# Stroke Rehabilitation with a Sensing Surface

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**ABSTRACT**

This paper presents a new sensing and interaction environment for post-stroke and upper extremity limb rehabilitation. The device is a combination of camera-based multitouch sensing and a supporting therapeutic software application that advances the treatment, provides feedback, and records a user's progress. The image-based analysis of hand position provided by a Microsoft Surface is used as an input into a tabletop game environment. Tailored image analysis algorithms assess rehabilitative hand movements. Visual feedback is provided in a game context. Experiments were conducted in a sub-acute rehabilitation center. Preliminary user studies with a stroke-afflicted population determined essential design criteria. Hand and wrist sensing, as well as the goals of the supporting game environment, engage therapeutic flexion and extension as defined by consulted physicians. Participants valued personalization of the activity, novelty, reward and the ability to work at their own pace in an otherwise repetitive therapeutic task. A "character" – game element personifying the participant's movement – was uniquely motivating relative to the media available in the typical therapeutic routine.

**Author Keywords**

HCI; rehabilitation; stroke; tabletop; gesture recognition.

**ACM CLASSIFICATION KEYWORDS**

H.5.m.

## INTRODUCTION & RELATED WORK

A stroke occurs when there is a sudden disruption in the brain's blood supply. This lack of blood can cause brain damage resulting in physical and/or mental disability. Stroke is the leading cause of serious, long-term disability in the United States [7]. Every year, approximately 800,000 people spanning all ages in the U.S. suffer a stroke and more than half of stroke survivors are concerned with regaining mobility and motor control more than any other after-effect [11]. Stroke rehabilitation techniques consist of various grasping, lifting, and repetitive gestures meant to regain strength and range of motion in affected limbs[4]. Ambulatory goals such as walking, or more simply, crossing the body's midline with an affected limb, are also common. Patients additionally focus rehabilitation effort on activities of daily life such as bathing, eating, and dressing. Immediately following a stroke, there is a limited biological window with which to introduce treatment to regain functionality in hemiplegic limbs. Typical treatment takes place in coordinated care centers, where patients undergo occupational, physical and ancillary supporting therapies. After a multi-month, high frequency, sub-acute phase, the structure and nature of treatment changes. The emphasis shifts into the home with a regimen of exercises that a patient is meant to perform on her own, maintaining strength in affected limbs, and adapting to manage a chronic condition, everyday.

In 2002, the WHO offered prescriptive recommendations to break down systemic barriers to chronic care management across diseases. The critical strategy was to form care triads between communities, family, and the healthcare organization, although the WHO falls short of identifying what low-cost platform could host such an engagement triad [17]. Technologies may provide structured, data-driven rehabilitation in novel contexts. Technological bridges built between the sub-acute clinic and the longitudinal care environment of the home carry the opportunity to bolster outcome measurement and reporting that are part of the definition of disease management.

Furthermore, from a neurological perspective, post-stroke rehabilitation is a multisensory problem. Movement is a complex phenomenon that draws on all available perceptual resources, including vision, audition and haptics. Behaviorally, a multisensory advantage has been documented where tasks incorporating multiple, reinforcing perceptual modalities are performed faster and more accurately than their unisensory counterparts [6, 10]. This advantage is based in the brain. Multisensory receptive fields are groups of neurons that respond to auditory, tactile or visual stimuli and often respond greater to multiple sensory domains presented with similar spatial and temporal proximity than the presentation of unisensory stimuli [15]. These are critical systems for the integration of sensory percepts to produce coordination of limb movement.

