Telerehabilitation: toward a cost-efficient platform for post-stroke neurorehabilitation

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Abstract— Motor deficits in the growing population of stroke survivors continue to strain global healthcare capacities. The use of telerehabilitation to address this need has been discussed for over a decade without a clear consensus on development strategy or a clear market success. In this paper, the cyclic and iterative phases of the Planning, Execution, Assessment (PLEXAS) rehabilitation cycle are discussed, and the potential roles of an integrated telerehabilitation platform within this cycle are presented. Some preliminary work on a multicenter project called TeleREHA is presented along with relevant clinical insight and discussion.

Keywords— Assessment, home rehabilitation, stroke, telerehabilitation, therapy planning, training goals.

I. INTRODUCTION

The growing population of stroke survivors continues to create a need for new strategies and tools for efficient provision of post-stroke care. In 2006, the direct and indirect costs of stroke in the US (estimated $57.9 billion) were nearly twice those of 1993, with over half produced by direct costs [1]. About 5% of these direct costs, almost $2 billion, are spent on inpatient rehabilitation [2]. Despite the fact that 90% of stroke survivors are left with lifelong deficits, however, existing facilities are only able to provide rehabilitation services for about 10-15% of patients [3].

A. Growing Trends in Stroke Care

The outlook on stroke rehabilitation for future patients is under rapid decline unless vital introductions of new treatment interventions are made. If the current treatment numbers of Prigatano & Pliskin [2] persist, it can be expected that by the year 2050, less than 5% of stroke patients will receive the treatment they need as a result of insufficiencies in patient care capacity. This lack of treatment availability is presumably the result of one or a combination of the following: a) the high cost of inpatient rehabilitation, b) a lack of trained therapists, or c) the unavailability of alternative care-delivery modalities.

The culminating situation creates a pressing need for new strategies to increase productivity that are capable of maintaining or bettering the current standard of care. The growing ratio of potential patients to trained therapists must be addressed by a multi-disciplinary approach that considers the needs of all stakeholders, the largest being the therapist and the patient [4]. A promising solution can be found in the development of a set of web-based telerehabilitation platform applications and compatible low-cost devices. The devices and applications should be designed to meet the fundamental needs of the patient and therapist throughout the phases of the rehabilitation process.

B. The Iterative Rehabilitation Cycle

The rehabilitation process is cyclic and iterative, composed of phases of Planning, Execution, and Assessment as shown in Figure 1. The process begins and ends with an assessment of impairment to guide the planning process and track the progress achieved during the previous rehabilitation cycle. Based on results of the assessment (progress results), the multi-disciplinary therapy staff develops a plan for the course of therapy (treatment plan), which defines how the training is to be executed. Throughout execution of the treatment plan, data is stored in a central and secure storage server (database). In this way, each phase of the rehabilitation process has a defined input and output that forms an integral part of the successful progression.

C. Technology for Rehab

For patients undergoing rehabilitation, training duration is often shorter than optimal for a number of reasons,
some of which being financial. For therapists, rehabilitation practice is labor-intensive, and therefore may be limited in duration or intensity by the fatigue of the therapist in lifting the patient limbs, or by shortages in personnel. This human involvement intrinsically lacks repeatability and objective measurability in following the patient’s improvements. When using a robotic device, training regimes can be programmed, and therapists have the opportunity to offer their patients more repetitive movement training, or massed practice [5]. At the same time, available sensors of the robotic device may provide the therapist objective measures about patient motor capabilities, which can help to follow patient progress or make decision about treatment revisions.

Recognizing the strength of robotics for repeated and measurable movements, it is no surprise that robotic technologies are gaining popularity in the rehabilitation cycle. Since the early devices by Hesse [6], Krebs [7], and others, research on robotics for rehabilitation has increased substantially. A common thread in developments, however, has been their focus on supporting primarily the phases of Execution and Assessment, whereas very few systems have put any real emphasis on supporting the Planning phase. Renkinsmeyer [8] was one of the earliest to present a prototype system for home-based therapy with the Java Therapy platform. The system used a force-feedback joystick as the training input device and was equipped with several primitive assessment games, training games, and methods of reporting progress. While more recent systems have begun to emerge (see Table 1), their success on the marketplace has been stunted for one reason or another. As a result, the current state of rehabilitation care for most patients remains largely dependent on frequent and repetitive supervision, involvement, and intervention on the part of the therapist.

