HCI and Stroke Rehabilitation: A Survey of Current Research Areas

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ABSTRACT
This paper explores the need for and current methods of using technology to help stroke victims. Recent methods of rehabilitation involving robotics, haptics, virtual reality and games are explored, compared and contrasted.

Author Keywords
Impairment; stroke; rehabilitation; technology.

INTRODUCTION
Up until the last century, there was very little research into stroke rehabilitation. Scientists and physicians knew the cause of strokes but little was known about how to treat the resulting paralysis. A stroke patient would likely end up in a mental institution or be left to finish out their days with limited mobility. This mindset would change in the early 20th century.

In 1918, Robert Oden published a paper in the Journal of the American Medical Association that challenged the current mentality of stroke treatment[12]. Oden suggested that “paralyzed limbs should be rubbed, moved passively” and “when voluntary power begins to return, this should be encouraged by practice, and the patient should have regular gymnastic exercise.” In other words, stroke patients should be treated by moving the impaired limbs, at first with assistance and later, without help. This practice is known today as Constraint-Induced Movement Therapy or CIMT. When it was published, Oden’s paper received very little attention and did not become common practice until some years later.

Since then, CIMT has become a staple in physical therapy and has led to many different applied fields of stroke rehabilitation including Neurodevelopmental Treatment or NDT. NDT stems from the works of Berta and Karel Bobath, a physiotherapist and psychiatrist/neurophysiologist, respectively. The Bobaths did most of their work with patients suffering from cerebral palsy and strokes. Their concept of rehabilitation involves learning to control movements and postures then progressing on to increasingly difficult movements and postures[3].

The main difference between CIMT and NDT is in their final goals for the patient. CIMT focuses on trying to return a patient to pre-stroke levels of movement where NDT wants to achieve a base level of functionality. NDT is applied to a specific area and CIMT is for the body as a whole. Both methods are used frequently in the treatment of stroke victims. A lot of different practices stem from these two ideas of treatment, many of which involve human-computer interaction. This paper will discuss a few current areas of research combining stroke rehabilitation and human-computer interaction. These include robotics, wearables, haptic feedback, virtual reality (VR) and games.

RELATED WORKS
Robotics and Wearables
Physical therapy is a repetitive, time-intensive process to restore range of motion to the patient’s body. As time with a professional therapist is limited, researchers are attempting to find new, technology-based methods of rehabilitation. One such approach is to replace or augment the traditional therapy with a robot. There are many variations of this idea, but they are all based around a device tracking the movement of a patient’s limbs. A robot or wearable device, strapped to the limb, can much more precisely measure the range of motion than a physician could. Some devices can even add an assistive or resistive force to help the patient complete the motion or increase the strength in the limb. “Advances in upper limb stroke rehabilitation: a technology push”[11] provides a good overview of the robots developed for upper limb rehabilitation, but similar technology can be used for the legs, as well. Wearables are similar to robots, in that they track range of motion, but are generally smaller and more portable than robots which are free standing or built into the room. Figures 1 and 2 show some of the different styles of robotic rehabilitation devices.
Wearable and robotic rehabilitation have some inherent advantages over a physical therapist. Devices can repeat the same exercise many times without tiring or growing bored. Evidence suggests that hundreds of repetitions are necessary to regain proper function, but a traditional therapy session might only have time for fifty\cite{7, 14}. While a therapist may only have time for one hour of work, a robot or wearable can provide a patient with hours of exercise, every day, allowing many more repetitions and a much better chance at recovery.

Another advantage technology has over a therapist is portability. Some robotic systems can be set up in patients’ homes providing easy access to therapy. Wearable devices, like the PT Viz\cite{2}, can be put in a bag and taken wherever the patient wants to exercise. The original goal of the PT Viz was to give the user an accurate measure of their range of motion. This would make it easier for the user to watch their range of motion increase over time and give them encouragement to continue the therapy. In addition, the research showed that the users liked the portability of the device. They took it to the gym with them and were able to exercise with it there. This suggests that users are more likely to participate in therapy if given the choice of not only when to exercise, but where they exercise.