The difficulty in researching the contribution of multisensory integration to the rehabilitation of pathological function is the lack of a tool that can structure a long-term intervention while simultaneously incorporating multiple modalities of presentation and feedback. For instance, in hemiparetic limb rehabilitation, several robotic and wearable devices are becoming platforms to examine long-term rehabilitation [13, 8]. This is where we see an opportunity in interaction design, by combining a multisensory environment - touch, visual, sound - to a rehabilitation platform. In addition to new contexts of rehabilitation, data, and structured multisensory engagement, a more game-like environment has the potential to be both entertaining and motivating. Research supports the use of games in stroke rehab environments towards motivation [9] and achieving cognitive goals [5]. The reality of stroke rehabilitation is that the exercises are often highly repetitive, painful, and discouraging. If these exercises could provide significant secondary reward, if they could be fun, as in a game, it would greatly improve patients' morale as well as their incentive to persevere..

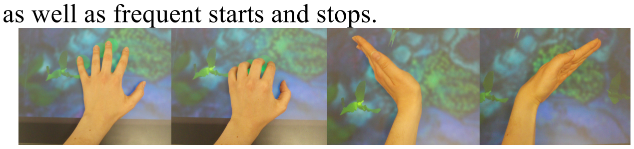
Research has focused on wearable robotic systems to support physical rehabilitation for stroke, traumatic brain injury and other movement impairments. The *Myomo* device uses electromyography to sense intended limb movement via muscle contraction on the forearm, and serves the information to a set of motors that assist the patient through the intended movement [13]. The *Rupert* device similarly actuates upper extremity movement in three-dimensional space [14]. Mechanical input devices have been designed to detect linear motions that enabled post-stroke patients to play the Pong game [3], but the one-dimensional control afforded by the application limits the scope of the exercise [2]. A haptic glove was created for hand rehabilitation with video games designed for stroke survivors [1]. The challenge for robotic rehabilitation systems is the design of control algorithms and actuators that are safe for the patient, as well as a device that is conducive to home installation and self-directed use.

We introduce the Microsoft Surface Table as a platform to research new contexts for stroke rehabilitation. Multitouch sensing of hands and limbs is accomplished along the table's surface plane, providing the body-kinematic structure to introduce established rehabilitative movements from physical and occupational therapy. The screen is a suitably large application environment that rarely gets obscured by the user's body as they interact with the table. We can capture and structure data as in any modern desktop application. The Surface is not limited by graphics or media capabilities, supporting rich multisensory applications. Finally, we can customize image-capture algorithms to analyze affected limb movement with detail and precision that is rarely realized in the exercise environments of standard post-stroke treatment. Our research contributes to the HCI community by presenting a system that tracks movements on a sensing platform to evaluate a range of motions associated with the fingers, hand, wrist, and arm that engage strength and range of motion while providing critical feedback. We propose a multisensory environment that is feasible for patients with a spectrum of cognitive and physical ability. Our case study elaborates a successful interaction model that motivates patients in continued therapeutic engagement.

## IMPLEMENTATION

The Microsoft Surface Table has the ability to recognize three distinct contacts and their respective orientations to the surface plane of the table: fingers, blobs, and tagged objects. The Surface separately identifies fingers whereas any other objects are handled as blob shapes.

A hand exercise was developed involving curling and uncurling fingers as well as a wrist exercise involving flexion and extension of the hand back and forth about the wrist (Figure 1.1). The mechanics of the chosen gestures were selected via consultation with occupational and physical therapists prior to development. The algorithmic challenges were to detect distinct single flexion and extension pairs, and to then collect series of motions as a group amidst the extant noise from pathological movement as well as frequent starts and stops.

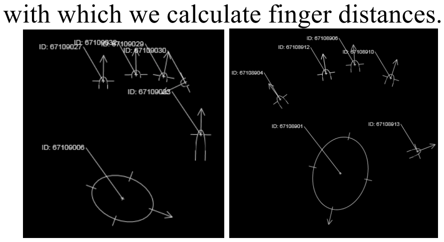


**a.** Uncurled fingers **b.** Curled fingers

**Figure 1.1 Interaction with the Jellyfish.**

The game's layout features a sea-creature (a fish or jellyfish), a goal (food or a hoop), a progress bar, and three buttons (the jellyfish button, the fish button, and the navigation button which lets the user go back to the splash screen). Users can play with two different sea creatures in this prototype, a fish and a jellyfish, selecting between finger and wrist exercises.

