring Health and Function

A number of the requests of the adult day care facility were for the robot to act independently, caring for and monitoring patients, i.e., to be autonomous. Ideally the system should be able to automatically collect diagnostic information to assess a patient's state such as mood, kinematics of the upper extremities, pulse rate etc. To meet the desires expressed in Tables 4 and 5, the mobile robot must function as an intelligent helper and assistant implying that the robot needs to be integrated within the clinical environments and support the clinicians to manage the health of their clients/patients over the long term. These desires are echoed by Schultz and colleagues (2014) who after reviewing the literature of assistive technologies for elders concluded that there is a need for technologies that enable long-term intervention and treatment of elders in care settings (Schulz et al., 2015). This study placed a high priority on the need for robots that can help to not only be social, monitor and diagnose elder health in the short-term, but to also provide long-term monitoring and treatment. To realize this type of robot helper, the robot may need to be equipped to provide data for the diagnosis of patient health or provide the data to support clinicians in determining direction and treatment of a patient. Typically, to do the above the robot must have information about the patient, be able to adapt its actions to the patient's action, and be able to support patients in these actions as needed. For example, some basic autonomous rehabilitative interactions have been demonstrated in the literature via the work on the *NAOTherapist* which can correct motions performed during rehab activities to improve patient performance (González, Pulido, & Fernández, 2017). In addition, Schwabacher and Goebel provide three requirements for the artificial intelligence (AI) of such a robot that would enable it to be integrated within the health care system or setting. These requirements indicate that the robot's AI should detect when the patient's health is deteriorating (fault detection), determine why or the source of the deterioration (fault diagnostics), and if possible determine when the failure may re-occur or occur based on past actions (fault prognostics) (Schwabacher & Goebel, 2007). With information about the patient's level of function and impairment, with historical data on the patient, and information about what is "normal", the robot may also be able to do fault diagnostics. To our knowledge, no rehabilitation mobile robot system currently meets all three requirements.

4.2.2. Ethical Implications

Increasing autonomy of robots in healthcare settings often raises ethical issues. First, using robots in therapy and assistive spaces increases the risk that robots could be used to remove clinicians from interactions with patients. However, failing to use robotic technologies to improve patient care could be considered irresponsible and in itself presents ethical concerns. The Flo concept robot proposed here would meld telepresence, robotics, and computer vision to allow more patients to access healthcare while promoting patient-clinician interactions. In doing so, we would address some of the shortage of clinicians and caretakers in the rehab and care spaces. Second, although we may preserve aspects of the human interaction, some may argue that using robots in these settings increases the risk that success of robots could be used to justify decreasing the allocation of resources for rehabilitation, especially in low resource and rural settings. While we agree that some jobs may be lost, in view of the growing shortage of rehabilitation healthcare workers, we believe these technologies offer a solution to clinicians and help clinicians not compromise care as the elder population grows (Christensen et al., 2009). Third, in the current climate of tightening security and privacy to protect patient's personal health information (PHI), there is some concern that collecting, aggregating, and learning from large amounts of subject data could make some subjects uncomfortable and their data vulnerable to hackers. It is therefore imperative to both communicate clearly to subjects/patients what is being collected and how it is being used as well as taking every precaution to safeguard any data which we have. Further, it is not clear how to safely share data within the research community to accelerate development. In general, Human Subject Ethic Committees do not allow the publication of identifying data. Balancing the competing needs of privacy and compliance against research progress can be difficult.

4.3. Study Limitations

The biggest practical limitation of this study was that sometimes, due to network connectivity issues, the *VGo* had trouble getting started. This caused delays, which could have altered the responses of those being surveyed. This also highlights the need for more system autonomy to handle challenges like poor network performance. It is also important that systems not only fail safely to prevent injury to the patient and damage to the system, but also fail well to prevent degradation of patient care.

From a data analysis perspective there were three major limitations. The first is that although we had clinicians rank the importance of design requirements, we did not have them score those requirements. As a result, it is impossible to tell how much more or less important one item is from another. In future studies, we will allow survey participants a fixed number of points to allocate among all requirements, to recover scale of need. The second is that we did not have enough statistical power within the different clinician groups to compare the needs of various users. For example, we were unable to discern the difference in needs between a therapist and an MD. Finally, because we only surveyed clinicians at two facilities, care must be taken in generalizing the comparison between needs of inpatient/outpatient facilities and day care facilities. The results that are seen are however logical/expected and therefore provide a good place to start. More generally, the sample size is sufficient to draw conclusions of a non-comparative nature.

5. CONCLUSIONS

There is overwhelming evidence that there is a shortage of rehab professionals and caregivers (Lin et al., 2015; Zimbelman et al., 2010; Ovbiagele et al., 2013) as well as a demographic shift towards an aging population (Christensen et al., 2009). We are seeking innovative ways to bridge this growing health care gap. With this in mind, we sought to define requirements for a socially assistive robot with telepresence to support in-person and remote therapy in diverse clinical settings.

There are off-the-shelf robots, but they remain limited in their function. After all, the commercial robots are designed for a specific purpose and researchers find a way to use them for basic prototyping. However, to design what would truly benefit the aging population, it is important to understand how health care practitioners perceive the new system. This study has shed light on user requirements and priorities for assistive robotics for elder care. Based on these insights, we are developing a socially assistive robot with telepresence that can meet the desired features. As we work to design our system, it is important to keep in mind how the ideas behind prognostics can improve the design in two ways. The first is in the classical interpretation, building systems that have predicted failures. With remotely placed robotic systems, this is critical as there are often no resources to handle a failure locally, so the robot must be recalled prior to failure since failing in front of a patient presents a risk.