Robotics can also enable therapies that are difficult or impossible to do traditionally. One such method is mirror therapy. It uses a force assist robot attached to the partially paralyzed or paretic arm and a tracking robot attached to the non-paretic side. The patient tries to move both arms through the same movement and the robots will keep the arms in sync. This connects the movement of the good arm in the brain with the impaired movement and has been found to be more effective than conventional therapy and has maintained that effectiveness over the following months\cite{11}.

While usable on their own, robotics and wearables pair well with the other techniques discussed below. They can be added to or are the basis of many haptic and VR methods. They can be combined with games, but modern video game consoles have their own methods for measuring motion, like the Wii Remote and Microsoft Kinect. So while bringing the game aspect to robotics would create more interest in the user, it is cheaper, easier and more portable to use the consoles’ native methods of capturing motion.

**Haptic Feedback**

An alternative or supplementary approach to robotics and wearables is the use of haptic feedback devices, or touch feedback. Haptics provide a touch response to the user through vibration or forced movement of the user’s body. The primary utility of haptic feedback in rehabilitation is in strengthening associations between movements of the body and the moved extremity’s location in space. An example of haptic feedback for this purpose in people who are visually impaired but otherwise neurotypical is found in “Haptic-feedback support for cognitive mapping of unknown spaces by people who are blind” by Lahav and Mioduser\cite{8}. In this study, blind subjects navigated a virtual environment created by the researchers using haptic and audio feedback produced by the experimental apparatus and then re-created the virtual environment scene using wooden blocks. 19 of the 20 subjects in the control group were able to accurately reconstruct the layout of both the virtual and real objects in the room, which demonstrates the usefulness of haptic and auditory feedback in navigation.

The same principles are applied to stroke patients in the experiment described in “Haptic Effects for Virtual Reality-based Post-Stroke Rehabilitation” as designed by researchers from Rutgers University and the University of Medicine and Dentistry of New Jersey\cite{4}. Subjects who had demonstrated deteriorated control of their legs were fitted with a haptic feedback device, attached to the foot, called the Rutgers Ankle haptic interface. This device measured torque and displacement during experimental tasks, which were supervised remotely via videoconference by a rehabilitation specialist. The patients interacted with the virtual world by moving their feet to send commands to the interface. The device was used as a joystick to fly a virtual plane through three-dimensional rings and to pilot a boat between buoys on choppy ocean.
waves. Air turbulence and wave displacement were communicated to the wearer both visually and via haptic feedback vibrations in the foot and ankle. The study demonstrated that the addition of haptic feedback did not interfere with the process of learning to navigate the simulations and that haptic feedback may have maintained the subject’s interest and involvement in the rehabilitative exercises.

Virtual Reality and Games

In a recent study of mobility, 74.6% of stroke survivors reported the ability to “get out and about” as essential or very important. Yet, 39.1% of them could not walk past their mailbox[10]. An intense physical therapy routine of repetitive exercises has proven necessary to recover motor skills and mend neural organization, but it can frustrate patients[1]. The exercises may seem irrelevant and monotonous, and the patient may not be motivated to repeat them outside of a clinic. Virtual reality systems can remedy these issues, as well as stimulate healing in ways conventional practices cannot.

Virtual reality systems immerse a user into an environment with which he or she can interact. Actions like limb movement are depicted as they are made and the environment reacts in time. This real time feedback provides a formative (rather than summative) assessment for the user to learn from and make immediate adjustments. Using user-specific data, programs can be individualized for even better progress.

The implementation of VR systems vary from 3D head-mounted displays to 2D programs on personal computer screens. The multisensory, immersive experience provides visual, auditory, and even haptic feedback through handheld or wearable devices. They often focus more on mobility than other systems in order to interact with the environment.

For systems such as the Kinect and Wii, users are relatively untethered since an infrared light records motion. Quick processing allows for these motions to be overlaid on the virtual landscape. This mirrored depiction stimulates the mirror neuron system which encourages cortical reorganization[6]. Since the primary motor cortex is “activated during observation as well as execution of motor tasks,” self-observation improves performance in reenactments of the games’ movements. Virtual systems can use this technique in one of two ways. Depicting a moderately worse movement than the one made by the user provides a challenge. Depicting a moderately improved movement, such as showing a slightly more extended arm, provides positive feedback and promotes better imitation in future attempts.

