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Long-Term Hand Tele-Rehabilitation on the PlayStation 3: Benefits and Challenges

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Abstract—**Rehabilitation interventions for the hand have shown benefits for children with Hemiplegia due to cerebral palsy or traumatic brain injury. Longer interventions are facilitated if training is provided in the patient's home, due to easier access to care and reduced impact on school or work activities. Providing remote rehabilitation over lengthy periods of time has however its own challenges. This paper presents two pediatric patients with hemiplegia, who practiced virtual hand rehabilitation games using a modified PlayStation 3 and 5DT sensing gloves. Despite severe initial hand spasticity, and occasional technology shortcomings, the subjects practiced for about 14 months, and 6 months, respectively. Game performance data for the second patient is presented. Follow-up evaluations 14 months from the removal of the PlayStation 3 from the home of the child with cerebral palsy showed that the patient had good retention in terms of grasp strength, hand function and bone health. Challenges of long-term home tele-rehabilitation are also discussed.**

I. INTRODUCTION

HEMIPLEGIC populations benefit from therapy to the affected hand, even when such interventions occur in the chronic phase of the disease causing their impairment [1]. In the case of stroke survivors, for example, it is well known that intensive, goal oriented, highly attended, and repetitive interventions are needed to increase hand function [2].

Virtual rehabilitation [3], in the form of games, has been used to facilitate such lengthy interventions, as a way to motivate the patient, maintain engagement, provide substantial knowledge of results and reward good performance [4]. When commercial off-the-shelf game consoles (such as the Wii [5] or the PlayStation 2 [6]) are used, therapy relies on existing off-the-shelf games to mediate motor training. However, off-the-shelf games may not be appropriate for patients with severe spasticity, as they will have extreme difficulty pushing buttons, or even holding the remote during energetic gameplay. Inability to win games that were essentially developed for healthy and fit young adults may lead to lowering of self-esteem and increased depression.

In order to allow severely spastic patients to enjoy game-based hand therapy, there is a need for custom games that automatically adapt to each patient's diminished function, while generating the necessary repetitions needed to induce neural change. Huber and colleagues [7] developed a PlayStation 3 home hand rehabilitation system for teens with Hemiplegia due to cerebral palsy. The system underwent a 9-to-14 month feasibility trial in which three teen participants practiced in rural Indiana, while being monitored from New Jersey (1000 km away) [8]. More recently, a child with severe traumatic brain injury due to a bicycling accident, practiced on the same system for 6 months. These may be the longest hand tele-rehabilitation interventions to-date. It is important to determine whether such lengthy therapy cost and effort is justified in terms of positive outcomes, and whether there is good retention of gains. While not standardized, game data may provide an objective measure of performance and progress over time, assuming data validity.

II. GAME DATA RESULTS

While the patients played the games their performance data was saved on the PlayStation 3s. The data files stored the scores for every trial of every session played, the time spent to complete each trial, along with the session date and time. This information allows for the longitudinal examination of progress throughout the therapy, as game scores were calculated in reference to the Baseline data (the maximum range of the patient's fingers and thumb).

Game performance for the adolescents with cerebral palsy was previously reported [7]. Here we look at the data stored for the participant with right-hand impairments following severe traumatic brain injury. The game most played by this participant was *Sliders*. In this game the patient must go from neutral posture to full flexion, or to full extension, such that a hand avatar "cleans" the display screen to reveal a pleasant image. Each finger is assigned a portion of the screen, such that all fingers need to contribute to the cleaning process. The game score is determined by the percent extension or flexion. If all of the four fingers are extended or flexed fully, the score is 4*100=400. Similarly, if all four fingers achieve 90%, of their baseline range, then the score is 4*90=360. The range the patient must extend or

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flex is a percentage of the full range. This threshold is adjusted to provide the patient with an easier or more challenging therapy based on their current progress.

The participant had initial threshold values of 45% for extension and 70% for flexion. After about 2 months of training (and over 1200 minutes played) the values were changed to 70% and 90%, respectively. This change led to a more challenging experience. The scores reflect this increase in difficulty and are therefore plotted combined and separately to show progress at a new difficulty range.

The scores for every trial of the *Sliders* game were averaged per session to give a mean score per session and plotted in Figure 1. These plots confirm that the patient did make progress in score throughout the therapy. To find any meaning behind the score improvement, another component of the data needs to be considered: time taken to complete each trial.

