Community-Based Neurorehabilitation in Underserved Populations

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Abstract - Despite the fact that stroke is the leading cause of long-term adult disability and a primary cause of death, one of the major problems in national healthcare systems is the inability to provide quality post-stroke rehabilitation. Geographical barriers, socioeconomic position, race, education, and cost all contribute to health care disparities. These disparities may not only obstruct access to the most appropriate rehabilitative care, but may contribute to psychological problems, reduced quality of life, and unsuccessful return to meaningful community participation. Information and communications technology (ICT) when combined with robotic technology can enhance the accessibility of rehabilitation in low-resource, capacity-constrained settings. In this paper we introduce a low cost, limited supervision, portable robot (H-Man) designed for upper extremity rehabilitation. A usability and feasibility study indicates that out-patient robotic treatment with the H-Man leads to positive improvements in arm movement, and that the system is usable and well accepted by key stakeholders. This paper also introduces an implementation strategy to assess the effectiveness, benefits and barriers of using the H-Man robot for community-based neurorehabilitation in underserved populations, such as those that live in low income neighborhoods or in rural areas.

Keywords - stroke; rehabilitation; low-income; information and communications technology

I. INTRODUCTION

Stroke is the leading cause of disability in the United States, with 65% of the nearly four million people who have survived a stroke living with minor to severe impairments [1]. It has been estimated that among the 75% of patients who survive the first month after a stroke, more than half will require specialized rehabilitation. Individuals are left with a broad range of disabilities, from mild paresis to complete paralysis of both the upper and lower extremities, proprioceptive deficits, disordered movement organization, loss of range of motion, muscle weakness and abnormal muscle tone, and impaired force generation. Impaired arm and hand function significantly contributes to limitations in the ability to perform activities of daily living (ADL) and has a detrimental effect on patients’ capacity for independent living and economic self-sufficiency [3]. Results from studies exploring the time course of recovery report that approximately 70% of the patients have residual impairment in the upper extremity 6-months post-stroke [1], and approximately 50% are left with disabilities making them dependent on others for activities of daily living [2].

After a patient’s release from the hospital, the patient is discharged to a rehab facility (or nursing home) or allowed to return home. In the former, patients will receive daily, or near daily, in-patient stroke rehabilitation for the duration of their stay. In the latter situation, upper extremity rehabilitation can be delivered in a variety of settings such as inpatient hospitals and outpatient clinics and within the community (i.e., in the individuals’ home, board and care, transitional living, intermediate care, or assisted living residence). It has been reported that stroke rehabilitation services conducted in a community setting result in similar [4,5] or improved [6] patient outcomes when compared with conventional or no care. Benefits associated with community-based rehabilitation programs include reduced costs, decreased length of hospital or institutional stay [7-8]. Moreover, patient and caregivers often prefer community-based rehabilitation programs as they place less stress on caregivers and family members and provide greater patient and family involvement [7].

For chronic stroke patients who exhibit residual upper extremity impairments, but face insurance restrictions on physical therapy, community-based rehabilitation is an attractive alternative to outpatient stroke rehabilitation because it allows for earlier, coordinated inpatient discharge [9-10], it provides a mechanism for rehabilitation for individuals who have been discharged from an inpatient setting but would benefit from further therapy [11], and does not require the intensive and expensive care of an acute, inpatient hospital.

Regardless of the location in which stroke rehabilitation occurs, neural reorganization and effective recovery of motor function requires high-intensity, repetitive, task-specific practice [12]. In the acute phase of stroke, this requires that participants visit the out-patient rehabilitation facility five days per week, and work one-on-one with clinicians. The
significant burden placed on the health care providers and the overall health care system have stimulated particular interest toward the development of robotic devices to train various task-related movements of the upper extremity (UE) [12–15]. In comparison to conventional clinician-to-patient therapy, robotic rehabilitation devices are able to consistently assist or resist human motions, to acquire accurate measurements of the dynamic and kinematic performance of participants during training using integrated sensors, and to administer repetitive task-specific training with limited supervision from a therapist.

