TheraDrive in a Robot Gym

Toward Stroke Rehabilitation beyond Inpatient Rehabilitation Settings in USA and Mexico

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Abstract: Affordable stroke rehabilitation approaches can maximize the functional independence of stroke survivors discharged after inpatient and outpatient services and improve access to rehabilitation for low-resource environments. This paper briefly describes the evolution of the Theradrive system and its novel use in a robot therapy gym in Mexico, where it was one of 6 devices aimed at improve motor function after stroke. Results from testing with TheraDrive in Mexico in a robot gym suggest it is an effective affordable solution for upper limb stroke rehabilitation whether alone or in a suite with other devices.

1 INTRODUCTION

Fifty percent of stroke survivors who are six months post stroke and post rehabilitation have residual impairments in their upper and lower limbs. Greater than 30% are unable to walk without some assistance and 26% remain dependent in activities of daily living (Rosamond et al., 2008). Affordable stroke rehabilitation approaches can maximize the functional independence of stroke survivors discharged after inpatient and outpatient services and improve access to rehabilitation for low-resource environments (Howitt et al., 2010). New affordable assistive/robotic devices for home and outpatient environments are needed for areas staffed by a few therapists. For example, Colombo and colleagues (Colombo et al., 2007) and Hesse and colleagues (Hesse et al., 2005) in separate efforts developed affordable robot devices for upper limb therapy and showed that they were motivational and useful for rehabilitation. Johnson and colleagues (Johnson et al., 2004); (Johnson et al., 2005); (Johnson et al., 2007) developed Driver's SEAT and Theradrive and later proposed the use of low-cost devices such as Theradrive in a device suite tied to Unitherapy, a unifying custom software that allowed stroke survivors to play therapeutic games (Feng and Winters, 2009). Recently, Buschfort and colleagues showed that a suite of four simple robotic devices (from Reha-STIM) can provide effective seated 'hands on' therapy to acute and sub-acute patients (Arm Studio) inside the Charite' Rehabilitation Hospital in Berlin, Germany. Arm Studio can deliver effective therapy to patients under the supervision of a single therapist (Buschfort et al., 2010).

This paper briefly describes the evolution of the Theradrive system and its novel use in a robot therapy gym in Mexico, where it was one of 6 devices aimed at improving motor function after stroke. We suggest it is an effective affordable solution for upper limb stroke rehabilitation whether alone or in a suite with other devices (Johnson et al., 2007); (Bustamante and Johnson, 2012).

2 TheraDrive

TheraDrive, initially sponsored by the American Heart Association, was developed as an affordable stroke therapy system. It uses commercial force-feedback wheels mounted on novel height adjustable frames to provide a therapy environment for the upper limb (Johnson et al., 2007). Figure 1 shows an example of the original system. The main

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components of the TheraDrive system are a pair of modified, commercial force-feedback steering wheels, commercial gaming software as well as a customized software called Unitherapy (Feng and Winters, 2009). The system can be utilized in several training modes; these are unilateral steering utilizing the Logitech force-feedback wheel in the front or on the side and bilateral steering utilizing the two steering wheels mounted in the front in a bus driving configuration (Paranjape et al., 2006). TheraDrive can be used with or without an autonomous mobile robot that can move about the perimeter. The robot can monitor arm and torso movements and provide visual feedback on activities (Johnson et al., 2011). Therapy with Theradrive consists of subjects playing off-the-shelf driving games such as Need for Speed or completing custom tracking tasks such as circle tracking or complex sine wave tracking. As subjects completed tracking tasks using the wheel, they experienced spring like assistive or resistive forces on the wheel; the magnitude of the force-feedback was proportional to the tracking error. The proportional gain was pre-adjusted according to a subject's tracking ability. The custom tracking tasks and the force-feedback experience were created via the Unitherapy program.

Theradrive was used in a pilot study where data were collected from ten stroke subjects who used the device in twenty-four, one-hour therapy sessions (Ruparel et al., 2009). Results showed that the device was useful for stroke rehabilitation of the upper limb [no hands], increasing range of motion in the shoulder and elbow flexion/extension degrees of freedom. The Theradrive system proved most suited for subjects with moderate-to-high function. The low torque output of the commercial wheels and the non-adaptive force-feedback algorithm applied during therapy made it difficult for stroke subjects with low motor function due to severe hemiparesis to experience a great benefit. The wheels were unable to apply sufficient assistive forces for these users.

The system's inability to support very low-functioning subjects lead to a re-design effort to improve its usefulness to them. The design efforts lead to the creation of Haptic Theradrive, a low-cost robot that is stronger in that it is able support larger forces. Custom adaptive control algorithms allow forces to be applied at the wheel that can adapt to a user's functional ability. The system also includes a novel mechanism for creating variable compliance and torque limits at the wheel; this enables safe use of the system (Theriault et al., 2014). Figure 2 shows a prototype of the newest Theradrive, Haptic Theradrive, with the custom crank arm capable of applying torques stronger than the commercial force-feedback wheel (45Nm versus 1.5Nm).