Since the game itself asks the patient to repeatedly reach the max flexion or extension, as long as the time taken is consistent, this will effectively measure endurance. Figure 2 shows the game time as a function of session. Since the time increases linearly throughout the therapy, the increase of score over time directly correlates to an increase in endurance.

Another game the participant played was *UFO*. This game asked the player to chase away a spaceship by fully flexing, or fully extending the fingers within a certain amount of time needed by the UFO entering the side of the screen to reach a centrally-located hand avatar. The participant's reaction time was a function of the UFO speed, with faster UFOs corresponding to higher difficulty. Points were deducted if finger movement was not completed by the time the UFO was close to the hand avatar. The longer the patient took to reach the threshold values set as a function of baseline values, the lower the score. These constraints cause the UFO scores to be a measure of speed or reaction time. The plotted results are shown in Figure 3.

III. TRANSFER TO ACTIVITIES OF DAILY LIVING

Progress in the games mapped well to increased hand use in daily activities in both teens with cerebral palsy (as reported previously [7]) and in the child with traumatic brain injury. Based on reports from the patient's mother, by week 4 the patient used his impaired hand to grasp a bottle. By week 10 he was able to pick up a fork and to pick up a pill by pinching thumb and index. Finally, after 4 months of training in the home, she reported the patient used his hand to brush his teeth.

IV. RETENTION OF GAINS 14 MONTHS POST THERAPY

One of the three teens with cerebral palsy participating in the PlayStation 3 home tele-rehabilitation feasibility study was followed up after therapy ended. The three main outcome measures were grasp strength (measured with a Jamar dynamometer), the Jebsen test of hand function [9] – a timed test that measures dexterity and function in a set of 7 standardized activities, and bone health measures [10]. Table I shows the measures at baseline (pre-therapy), at the removal of the PlayStation 3 from the participant's home, and 14 months after therapy ended.

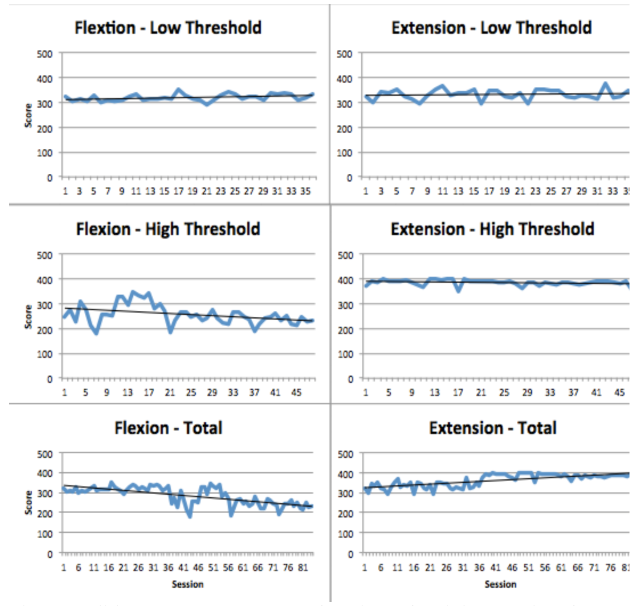

Fig. 1. Sliders game scores as a function of training session for a patient chronic post severe traumatic brain injury. © Rutgers Tele-Rehabilitation Institute and Indiana University School of Medicine. Reprinted by permission.

A. *Grasp strength*

Strength in the plegic hand improved 50% following therapy, even though no strength training was attempted. It is possible that these gains were due to neural remapping as a result of training, to muscle strengthening due to the repeated finger flexion and extension during game play, and to natural growth over the rehabilitation intervention duration. At follow-up, grasp strength continued to grow, reaching more than double that measured at baseline. While therapy ended, 14 months prior, the maintenance of grasp strength may be due to increased use of the plegic hand in the daily activities of the teen with cerebral palsy.

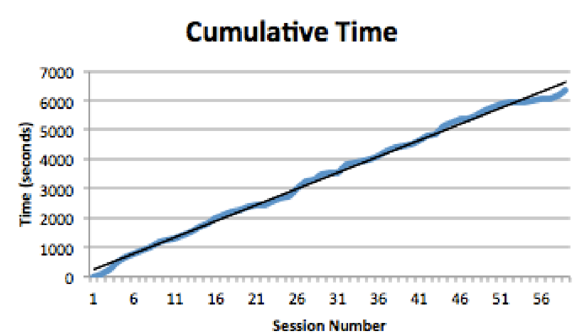

Fig. 2. Cumulative time playing "sliders" game, implying endurance for a patient chronic post severe traumatic brain injury. © Rutgers Tele-Rehabilitation Institute and Indiana University School of Medicine. Reprinted by permission.