The recovery of upper-extremity function is especially important. Though 75% of stroke survivors learn to walk again, 55-75% still struggle with upper-extremities. Traditional therapy is often unbalanced, focusing on easily measurable leg movements and progress, whereas VR therapy can measure both leg utility and fine motor movements in the wrist. VR rehabilitation systems can precisely measure range of motion, force production and movement speed[1].

Using the Kinect and a stroke rehabilitation game called Duck Duck Punch[7], participants improved range of motion in both their upper and lower body. These results are shown in figure 5. Established function tests also show the effects of VR rehabilitation. A study using 3D graphics on flat monitors with visual, auditory, and haptic glove feedback exhibited significantly better results on the Jebsen Test of Hand Function, a timed test of tasks, figure 6. In it, all three subjects used a VR system, there were no control subjects.

The Wolf Motor Function Test (WMFT) includes timed tasks of positioning and gripping objects. Such tasks can be emulated with VR and simulations that reward faster, more accurate movements and steady grips can improve performance on these tests[13]. Figure 7 shows the unadjusted results from an intensive two week study of stroke survivors that either
played Wii games, such as bowling and cooking, or attended recreational therapy sessions.

When adjusted for factors such as age and stroke severity, the Stroke Impact Scale, Box and Block Test, and grip strength results are similar, but Wii players were on average 7.4 seconds faster in the WMFT test. 1.5–2 seconds is the minimum (set by precedent) requirement for clinical significance.

Though the goal of these systems is not necessarily to eliminate specialized, clinical therapy, the success of regular games such as Wii tennis highlights the benefits of extending therapy into virtual reality and games. Many systems used are consumer products that are accessible and affordable. Users can navigate many different environments using the same equipment. At a simulated carnival, users are motivated to improve performance in an enjoyable way. In an “everyday” simulation, users are reintroduced to daily living tasks such as using public transit. A 2D VR program that emulated a Mass Transit Railway station significantly improved self-efficacy ($p < 0.01$) of participants in four weeks. The control participants’ scores remained the constant during the same interval[9].

There are still certain concerns and room for improvement in these systems. Though no photosensitivity-induced seizures occurred during the studies, lighting and distance to monitor
adjustments were made and monitored proactively to prevent them.

CONCLUSION
This paper explored some of the technologies and concepts related to stroke rehabilitation and human–computer interaction. Robotics covers large scale devices that can augment or replace traditional physical therapy activities. Wearable devices may be considered a subclass of robotics, but usually come in much smaller forms that can be worn on and moved by the human body. Wearables are the smaller overachieving brother of robotics because they can move around in the world, but cannot provide as much data as their larger siblings. Haptic feedback devices are those that provide touch feedback to a user. They integrate well with all the other techniques mentioned and give a more immersive experience. VR includes everything from 3D head–mounted displays to playing Wii games and can easily be repurposed for rehabilitation by encouraging exercise and repetitive movement. Using games in therapy makes the sessions more interesting and encourages the patients to work harder at their rehabilitation.

There is quite a bit of overlap when discussing these categories. Many of the techniques could easily be combined. Some of the robotic devices were integrated with games and VR simulations, providing entertainment for the exercising patients. The Rutgers Ankle successfully combines robotic measuring, haptic feedback and a VR simulation. While possible, there are disadvantages to doing so. The more things that are combined into a single system, the higher the likelihood of one of those components failing. Also, robotic installations tend to be large, expensive and fixed to one location. Alternatively, game consoles provide many of these same features in relatively inexpensive, portable packages. They can measure movement range and speed, provide haptic feedback through vibrating remotes and are designed to play games. They cannot measure or apply force, like a robot can, but they cost much less. Specialized devices can always beat game consoles at specific tasks, but consoles can accomplish many different tasks very well. Since the price of a console is low enough that any patient can own one and they provide a huge encouragement to exercise, using game consoles to treat stroke rehabilitation is a very promising area of research.
REFERENCES