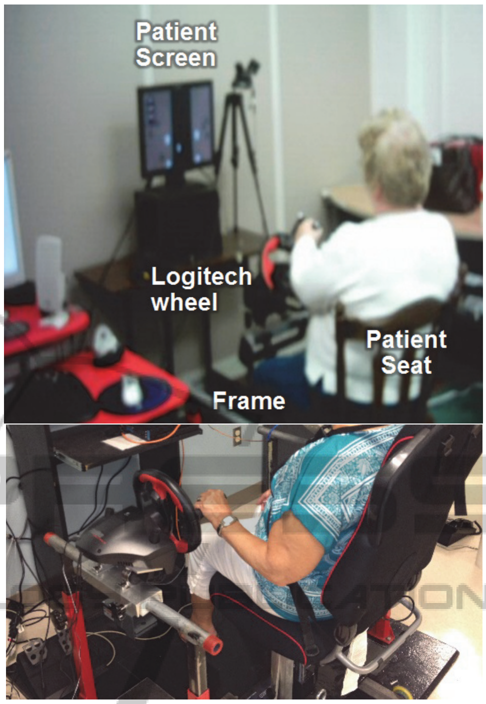

Figure 1: Theradrive original in front and side drive.

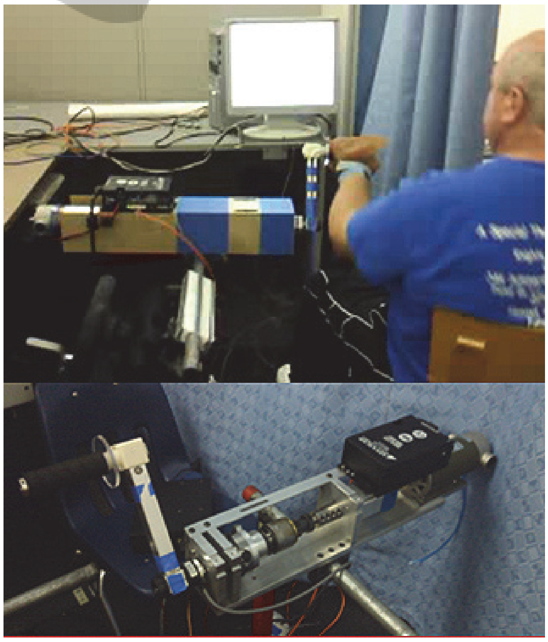

Figure 2: Haptic Theradrive.

2.1 TheraDrive in Mexico

Simultaneous to the Haptic Theradrive development, the original Theradrive was recreated in Mexico by Co-PI, Karla Bustamante with specifications given by PI Johnson. As in the USA stroke survivors in Mexico are discharged from rehabilitation still having residual disabilities and needing access to services in the community. Unfortunately, in developing countries such as Mexico a disproportion number of the population is without easy access to rehabilitation services (Lozano-Ascencio et al., 1996); (Kurland, 1977). Access is very limited by, 1) economics: rehabilitation services and associated technologies may not exist outside of major urban areas and many times are not affordable by low income patients; 2) training: skilled therapists and physiatrists are often not available in large numbers inside or outside of cities; and 3) technology: access to state of art rehabilitation technologies may be limited and gaining access may be too costly.

The Mexican version of the Theradrive system essentially mimicked the original version with commercial force-feedback steering wheel and a height adjustable frame (Bustamante and Johnson, 2012). Several custom games were used with the Mexican system. Figures 3 and 4 show the Theradrive Mexican version. The Mexican version of the system maintained the key features of a height adjustable frame and a variety of mounting positions for the force-feedback wheel. It improved upon the seating by creating a rail-mounted seating system that made adjusting patients easier. The Unitherapy custom software was also used. Therapy with this system was similar and consisted of stroke survivors playing off-the-shelf games and custom tracking tasks.

Figure 3: Theradrive the version in Mexico.

Figure 4: Mexico Theradrive with user.

2.2 Robot Gym Study

The Mexican Theradrive was deployed in a novel concept, we develop and called the robot gym (Bustamante and Johnson, 2012). The robot gym offered therapy based on circuit training where patients could rotate to 6 stations under a clinician's supervision; each station used a custom or commercially built robot/mechatronic rehabilitation technology. On four machines subjects did activities of daily living (ADLs), cycling, or game-based visuomotor tracking tasks using the upper limb and on two machines, cycling and gait training using the lower limb.