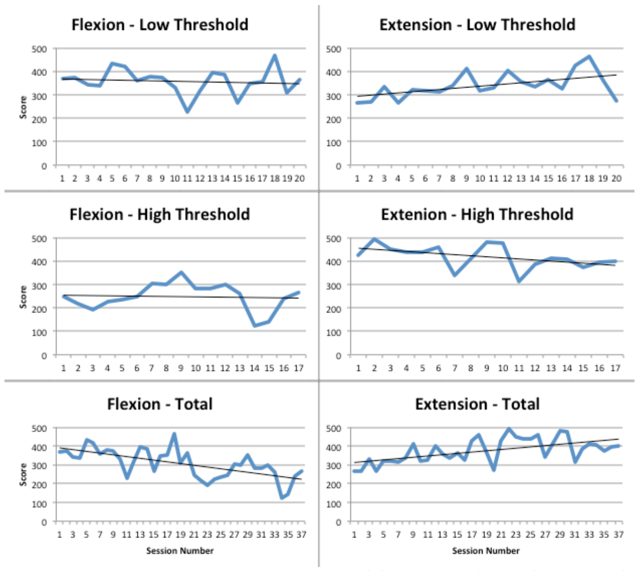

Fig. 3. UFO game scores as a measure of finger speed as a function of training session, for a patient chronic post severe traumatic brain jury. © Rutgers Tele-Rehabilitation Institute and Indiana University School of Medicine. Reprinted by permission.

B. *Jebsen test of hand function*

There was good progress in hand function during the therapy, as exemplified by shorter task completion time post-training. Significantly, the adolescent with cerebral palsy was now able to write, stack checkers and lift large heavy objects, activities he had not been able to perform at baseline. At follow-up the patient was again able to perform all 7 standardized tasks of the Jebsen test, and was faster in all of them compared to baseline.

C. *Bone health*

Weight bearing is a known factor benefitting bone growth. While the virtual reality games were played with the forearm supported (minimal weight bearing on the forearm), there was substantial improvement in the mineral content of the plegic forearm bone. The patient started with a 40.5% lower mineralization of the distal radius bone and a 51.8% lower mineral content in the ultradistal radius trabecular bone, compared to the mineralization of the corresponding bones in the healthy forearm. Post-therapy there was a substantial increase in the plegic forearm bones mineral content, such that the difference vs. the healthy arm was now only 33.5% and 37.5 % in the distal radius and the ultradistal radius trabecular bones, respectively. This was maintained 14 months after the therapy ended.

V. CHALLENGES OF LONG-TERM HOME TELE-REHABILITATION

A number of factors have been found to be important in maintaining engagement during long-term home rehabilitation interventions of the type described. These include the virtual reality gaming technology, the home family/caregiver, and the ability to remotely monitor and intervene when adherence to the protocol starts to degrade.

A. *Limits of the virtual reality technology*

Three aspects are important when doing remote hand rehabilitation, namely the gloves used, the games/game console and the Internet connection. The sensing gloves used in the projects described here were custom (smaller size) adaptation of an off-the-shelf 5DT "Ultra" sensing glove. These gloves use a single fiber optic sensor per finger, such that only "global flexing" can be measured, based on hand calibration. Calibration is needed since sensor output is in the form of integers, with values varying linearly depending of the amount of bending. However, each sensor of each glove has its own linearity curve (slope), such that each glove has its own "signature." This complicates data analysis, since the software installed on the PlayStation needs to detect which particular glove is connected to it and use its specific characteristics based on a custom library. The second limitation with the gloves used here is their design (close palm), which unlike the Meditouch HandTutor glove [11], makes donning the 5DT glove difficult on spastic hands. The optical sensors tend to dislodge when the glove is taken off, degrading measurement accuracy. More

TABLE I
BENEFITS AND RETENTION OF HAND TELE-REHABILITATION ON A PLAYSTATION 3 FOR AN ADOLESCENT WITH HEMIPLEGIA DUE TO CEREBRAL PALSY (BASED ON [10])