Of the over 120 robotic devices developed for upper-extremity rehabilitation, only a few have been tested in clinical populations, and even less are commercially available [16]. The most popular devices are the MIT-Manus (commercially known as the InMotion2 Shoulder-Elbow Robot) [17], the ARMEO Spring [18], and the ARMin (commercially known as ARMEO Power) [19]. Upper extremity robotics provide visuo-haptic feedback to the user, and employ control algorithms that provide the patient with the minimal amount of robotic assistance necessary for them to complete a task [16]. Clinical studies have shown that upper extremity robot-assisted therapy is at least as effective as conventional rehabilitation therapy (in terms of reducing motor impairments) [14], [15], and has similar average total costs as intensive conventional therapy and usual care programs [20].

Despite the effectiveness of robot-aided therapy after neurological damage, existing devices are often specifically for use in clinical settings as they require supervised assistance from qualified personnel, and are too expensive to be used in community-based settings. In addition, the majority of these devices are bulky, and as such cannot easily be transported between sites. In recent years, there have been efforts to develop portable, low-cost devices that can be deployed in community setting [21–26]. For example, Johnson and colleagues [21] developed a robotic driving simulator (Driver’s SEAT) with a force sensors embedded within the split-steering wheel that resists force applied by the unimpaired extremity, thereby forcing the patient to use the impaired arm to compete the task. TheraDrive [25] is a 1 degree of freedom (DoF) robotic system built using off-the-shelf force feedback steering wheels that render assistive or resistive forces to the user. The TheraDrive system was evaluated in 10 stroke patients [26] who completed 24 training sessions (1 hr. each) over a 6 to 8-week period. Overall, there was an improvement in upper extremity motor function and a decrease in spasticity, and patients found the rehabilitation to be motivating and engaging. However, the system was unable to provide sufficient assistive force for a number of patients, the motors were underpowered and could only supply 1.5 Nm of torque at the end-effector, and several steering wheels wore out over the course of the 8-week period.

While significant technological progress has been made, at present there does not exist a portable, low-cost, visuo-haptic system that can be deployed for community-based stroke neurorehabilitation. The current paper builds on prior work, and introduces a low cost, limited supervision, portable robot (H-Man) designed for upper extremity rehabilitation [27–29]. In this paper we introduce the H-Man device (section 2), and present empirical evidence demonstrating its use in stroke populations (section 3). We then outline our upcoming implementation strategy (section 4) to identify barriers that preclude chronic stroke patients that reside in low-income neighborhoods from fully utilizing community-based neurorehabilitation, and implement a delayed intervention randomized controlled trial based on this information.

II. H-MAN DEVICE

The H-Man is a compact 2D planar, end-effector robot developed specifically for the study of human motor control and neurorehabilitation (Fig. 1a). The current H-Man system consists of a 6 DoF force/torque sensor, 2 DC-motors controlled by a driver, and a PC with data acquisition system. Force transmission from the DC-motors to the end-effector occurs via the H-shaped cable-driven differential mechanism, which enables two independent or simultaneous movements in the x and y axis with a single cable loop. Although the DC-motors are grounded, each rotor is coupled with a driving pulley, which is in turn wound around four freely rotating grounded corner idlers. Four additional idlers are located on top of the carriage and allow for the transmission of the motor torques to the handle. To produce movements in the x axis, the left and right motor (ML and MR, respectively) must rotate at the same speed and in the same direction (i.e. either both clockwise or both counter-clockwise). To produce movements in the y axis, ML and MR must rotate in opposite directions. This configuration provides a friction that can hold 50N force at the end-effector when both pulleys are blocked. In the unlikely event (i.e., in the case of malfunctioning or instability) that a motor produces end-effector forces above 50N, the cable will slip on the driving pulley, thereby avoiding the transmission of high force to the user through the robot end-effector. We refer the reader to [27] for further information regarding the characteristic parameters of H-Man, along with references to works in which H-Man has been studied with control and stroke participants [28–30].