The long-term goal of the robot gym is to provide therapy for the upper and lower extremities of stroke patients in an environment where limited supervision is available. Our main objective in this pilot study was to determine if the robot gym can deliver comparable care as standard therapy administered at CREE, the only low-cost public rehabilitation healthcare center located in Chihuahua, Mexico. Seventeen patients with right hemiparesis due to a stroke were randomized to either a standard therapy group (Control Group:N=7) or the robot gym group (Robot Group:N=10). All patients had 24, 1-hour therapy sessions for the upper and/or lower limb. Patients in the standard therapy group experienced 1-on-1 manual therapy. Patients in the robot therapy group rotated through the six stations with an engineer and therapist as supervisors that assist with set-up and use of the devices.

All patients were evaluated pre- and post-therapy for arm/hand motor impairment using the Fugl-Meyer (Fugl-Meyer et al., 1975). Their engagement in the therapy was assessed using the intrinsic motivation scale (Wilson et al., 1984). Unpaired t-tests determined significant differences with $p \leq 0.05$ as threshold.

3 RESULTS AND DISCUSSION

Both Control Group (CG) and Robot Group (RG) experienced a mean 4 point change in the Fugl-Meyer motor control scores (RG: 4.6±1.23 and CG: 4±1.85: p=0.79), representing a more than 20% increase over baseline (Figure 5). On average both CG and RG perceived the therapy received as valuable (RG: 6.83±0.56 and CG: 6.57±1.04: p=0.14) and engaging (RG: 6.36±1.23 and CG: 5.89±1.6: p=0.27) (Figure 6). The differences in upper limb outcomes and engagement were not significant suggesting comparable therapy (Johnson and Bustamante, 2014). Figures 5 and 6 summarize the FM and motivation results.

The Mexican study shows that TheraDrive was effective in concert with the other upper limb devices. The impact of TheraDrive alone on motor recovery cannot be separated from the Bioness device or the Motormed upper limb. However, the previous pilot data in the USA suggested TheraDrive main contribution would be in shoulder and elbow flexion and extension improvements (Ruparel et al., 2009) and (Johnson et al., 2007).

Our overall goal for the pilot study in Mexico was to determine if a low-cost system of robot/computer-driven devices under limited supervision by clinicians could improve motor function of stroke survivors. The pilot study demonstrated that the robot gym was effective and was just as good as the control group. This is a successful outcome given our goal and suggest that we could potentially address issues of access to rehabilitation services in more rural locations in Mexico. The results suggest that creating a robot gym in more rural Mexico where access to rehabilitation is limited and staffing it with both a remote supervisor and at least one skilled clinician could not only provide access to rehabilitation for stroke survivors in these locations but also given them ways of further improving their rehabilitation outcomes.

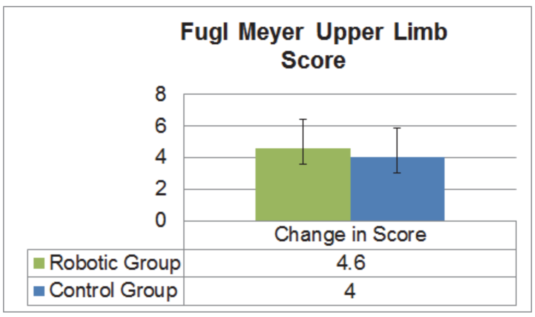

Figure 5: Fugl-Meyer score.

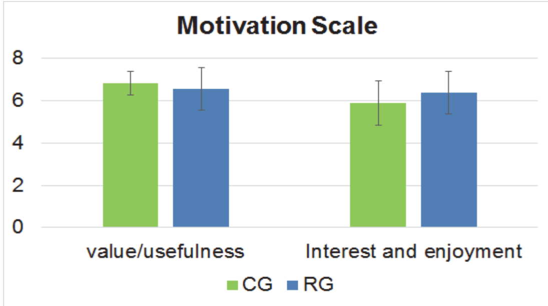

Figure 6: Motivation scores.

3.1 Lesson Learned

There is a need for appropriate rehabilitation technologies. Except for one of the machines used, all other devices were commercial products that were not developed with Mexico in mind or developed to be deployed in a resource poor environment. As a result, when the devices developed issues, getting technical help was difficult and getting replacement parts were a challenge.

There is a need for low-cost solutions that are rugged and simple to use. Problems with the technology were sometimes complex and greater than a clinician could troubleshoot and therefore, the reliance on the engineer for assistance with the use of the equipment was more than anticipated.

There is a need for reliable metrics that are able to be administered, analysed and interpreted quickly. We found that post assessment of changes after therapy was difficult to obtain quickly. Clinical, motion, and engineering analyses were done by the clinician or an engineer and required many hours of analysis. As a result, meaningful changes in function were not feedback to patients in a timely manner.

4 CONCLUSIONS

We briefly presented the TheraDrive, its evolution, and a feasibility study of its use in robot gym with five low-cost therapy devices. Our overall goal was to test the concept of affordable technology-mediated care delivery in Mexico. Since access to rehabilitation services and associated technologies may not exist outside of major urban areas and many times are not affordable to low income patients, our robot gym is an innovative solution that has the potential to augment the delivery of rehabilitation care.

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