Variable	Outcome	When Measured
Grip strength		
Jamar dynamometer readings	4 lbf	Baseline
	6 lbf	Post-therapy
	9 lbf	14 month follow-up
Jebsen test of hand function		
Writing	unable	Baseline
	24 sec	Post-therapy
	28 sec	14 month follow-up
Simulated page turning	70 sec	Baseline
	39 sec	Post-therapy
	55 sec	14 month follow-up
Pickup small common objects	101 sec	Baseline
	64 sec	Post-therapy
	48 sec	14 month follow-up
Simulated feeding	77 sec	Baseline
	158 sec	Post-therapy
	65 sec	14 month follow-up
Stacking checkers	unable	Baseline
	44	Post-therapy
	108	14 month follow-up
Lifting large light objects	85	Baseline
	46	Post-therapy
	77	14 month follow-up
Lifting large heavy objects	unable	Baseline
	37	Post-therapy
	43	14 month follow-up
Forearm bone health		
distal radius bone mineral content paretic vs. healthy UE	Lower by 40.5%	Baseline
	33.5%	Post-therapy
	33.3%	14 month follow-up
ultradistal radius trabecular bone mineral content vs. healthy UE	Lower by 51.8%	Baseline
	37.5%	Post-therapy
	35.7%	14 month follow-up

importantly, the wires connecting to the finger sensors are subject to wear and tear, and once broken the glove needs to be repaired. Sending gloves for repair is a lengthy proposition since the manufacturer is in South Africa. Therefore a hot swap, a second glove, needs to be on stand-by for each patient so to assure therapy continuity (something that increases overall system cost).

Another limitation of the virtual reality technology relates to the use of game consoles. Each manufacturer has a different "philosophy" when it comes to granting access to developers, with Japanese companies being less open than American ones. In the case of Sony, when the system was set up developers were able to replace the operating system with Linux. In our case this was needed to develop drivers that communicate with the sensing glove, and to integrate the PlayStation 3 with the custom games written in Java3d [12]. More recently Sony closed that option, such that legally one can no-longer develop a project based on another operating system than Sony's. At the time the system was developed by our group, it was not possible to access the dedicated graphics chip of the PlayStation 3, something that remains true today. This had direct consequences in terms of reduced scene complexity and slower graphics. Fortunately, the teens participating in the study did not mind the simplified graphics, and occasional freezes, at least initially.

Performing remote rehabilitation is especially beneficial to patients that live in remote/rural areas where clinics and therapists are scarce. Unfortunately, these are also the areas where Internet speed and availability cannot be guaranteed. While Internet stoppage affects the tele-rehabilitation system ability to upload clinical data (in our case game data performance), thunderstorms and other weather events are known to cause power outages, especially in rural areas. Complete loss of power will, of course, prevent the PlayStation 3 from functioning, and thus virtual reality therapy will be involuntarily interrupted.

B. Family environment

The home environment plays an important role in motivating and supporting the patient, and tele-rehabilitation is no exception. The technology limitations outlined above make the role of the caregiver even more important, in making sure the amount of time and frequency of rehabilitation sessions are maintained.

Pediatric populations generally exhibit short attention spans, and low tolerance for technical problems, especially once the initial novelty of the virtual rehabilitation intervention wears off. One way to maintain patient engagement is the encouragement received from the family. Another is to periodically add new games, to maintain some novelty in the therapy. Yet another is to ensure therapy flexibility and empower the patient to choose favorite games to play among the library available, and to even allow a choice of the level of difficulty in a particular day.

In the more recent pilot study with the boy who had suffered a traumatic brain injury, similar to the case described earlier, he had a very nurturing home environment, and was very motivated to exercise. This was one factor in his ability to adhere to the hand rehabilitation protocol for about 6 months, practicing up to five days/week.

The reverse is true when there are problems in the home, due to parental conflicts, and physical or drug abuse. Such unstable situations affect the young especially, and add to the emotive correlates, such as depression, associated with disability. Without strong positive parental involvement, once the novelty of the games and therapy wear off, and once the technology limitations become apparent, it is easy for the teen to stop practicing, temporarily or permanently.

VI. CONCLUSIONS

Results presented here are encouraging in terms of the potential of lengthy tele-rehabilitation of the hand to induce long-term improvements in hand strength, function and bone health. Naturally, more patients will have to undergo such interventions before a definitive answer can be given.

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