*The jellyfish motion* consists of five fingers and palm detection on the planar surface. The bottom of the palm of the hand, flush against the surface (Figure 1.2), is the baseline with which we calculate finger distances.



**a.** Fingers curled **b.** Fingers uncurled

**Figure 1.2 Data Visualization of Jellyfish Motion.**

The closest blob to the fingers is identified as the palm/wrist. The detection algorithm rejects spurious blobs from distal limbs or the forearm. A local maximum is the greatest average distance between the fingers and the wrist.

Maxima for this gesture can only occur when the fingers are outstretched. Therefore, the system tracks the original direction of movement of the fingers and records when the user has changed directions. If the direction changes after the user begins returning to his or her original position, it is a maximum, so the system recognizes that the gesture is complete and stores it. After a gesture is complete, the system creates a new gesture object based on the recognition of the contact information. To play with the jellyfish, the user repeatedly curls and uncurls her fingers while keeping the fingers and palm in contact with the table in order to propel the jellyfish through a hoop. The jellyfish automatically orients itself toward the hoop.

*The fish motion* detects wrist flexion and extension. To play with the fish, the user repeatedly moves her hand back and forth- a rehabilitation exercise to practice flexing the wrist- in order to make the fish flap its tail and move toward a piece of food. The fish automatically orients itself toward the food. The system tracks hand movement by calculating the change in orientation of the hand and forearm blobs about the wrist. The average speed of changing orientation is the primary control input into the game, again, driving the movement of an aquatic character.

The system defines a gesture such that it contains only one local maximum. For the fish motion, a local maximum is the greatest recorded angle between the hand and the wrist. If the system recognizes that the user has changed directions – that the angle is no longer increasing - the system identifies that the gesture is complete and stores it. The authors took this approach to allow for different maxima in the two movement directions, which is often observed due to pathology such as muscle weakness and neurological damage.

The interaction is sufficiently novel to warrant visual feedback as to successful hand sensing. The system displays light green ellipses underneath the users' recognized fingers and/or blobs as they perform gestures. If users perform an unrecognizable gesture on the Surface, the system does not display any gesture feedback. Therefore, the ellipses help users determine if they are performing gestures correctly.

Each user has a profile that contains her overall work with respect to treatment goals. The system saves a user's profile to an Extensible Markup Language (XML) document after each session the user plays the game. The data architecture is divided into discrete gestures; groups of gestures collected into a session, and sessions as well as associated scores collected under a particular user.

## CASE STUDY

All of the recruited patients from both sessions (N=6, N=5) were male (age range 45-65), in the sub-acute stage of treatment (one week to one month after trauma) from an inpatient facility (residents, working towards discharge). Patients had suffered a stroke, traumatic brain injury, or cerebrovascular accident resulting in upper extremity hemiparesis. Patients were successful in their prescribed therapies. They were adhering to treatment and positively progressing towards their discharge criteria of increased strength, range of motion, and successful activities of daily living. However, patients described therapy as frequently frustrating, rarely tailored to their level, and frequently demotivating. Most patients began treatment needing complete assistance for basic reaching and mobility tasks. The patients we interviewed and measured were self sufficient to conduct the requested movement and adjust body position relative to the Surface. The pilot study lasted one hour per user including patient transport. The 2-day user study consisted of two 20-minute sessions focusing on movement with the Surface over two days. Duration of application use was consistent with other individual exercises encountered in the participants' physical and occupation therapy regimens.

### Pilot study

The purpose of the pilot study was to determine the feasibility of a surface sensing environment for sub-acute stroke rehabilitation. The authors conducted interviews. Additionally, study participants performed the two game gestures on the Surface without the support of the game environment. The system recorded their Surface interaction data that were later used to design the averaging filters and fit gestures to wrist and finger movements. Therefore, the pilot data generated the definition of "gesture" used in this research, and as an input to the game environment.