The current H-Man software interface is comprised of a workstation, a real time controller, and a display unit (Fig. 2). The software interface is programmed on a workstation (PC) using MATLAB’s graphical user interface (GUIDE tool), and serves as the front end for the H-MAN system. Custom built algorithms (e.g., an adaptive controller that can generate damped spring-like force fields to guide movement) adjust the H-Man controller based on user performance in previous trials/ sessions or the therapist input, then pass this information to the real-time control unit to update the control policy. A real-time data acquisition board (Quanser QPIDe, Quanser Inc.) is used to control the H-Man device during each trial. At present, the parameters of the real time controller can be altered after each trial via the adaptation algorithm in order to limit the amount of real time processing. The real-time controller communicates with the display unit (PC monitor/laptop/tablet) via transmission control protocol (TCP, also sometimes referred as internet protocol).
The visual interface is programmed in Unity 3D, and provides access to a set of games, assessment tools (Fig 2c), and general progress results through a secure user login screen. The visual interface is programmed in the four official languages of Singapore (English, Mandarin, Malay, and Tamil). Patients can select between six different game environments (exemplar game “Astronaut Rescue” is shown in Fig 2b), and can switch between games during a training session. In addition, multimodal feedback can be rendered to the user via the feedback block. Proprioceptive information (e.g., an assistive force field) and tactile information (e.g., subtle vibrations to guide users along a given trajectory) is provided by the real-time controller. Online visual and auditory feedback (e.g., congratulatory words when a task was successful and encouraging words when the task was not successful) is provided via the display unit.

In sum, H-Man offers the following advantages over existing prototypes and commercial devices. First, the system is portable and much smaller (workspace = 44 cm x 22 cm, weight = < 10 kg) than commercially available devices (InMotion2 Shoulder-Elbow Robot = 83 kg, ARMOE Spring = 82 kg, ARMOE Power = 205 kg). Second, the Cartesian mechanism of the H-Man ensures that inertia and friction are low and constant throughout the workspace, while the H-shaped arrangement provides a means to constrain motion along pre-determined directions using simple mechanical stoppers. Other 2D planar robots (e.g., MIT-MANUS or Braccio di Ferro) have to use active control and extremely powerful (and therefore dangerous) motors to implement these features. Third, H-Man can be built using a combination of commercial hardware components, 3D printed parts, and off-the-shelf components. It is estimated that the commercial H-Man platform will be priced around $10,000 USD, which is substantially lower than current commercially available upper extremity robots (ARMOE Power = $277,637 USD, InMotion2 Shoulder-Elbow Robot = $84,500 USD, ARMOE Spring = $60,500 USD).

III. CLINICAL EVALUATION

In this section we provide information on a clinical trial on that examined variations in kinematic parameters due to neurological status (chronic stroke patients, healthy controls), movement direction (−45°, 0°, +45°), and movement segment (outbound, inbound). In addition, we collected data regarding patient satisfaction with the H-Man device overall and the robotic therapy protocol.

Twelve stroke participants (mean age: 55, SD = 10.0 yrs., 7 men, mean time since stroke = 11.2 months, SD = 6.0) were recruited from the Centre for Advanced Rehabilitation Therapeutics at Tan Tock Seng Hospital (CART@TTSH). Five patients had hemiplegia of the right arm, and three patients had hemiplegia of the left arm. The mean age of patients was 56.9 years (SD = 8.6, range = 50-74 years). The mean time since stroke onset was 9 months (SD = 5.9 months, range = 4-23 months). In addition, data was collected from nine age-matched healthy participants (mean age = 53±4.3, 4 male, 5 female).

Patients completed 8 robot-assisted therapy training sessions within a 2-week period. A single training session consisted of 1 hour of robotic training and 30 minutes of conventional occupational therapy directed towards neurofacilitation, active range of motion exercises, self-care activities of daily living and home exercise program. Training sessions were always led by the same therapist. Clinical and robotic assessments were conducted prior to robotic training (baseline, week-0), immediately after robotic training (post-training, week-2), and 2 weeks after robotic training (follow-up, 2-weeks post-training). Clinical outcome measures included the FMA, Action Research Arm Test (ARAT) and grip strength. Adverse events such as increased pain (visual analogue scale 0-100), increased arm spasticity (Modified Ashworth Scale), and dropout rate were also measured.

Upper extremity function was evaluated using the H-Man robot. The H-Man was placed in front of the subject on a fixed table, behind which a 43 cm flat screen monitor (Sync Master 943T, Samsung) served to display a virtual representation of the workspace/task and provide visual feedback throughout the experiment. The visual stimuli (Fig. 1c) consisted of a required movement path and the task instructions. The
movement path was presented as a grass path with a cursor controlled by H-Man handle represented as a cat. Participants were seated in a height-adjustable chair in front of the table, so that the center of the sternum was aligned with the handle of the H-Man robot, and the elbow bent at 90°.

At the start of each trial a movement path was visually displayed on the computer monitor (-45°, 0°, +45°) and participants used the robot handle to move the virtual object (i.e., the cat) as far as possible along the movement path. Instructions emphasized that after reaching the maximum distance they should hold that position for 3 seconds, after which the participants were allowed to bring the virtual object back to the start position (i.e., the house) while remaining on the movement path. No physical trunk restraint was used during the experiment in order to assess the natural performance of the subject. However, the subjects were instructed to limit their trunk movements while performing the task. The presentation of movement directions conditions was presented in a randomized order, with each condition being performed 12 times. This yielded a total of 36 trials per patient.

As expected, movements performed by stroke patients had larger SAL values, featured longer normalized time to peak velocities, and larger RMSE errors, compared to their age-matched neurologically healthy counterparts (Fig. 3). Kinematic differences were also observed between movement directions, with lower SAL values and higher RMSE values for movements to the center target, compared to movements to the ipsilateral and contralateral movement directions. These results indicate that ipsilateral and contralateral directions may be more challenging for neurologically impaired patients. This data indicate that future rehabilitation protocols should include more targets located in the left and right of the workspace, as this might facilitate cortical reorganization and motor recovery post-stroke.

While results of the clinical assessment indicated that there was no significant change for any of the measured variables, the kinematic parameters used in the current study were generally sensitive to changes in the performance of stroke participants across the three assessment time points. When reaching movements were quantified using kinematic parameters, it was observed that reaching movements were smoother and had lower task error values at post- compared to pre-training. These results are encouraging and lead to the hypothesis that these effects would be amplified if robotic rehabilitation training continued. That said, improvements in kinematic performance was not maintained at 2 week follow up. This is congruent with prior research [31] reporting that consistent and continued practice is required in order to offset decreases in motor function.

In sum, results of the present study indicate that H-Man is sensitive enough to distinguish between neurological statuses, movement direction, movement segment, and time. Moreover, the kinematic parameters measured using the H-Man were sensitive to changes in performance over time, which was not observed through standard clinical scales.

A. Device Use and Satisfaction

We obtained feedback regarding the training and device use satisfaction. Patients provided an overall rating of satisfaction of 3.5/4.0, with half of the patients stating that they were completely satisfied (4.0/5.0) and half patients stated that they were very satisfied (3.0/4.0). In addition, patients strongly agreed (mean = 4.7/5.0, median = 5.0/5.0) that it was easy to learn how to use the system, that the set-up was comfortable (mean = 4.6/5.0, median = 5.0/5.0), and that the computer images were easy to understand (mean = 4.7/5.0, median = 5.0/5.0). Patients agreed that the training was useful for exercising my arm (mean = 4.1/5.0, median = 4.0/5.0), and that the training was not boring (mean = 3.1/5.0, median = 3.0/5.0).

Patients were asked whether training benefited their overall functional abilities. Although two patients did not report any changes in overall functional abilities, the majority of patients reported positive changes. One patients stated that his joint is “more lively” (H001), another stated that “the joint is more loose at the shoulder and there is some finger movements that I’ve not seen before” (H002). Patient H008 stated that “there was an overall improvement in arm functional abilities, and that the shoulder blade was stronger”, and Patient H010 stated that their “movements were smoother, and the elbow was less bent and less tense when walking”.

Patients were given the opportunity to provide comments and feedback regarding the training and the system. One patient reported that the “purpose of training is there, and was happy with the training” (H001) and another patient reported that the training was “helpful for my condition” (H004). Patient H010 suggested that “the clinician should assist the patient during the initial part of each training session, and that there should be some relaxation training for the neck and shoulder areas at the end of each session”. Patient comments about the system were less positive, with one patient stating that “the games were a bit boring and that more interesting and stimulating games would be better” (H007), and “the sound effects of the game need to be better” (H002).

IV. IMPLEMENTATION STRATEGY

Systematic reviews demonstrate that community-based stroke rehabilitation improves patient outcomes and is more
cost effective than conventional out-patient therapy. However, it remains an open question whether such benefits will be observed when using rehabilitation robots. In this section, we describe the hardware and software components of H-Man that will are currently being developed and revised, the methods by which we will identify barriers to implementing a community-based neurorehabilitation in low-income neighborhoods, and the proposed protocol for evaluating the effectiveness of this approach in a multi-cultural metropolitan U.S. city.

A. Revised H-Man

Results of the pilot study, along with feedback from clinical staff at CART@TTSH, were used to define guidelines for a safer and more refined version of H-Man for community-based rehabilitation. The revised version of H-Man (Fig. 4) will add extra layers of safety for user, in particular from the cables used to transmit force to the robot end-effector. The new version is designed to be more compact and aesthetically pleasing for clinicians, patients, and caregivers. In addition, we are currently designing an embedded controller that would reduce the cost of the real time controller (Quansar QPIDe, Quanser Inc.) from ~$20,000 USD to less than $300 USD. This will not only make the system truly portable but also will significantly reduce the cost making it potentially feasible for home use.

![Fig. 4. CAD model of the revised community-based H-MAN system.](image)

H-Man software modifications include developing a module for the evaluation of intra-limb coordination (i.e. between the shoulder, elbow, and wrist), and a quantitative assessment of upper limb proprioception. In addition, a more accessible and user-friendly interface will be refined, and will allow the therapist to maneuver between the training session and other system operations such as viewing the training calendar, general progress results, and messaging. In addition, a help function will be developed that details how to perform each training exercise (e.g., video demonstrations, virtual animations, etc), and the training objective associated with each exercise.

The serious gaming interface for the therapist will display a set of general setup and configuration tabs, and a set of patient-specific planning and assessment tabs. Tabs will be functional in that they open a visual representation of the material contained within. The general setup and configuration tabs (games, routines, patients) enable the user to view general patient data and progress results. The planning and assessment tabs (Profile, Training, and Results) will be available after selecting a patient, and provide a detailed view of the patient profile, allow training routines to be assigned to the patient, and display the history of progress results. Results and data from the assessment and training modules are accessible to the therapist, and provide information about the number of trials performed in a training session, time played, or data about arm kinematics and dynamics. We will implement the following training parameters that can be accessed at the end of each block and/or training session: range of motion, exerted force, speed, precision and accuracy, control, and task execution time.

B. Determine the barriers for community-based neurorehabilitation in low-income communities

Prior to implementing a clinical study in a vulnerable population it is essential to understand the individual, societal, organizational, structural, and/or provider barriers that preclude an individual from fully utilizing healthcare services [32].

Participants will be allied health professionals and chronic stroke patients who utilize services two community based organizations (CBO’s) located in the Bay Area (Fig. 5). The Asian and Pacific Islander (A&PI) Wellness Center is a fully-licensed, federally qualified health center (FQHC) and Patient-Centered Medical Home serving vulnerable and stigmatized individuals in San Francisco (e.g., people of color and the LGBTQ community). The A&PI Wellness Center is located in the Tenderloin neighborhood in downtown San Francisco, California. The Tenderloin has the highest crime rate of any district in San Francisco, particularly violent street crime such as robbery and aggravated assault [33], and has the highest rate of unsheltered homeless persons in San Francisco (57%, 3,836 total persons) [34]. In 2015, A&PI wellness provided healthcare services to 600 patients (1,546 unique patient visits). However, due to its appointment as a FQHC and a recent remodeling and expansion project, it is estimated that A&PI wellness will serve 4,000 (15,000 unique patient visits) in 2017.

The Mission Neighborhood Health Center (MNHC) is a Federally Qualified Health Center Program that provides healthcare to the medically underserved with a focus on the Latino/Hispanic Spanish-speaking community in the Mission neighborhood community in San Francisco. Each year the MNHC serves approximately 13,000 patients at its four sites. The Mission District has the highest concentration of Latinos in all of San Francisco with 38.6 percent (more than double the City’s overall 15.20 percent) [35]. In the Mission District, 45.6% are foreign born (naturalized and non-citizens), and 35% of Mission residents speaking Spanish at home [36]. As of 2013, the Mission District had a poverty rate of 17% (above the City’s rate of 14%), with 20% of Latinos living in the Mission living below the poverty line [35] and 30.7% earning less than $35,000 annually [37].
Fig. 5. Percentage of low-income households in San Francisco county in 2013. The H-Man device will be placed in CBO’s located in the Mission (solid dashed black outline and grid) and Tenderloin neighborhoods (solid black outline and grid). The Tenderloin neighborhood has a large commercial area, and thus no data is recorded for that section of the neighborhood.

Qualitative research methods will be used to examine the perceived barrier-to-care and attitudes about community-based stroke rehabilitation among low-income communities. The intervention design will involve establishing a theoretical basis by reviewing the problems faced by low-income neurological patients and their families/caregivers and of approaches that had proved successful in related fields, such as palliative care, chronic disease and rehabilitation. To identify the diversity of perceptions regarding the needs, concerns, and issues affecting a select group of participants, we will conduct face-to-face, in-depth semi-structured interviews with health care professionals (HCPs), chronic stroke patients and caregivers that reside in two San Francisco low-income neighborhoods. Interviews with stroke patients and caregivers will focus on questions regarding access, acceptability and utilization of current out-patient stroke rehabilitation services. Interview sessions with HCPs are designed to elicit information regarding critical aspects of recruitment and retention (e.g., identifying eligible patient populations, recruiting an adequate, representative sample, likelihood of retaining participants until study completion). The interviews will be digitally recorded with permission from the participants, and excerpts of the interviews will be transcribed verbatim. The interview transcripts will be input into NVivo qualitative data analysis software for content coding and analysis. As a first step, interview data will be inductively analyzed by creating codes organized around key themes and subthemes. As the coding progressed, subthemes will be identified and grouped within overarching themes as patterns emerge about how the codes relate to one another. The interviewers will discuss overarching themes after each of the interviews are conducted, allowing them to identify emerging themes and areas that require further exploration. The results will provide some guidance for the design of interventions to increase the use of out-patient stroke rehabilitation in this population.

C. Determine the feasibility of a community-based neurorehabilitation intervention in low-income areas

The objective of the proposed study is to compare user acceptance, upper extremity function, and implementation costs of a community-based robotic rehabilitation in two low-income areas of San Francisco. A secondary aim is to investigate potential relations between clinical and robotic measures.

The study design will be a six week delayed intervention randomized controlled trial. Participants will be recruited from two San Francisco CBO’s (A&PI wellness, MNHC). Participants must be at least 6 months post-stroke, between 18 and 80 years old, exhibit upper extremity motor ataxia or incoordination, and reside within 2 miles of the either CBO. Patients will be randomized to either receive the robotic rehabilitation immediately (fast track [FT]) or to receive standard best practice alone for three months and then be offered the intervention (standard best practice [SBP]).

Intervention will consist of a community-based individual robotic rehabilitation under the supervision of a physical therapist (or aide). Participants will travel to the closest CBO and engage in robotic training 4 times a week (45 minutes per session) for 6 weeks. Using the H-Man device, participants will perform planar reaching movements in seven directions. The robotic device will provide online assistance that is always tailored to the participant’s capabilities. Specifically, the robotic device provides more assistance during the trial when the patient requires it, and less intervention when the participant is able to move toward the target.

Outcome measures will be independently assessed by a blinded occupational therapist at weeks 0, 3, 6, 12 and 24 during the research trial. Subject involvement will be a total of 6 months. Upper extremity function will be evaluated using the following valid, standardized, clinical assessments: Fugl-Meyer Assessment, grip strength, Action Research Arm Test, Stroke Impact Scale, and the Modified Ashworth Scale. User acceptance will be assessed in terms of training duration and motivation. Participants will self-report frequency and duration online after each training session. Motivation will be assessed post-training (week 6) using the Intrinsic Motivation Inventory questionnaire. In addition, an assessment of health and social care costs will be undertaken. Patients will be asked to complete a health and social care questionnaire at 3 and 6 months to estimate all condition-related primary and secondary care costs and use of any social care services. The cost of delivering robotic stroke rehabilitation will also be estimated, and details such as actual time spent by the therapist with the patient, travel costs, frequency of visits, and equipment used will be recorded. This is in preparation for economic analysis in a large scale multi-site RCT.

The central hypothesis is that the novel application of technology to community-based rehabilitation will improve quality of life, lead to more efficient use of healthcare resources, and reduce the financial burden on patients and their families, third-party payers, and governments.
V. CONCLUSION

The H-Man system is a lightweight, portable, and low-cost alternative to currently available commercial robotic rehabilitation systems. Results of the clinical evaluation indicate that the system is sensitive to neurological status and changes in performance over time, and is usable and well accepted by patients. This innovative community-based neurorehabilitation plan is expected to have an important impact on the design of clinical interventions to shift outpatient rehabilitation in low-income communities toward community-based telerobotic care. This research builds logically toward a multi-site long-term randomized-control trial targeted at individuals in underserved populations who require specialized, neurological rehabilitation for individuals with chronic, progressive neurological disorders, but who do not require hospitalization.

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