The integrated telerehabilitation concept of today is that of patients with similar impairments. Profile information can be linked not only with the data-base of the patient’s own training histories, but also with similar one or several training sessions can be repeated to form a therapy. Under this model, the therapy can be reviewed and revised at anytime by the therapist, and selectively modified at any of the three task-session-therapy (TST) levels.

Before the availability of robotically-assisted-rehabilitation (RAR), all three TST levels were assessed, planned, and executed in the presence of the therapist. The therapist was needed equally for the burdensome load of manual movement assistance in tasks, modifying the task difficulty and eventually in selecting new tasks as the patient’s functional mobility improves. In this pre-RAR era, the therapist had at least partial responsibility for the completion of all PLEXAS phases on all TST cycle levels. Post-RAR technologies shift the responsibility more to the side of the patient and away from the therapist. The separation between the patient and therapist responsibilities is defined here as the boundary of responsibility and has been drawn in Figure 2 for two boundary cases. First, the boundary B1 represents the current model that is allowed within the framework of existing RAR and telerehabilitation technologies, where only the task level cycle can be automated. Second, the boundary B2 shows how the introduction of an integrated telerehabilitation platform shifts the boundary to encompass both the task and session level cycles. In this model, the therapist maintains control of the therapy (down to the task level) through the therapy planning phase, but is at the same time freed from the burden of task level execution and assessment. This introduces the concept of the “Virtual Therapist”, which will be discussed later in section III.B.

While some of the current tasks of the therapists should clearly not be offloaded to a technological counterpart (even if they could), it is worth considering the potential benefit that an integrated telerehabilitation platform can bring to the overall efficiency and effectiveness of post-stroke care. With integrated solutions, patient profile information can be linked not only with the database of the patient’s own training histories, but also with that of patients with similar impairments.

In an integrated telerehabilitation platform, treatment plans can be modified from pre-existing therapies, or...
assembled from more primitive TST level building blocks. The ability to create, modify, and save routines provides an enormous advantage over the current standard of treatment in terms of recordability, scalability, and accessibility. A treatment plan under this model is immediately accessible at the task, session, or therapy level for review or revision at the discretion and availability of the therapist. Similarly, the results of training can be assessed at each level either as raw output from the Execution phase, or as a post-processed aggregation of results from the Assessment phase, again, at any TST level.

In order to align the project with clinical perspectives, a series of focus groups with medical doctors, physical therapists, occupational therapists, and nurses were conducted on the following topics: 1) clinical needs and expectations for in-home rehabilitation (conducted at 2 centers); 2) evaluation and exploration of two hardware prototypes for rehabilitation; 3) relevant games for training and assessment.

Table 2 enumerates a list of functions under development in the project, categorized by their relation to the PLEXAS cycle. As illustrated in the table a large emphasis is placed on the Planning (P) and Assessment (A) phases. The project is further developing training environment software in the form of assessment games and training games, together with a telecommunication infrastructure designed with the guidance and feedback of clinical partners and focus group results.

C. Preliminary Usability Testing

A preliminary version of the TeleREHA software along with three versions of an arm reach training game and a second-generation ArmAssist prototype (first generation described in [10]) were presented to therapists during a usability test at a rehabilitation clinic in Bordeaux. Six therapists (3 physiotherapists and 3 occupational therapists) and 6 stroke patients participated in the testing. Stroke patients were selected by the group of therapists from a wide spectrum across the patient popu-
Impairment scores ranged from 0-5, where 3 corresponded to an ability to move the arm against gravity.

2D vs. 3D Training Games – Patients were asked to perform extension arm reach tasks in order to reach a target for each of three game conditions, where the game conditions were 1) a 2D movement represented in a 2D environment, 2) a 2D movement represented in a 3D environment, and 3) a 3D movement represented in a 3D environment, (see Figure 3). Each game task involved similar movements in arm extension where the path went forward and right for right-handed patients, and forward and left for left-handed patients. The 3D task involved a combination of planar arm motion and orthogonal lifting force. Although tasks, avatar images, and target sizes differed in each of the three game environments, valuable observations were made regarding the usability of each setup. Most notable was the difficulty several patients had in visualizing the third dimension despite the perspective views, reference objects, and shadows. While this challenge can provide motivation for some persons, for others it can be a source of frustration, making the task too complex. For this reason, it is recommended that assessment games avoid the use of unconstrained 3D environments in conveying the target end position of three-dimensional paths.

Prototype therapist interface – In evaluating a first version of the therapist interface, the therapist was seated in front of a computer and asked to perform the following three tasks using the interface: a) send a message to a patient, b) view the results of the patient from a specific date, and c) set-up a therapy for the patient. These tasks allowed the therapist to view most of the fundamental parts of the software (communication, therapy set-up, and results).

A think-aloud protocol was followed where the therapist was asked to explain the actions he or she was performing, why he or she was doing them, and what he or she expected to happen as a result of the action. When the therapist had finished the 3 tasks, an open discussion took place to record general impressions of the software. The feedback provided was positive and gave valuable insight on a number of aspects from color and contrast, to layout, wording, and workflow. On the positive side, therapists "really appreciated the global logic to assign a therapy" (sic), which followed the sequence: (1) select a patient – (2) select a game – (3) select a date. Some examples of the interface and icons presented are shown in Figure 4.

![Figure 3](image1.png)

Figure 3. Usability testing of training game presentation using 2D task in a 2D environment (top-left), 2D task in a 3D environment (top-right), and a 3D task in a 3D environment (lower-right). Close-up view of the 3D task screen (lower-left).

![Figure 4](image2.png)

Figure 4. Prototype icons used in the therapist interface (a), the communications page icons (b), and a 4-day view of the therapist’s assignment calendar (c).

A few points that needed revision related to the appearance of some icons, homogeneity of results, the use of relatively new terms, and the incorporation of a navigation tree.

- **Appearance of icons** – It was discovered that many users didn’t know exactly what they were clicking on until after they clicked and found where it took them. A more explicit formulation of the buttons was expected.
- **Homogeneity of results** – The results page (for therapists) should be homogeneous for every kind of game. This refers to the way data is shown, that the same graph families should be used to present the data from each game rather than the format being unique to the game.
- **Terminology** – The use of terminology should be carefully chosen as not all therapists are familiar with services that many engineers consider mainstream. Many therapists have never heard of "twitts" or "twitter". As a result, they were unable to understand the "short messages" functionality that had been implemented in the first version platform.
- **Navigation** – It was also noted that maintaining orientation while navigating pages was difficult, and that a clear indicator of the location within the submenus, (e.g., the
use of breadcrumbs, etc.) would improve the sense of location within the platform page structure.

**D. The RESPECT Training Goals**

Depending on the patient, it is known that stroke can affect a number of functions, including range of motion, speed, coordination, precision, or the ability to regulate forces. Effective rehabilitation requires that the therapy is goal oriented and involves the active participation of the patient. Even for the same hand trajectories, however, motor control strategies are affected by the goal of the task [11], and therefore, it is assumed that different types of tasks are necessary to retrain all the impaired aspects of reaching. As a result, the RESPECT rehabilitation training goals (reproduced in Table 3) have been proposed as the key elements to incorporate into movement tasks of rehabilitation training games [4]. These are the basic time- and position-sensitive elements that should be incorporated into both assessment games and training games. Combinations of these goals are then to be trained during the training execution phase, and their components can be extracted and processed to compute meaningful indicators of progression and functional ability in the assessment phase.

![Table 3 The RESPECT training goals for motor rehabilitation](image)

In the case of RAR therapy, the rehabilitation movements to be executed must satisfy the therapeutic training goals while at the same time take into consideration the limitations of the device hardware being used. The training movements of interest may include movement of individual joints, such as shoulder or elbow extension, or coordinated movement of multiple articulations at the same time, such as simultaneous shoulder and elbow extension. Research has shown the detrimental impact stroke can have on coordinated movements of the shoulder and elbow, eliciting abnormal synergies between shoulder flexion and elbow extension [12]. As a result of such synergies, many therapists place a high priority on trying to train multi-joint movements. In general, any coordinated movement that goes against the abnormal muscle synergies is of interest. At the same time, therapists recommend avoiding movements that can reinforce the flexor muscles, since those muscles are typically overactive as a result of spasticity.

Furthermore, a distinction can be made between repetitive movements like cycling or rowing, and independent movements like pick-and-place tasks, since they involve different neural pathways. In each case, the RESPECT training goals can be used as guidelines for the components of motion and force to be trained and recorded.

**III. DISCUSSION**

**A. Therapist Acceptance**

For successful introduction of telerehabilitation technologies, developers must acknowledge the critical role of the therapist and design technologies that offer themselves as tools at his/her disposal. A telerehabilitation software platform should assist the therapist in the provision of repetitive training exercises and perform necessary data reduction to present the therapist with relevant patient statistics. Therapists are typically very limited on time and cannot afford to review extensive results. The data reductions process should seek to reduce the set of information to the bare minimum of elements that transmit the patient progress with respect to the desired training goals. The data should allow the therapist to make educated and efficient judgments toward planning the most effective therapeutic intervention.

The platform should also have the capacity to provide intelligent suggestions about the training needed based on the assessment trends and comparisons to similar trends in the patient database. Providing the therapist with automated suggestions is a promising way to reduce setup and prescription time for the therapist. This component will be especially important when the technology is first introduced and the therapist is still getting acquainted with the process for configuring the system. At the same time, this is also the period in which the therapist is most unfamiliar with the technology and therefore most likely to distrust the “intelligence” of the system.

**B. The Virtual Therapist**

As mentioned in section 2.A (The PLEXAS Cycle), a promising technology is toward the development of a “Virtual Therapist”, or “Virtual Helping Hand”. It is important that in approaching this topic, the context is not misinterpreted as a tool that provides more than it should. The goal of a “Virtual Therapist” is not to control or fully automate the therapy, but rather to present the therapist with a tool that can be turned on or off, and adjusted as desired. It can be thought of much like the function of cruise control or navigational assistance in cars, and should never be confused with the irreplaceable function...
of the steering wheel or the brake. The “Virtual Helping Hand” can provide the therapist with suggestions and roadmaps, and automatically report on the progress as well as deviations from the selected roadmap. The roadmaps are training regimes composed of predefined sets of training goals, threshold settings, and measured parameters. It allows a plan to be devised, modified, and set in motion under periodic approval and direction.

C. Improved Efficiency

Addressing the growing deficit of treatment capacity, the use of an integrated rehabilitation platform can be used in a parallel treatment model, where a single therapist could manage sessions for multiple patients together. The therapist could observe real-time task and postural feedback on a master therapy console, and be able to select which of the patients to observe, what progress parameters to display, and select the format of display. Examples of display options might include: live streaming video of the patient’s movements or the patient’s display screen, a 3D virtual representation of the patient’s movements, or a numeric performance score. The introduction of such a platform frees the therapist from his conventional burden (physical and temporal) of manual therapeutic interactions with the patient, without removing his control over the therapeutic phases of assessment and planning.

D. Game Environment Display

As a result of the patient and therapist feedback in usability testing with various game interfaces, it was noted that patients had a difficult time distinguishing positions of objects in the three-dimensional space even in the midst of multiple environmental cues. In this case, subjects only payed attention to the proximity of object boundaries on the screen and ignored extra information that conveyed distance such as size and shading. Further testing would have to be performed to know the prevalence of this occurrence, but the effect was strong enough to recommend using only two-dimensional movement tasks in games for ability assessment.

IV. CONCLUSIONS

From the growing trends of the stroke population and the decreasing ratio of patients to therapists, it is clear that more treatment modalities must be extended beyond the borders of the in-patient setting to locations outside of the hospital. It is believe that integrated solutions in telerehabilitation technologies have a high potential to address this need in an efficient and economic way, extending the ability to perform entire therapeutic sessions within the patient home.

Regardless of the sophistication of new telerehabilitation platforms, it is clear that the therapist remains an integral part of the therapeutic process, and as such, developers must fit therapy-assistance technologies within the context of the foreseen needs of therapists.

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