Participants were instructed that the research was to develop new technology to aid in stroke rehabilitation. The interview primarily contained questions of an open nature; the researchers asked about the patients' experiences with physical therapy, their most and least favorite exercises, and if there were anything they found particularly frustrating about the ongoing rehabilitation regimen.

The predominant finding from the pilot study was that self-directed physical therapy using the sensing platform could be extremely valuable to address patient frustration with rehabilitation. Participants consistently agreed that they became frustrated with physical therapy when they were not challenged or did not feel like they were working toward their full recovery. This occurred when physical therapists paired patients of different recovery levels together, such that one patient was essentially holding back the other. Inclusion settings are the basis of a taxed, center-based, rehabilitation system, yielding a systemic need for self-directed, personalized treatments. Our system could be greatly beneficial when patients need treatment at different levels if there are not enough physical therapists to attend to each patient individually. Physical therapists could prescribe interactions with the Surface that could be used remotely as long as the system adjusts the level of difficulty appropriately for a given patient.

### Two-day patient study

The study combined standard quantitative and qualitative measures to include motivation, reliability, usability, range of motion, game score and other aspects of how the participant moved within the game environment. Data collection consists of notes, saved interaction data, videos, and interview responses.

### *Scaling to the Users' Needs*

We noticed a vast range in both the physical and mental capabilities of the patients. Stroke is sometimes limited to just movement pathology, but often incurs collateral cognitive impairments. Heterogeny in the population for a given motor functional level emerged as a critical design criteria. For some patients, the game was over-stimulating while for other patients, the graphics and feedback were not as exciting and stimulating as they would have liked. These participants wanted lights, brighter colors, and sounds. Thus, our interface could also add scaling features for the graphics and game feedback. The key finding is that multisensory stimulation is not a "silver-bullet" solution for motor rehabilitation when accompanying cognitive deficits modulate the effectiveness of otherwise supporting visual and auditory feedback. The system needs to be flexible to accommodate different users' physical and mental capabilities. To address the different physical capabilities of users, a physical therapist should be able to set specific parameters that describe the expected abilities of the user.

### *Metaphorical gestures as a motivation factor*

A player-character gesture connection was a motivating factor. Most participants spoke to the creatures as they played the game, e.g. "Go fishy!" Additionally, one patient said, "*I would definitely... rather do that with my hand than squeeze a ball.*" The characterization of the movement is significant both emotionally and neurologically. The observation that the hand movements were inherently "fish-like" (the fingers become like jellyfish tendrils, the waving hand like the body of the fish) makes them semantically relevant. They model motor actions that have analogs in the natural world. Research supports the existence of specialized neurological mechanism for integrating multisensory percepts in motor representations of semantically relevant actions [12]. This is likely to reinforce attempted movement. More gestures could be integrated into the game to further broaden the scope of range of motion and strength exercises such as dragging a forearm forward on the sensing table, pinching fingers that rest on the sensing platform, spreading fingers radially, poking, pushing down on a tangible ball on the screen.

## CONCLUSION

A sensing surface with an engaging user interface is a promising rehabilitation tool. Our research has enabled future work in motivation and therapeutic outcome. Reward design, personalization, new vistas of gesture analysis, object involvement, longitudinal study in a clinic environment, and embedding the device in chronic home environment are all now possible due to the described explorations. Current physical rehabilitation techniques could benefit from this technology. Clinically, this tool successfully quantifies the motor skills of patients engaged in hand movements that parallel their wrist and hand movements during therapy. Motivationally, patients explained that they preferred playing this game to performing their current rehabilitation activities. This system has the potential to positively impact how physical therapy addresses specific patients' needs and how physical therapists assess patients' progress over time.

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