As our populations age their needs grow and become more diverse, so will their needs and preferences for living environments. The role of the assistive robot must adapt to these different environments (Mitzner, Chen, Kemp, & Rogers, 2014). More independent elders will be in day care centers, while those needing more therapeutic interventions will be in hospital-based settings or skilled nursing facilities where the need for real-time feedback and more therapeutic interaction increases as well as the desire to have robot interactions that are focused not only on motor impairment, but also on cognitive and speech therapy exercises. We are developing a robot that will be able to provide real-time feedback and more therapeutic interaction as well as support long-term intervention and treatment by leveraging fault detection and diagnostics of the patients themselves (Schulz et al., 2015; Schwabacher & Goebel, 2007). If our systems can use data which we are collecting to predict degradation in patient function, then intervention can be taken earlier, leading to better outcomes. If we can understand how, why, and ideally when patients will fail, we will be better able to meet the need raised by clinicians for smarter service and therapy robots.

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6. DECLARATION OF INTERESTS

Michelle Jillian Johnson, PhD and Rochelle Mendonca, OTR, PhD are co-founders in Recupero Robotics LLC. The company does not license any of the hardware above.

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BIOGRAPHIES

Michelle J. Johnson, PhD is an Assistant professor of Physical Medicine and Rehabilitation at the University of Pennsylvania. She has secondary appointments in Bioengineering and in the Mechanical Engineering and Applied Mechanics graduate group. She has a PhD in Mechanical Engineering, with an emphasis in mechatronics, robotics, and design, from Stanford University. She directs the Rehabilitation Robotics Laboratory, University of Pennsylvania. Her lab is a part of the General Robotics Automation Sensing and Perception (GRASP) Lab. She is a member of the IEEE Robotics and Automation Society and the Engineering Medicine and Biology Society.

Michael J. Sobrepera, BS is a doctoral student at The University of Pennsylvania in the department of Mechanical Engineering and Applied Mechanics. He is a part of the Rehabilitation Robotics Laboratory, which is affiliated with the General Robotics, Automation, Sensing, and Perception (GRASP) Lab. His research focuses on building and testing social robots for cognitive and upper extremity motor diagnostics and rehab. He has a bachelor's degree in Biomedical Engineering from The Georgia Institute of Technology.

Enri Kina is an undergraduate student at The University of Pennsylvania in the department of Mechanical Engineering and Applied Mechanics, as part of the Class of 2020. His research focus involves the design of social robot heads and faces, particularly in a manner that facilitates cooperation and effective HRI.

Rochelle Mendonca, PhD, OTR is an Assistant Professor in Occupational Therapy at Temple University in Philadelphia. She has a bachelor's and master's degree in Occupational Therapy and a PhD in Health Sciences. She has ten years of research experience developing and measuring outcomes related to rehabilitation technologies and participation for people with disabilities. She is a member of the American Occupational Therapy Association.

APPENDIX

Health Professional Survey HRC#______ DATE:__________

	Demographic Questions	Circle Answer		
1	Gender	Male	Female	
2	Age Range	<30	30-50	>50
3	Clinician Type	MD	Therapist/Nurse/CNA	
4	Could you describe the population of patients at the facility?			

	Questions	Circle Answer	
1	Do you use a computer?	Yes	No
2	Would you want patients to interact with family members more frequently?	Yes	No
3	Would you want to contact patients or their families remotely?	Yes	No

	Demonstration Questions	Circle Answer				
		Very Little		Somewhat		Very Much
1	How likely would you be to recommend the robot to other clinicians?	1	2	3	4	5
2	How much would you like to use the robot to exercise with patients in the future?	1	2	3	4	5
3	How important is it that the robot be supervised?	1	2	3	4	5
	During the demonstration how strongly did you feel as if:					
4	You were interacting with an intelligent being?	1	2	3	4	5
5	You were interacting with a helpful being?	1	2	3	4	5
6	You were interacting with a useful being?	1	2	3	4	5
7	You were interacting with a social being?	1	2	3	4	5
8	The robot was communicating with your patients?	1	2	3	4	5
9	The robot was interesting?	1	2	3	4	5
10	How would you rate this robot as a companion/coach	1	2	3	4	5
11	Overall impression of the robot's performance	1	2	3	4	5

1

	Design Questions	**Answer**				
	In your opinion, how important is:	Not Important		Neutral		Very Important
1	The portability of the robot?	1	2	3	4	5
2	Ease of Setup?	1	2	3	4	5
3	Weight?	1	2	3	4	5
4	Cost?	1	2	3	4	5
5	Maintainability?	1	2	3	4	5
6	Durability?	1	2	3	4	5
7	Comfort?	1	2	3	4	5
8	Appearance?	1	2	3	4	5
9	Operation Noise Level?	1	2	3	4	5
10	Should the therapist observe while the robot performs the exercise?	Undecided	Not Necessary	Does Not Matter	Maybe	Definitely

11	Can you think of any activities that the robot should do with patients, and if so list them?
12	Do you think the robot is easy to use? If not, could you list the parts that need improvement and/or make suggestions?
13	How can the safety of the robot be maximized? (You may choose more than one option)
	◊ A button for patient to stop robot
	◊ A control mechanism for patient
	◊ Development of robot by the help of experiments
	◊ Doctor counseling
	◊ Exercises should be made slowly and carefully
	◊ Non allergic, non-smelling, and washable material should be used
	◊ Quality of sensors should be maximal
	◊ Other: