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# Feasibility Study of TheraDrive: A Low-Cost Game-Based Environment for the Delivery of Upper Arm Stroke Therapy

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*Abstract*— **Rising healthcare costs combined with an increase in the number of people living with disabilities due to stroke have created a need for affordable stroke therapy that can be administered in both home and clinical environments. Studies show that robot and computer-assisted devices are promising tools for rehabilitating persons with impairment and disabilities due to stroke. Studies also have shown that highly motivating therapy produces neuromotor relearning that aids the rehabilitative process. Combining these concepts, this paper discusses TheraDrive, a simple, but novel robotic system for more motivating stroke therapy. We conducted two feasibility studies. The paper discusses these studies. Findings demonstrate the ability of the system to grade therapy and the sensitivity of its metrics to the level of motor function in the impaired arm. In addition, findings confirm the ability of the system to administer fun therapy leading to improved motor performance on steering tasks. However, further work is needed to improve the system's ability to increase motor function in the impaired arm.**

## I. Introduction

Stroke is the leading cause of disability, with approximately 500,000 new cases every year [1]. Rising healthcare costs and increasing numbers of persons living with disabilities due to stroke have created a need for affordable stroke therapy that can be administered in both home and clinical environments. Studies have shown that motivating therapy produces neuro-motor relearning that aids the rehabilitative process [2]. Building on this, Bach-y-Rita and colleagues [3] created a home-based therapy environment that focused on encouraging the use of the impaired arm in fun, challenging, and motivating tasks to induce CNS plasticity. Therapy using "Palanca" device, a game computerized game of pong with a mechatronized handle, reduced motor impairment and functional disability. Following in this idea of motivating rehabilitation, Ellsworth and colleagues further demonstrated its feasibility. They successfully created the TheraJoy [4], a telerehabilitation environment that uses a large, modified force-feedback joystick to complete games and tracking tasks created with the custom software, UniTherapy [5]. Johnson and colleagues [6] used a simple, robotic, car-steering environment, Driver's Simulation Environment for Arm Therapy (Driver's SEAT) to create a device to test motivational principles in the face of learned nonuse, which promotes compensatory use of the less-affected arm. Inspired by the potential of Driver's SEAT, a more versatile, commercially viable, functional steering environment was developed and called TheraDrive [7] (fig. 1). Built on the principles of play therapy, TheraDrive creates a fun driving therapy environment; it uses assessment tasks along with commercial driving games to do so.

This study determined the usability of TheraDrive system for stroke therapy and the ability of the system to motivate subjects and keep them engaged during therapy. We present findings that demonstrate the ability of the system to grade therapy and the sensitivity of its metrics to motor functional levels. We also present results on performance of a low functioning stroke subjects over twelve sessions with the device. These results support that performance on the system leads to motor learning and was able to maintain task engagement and motivation.

## II. Methodology

The study was approved by the Institutional Review Board of the Clement J. Zablocki VA.

### A. Experimental Setup

The TheraDrive system as shown in fig. 1 was used as the experimental apparatus for the study. The system consisted of a Logitech force-reflecting wheel mounted on a height-adjustable metal frame. The wheel is connected to the UniTherapy software platform [10], which records the angular movement of the wheel as subjects complete the custom and commercial tracking tasks displayed on the screen. Subjects were seated at a comfortable distance from the wheel. The wheel was tilted through 20 degrees from the vertical to create the real driving experience. The steering wheel height was adjusted for comfort. The maximum angle through which the wheel can rotate is 270 degrees. To standardize the group, subjects held on to a Vertical-gripper to complete the unimanual as well as bimanual steering task.

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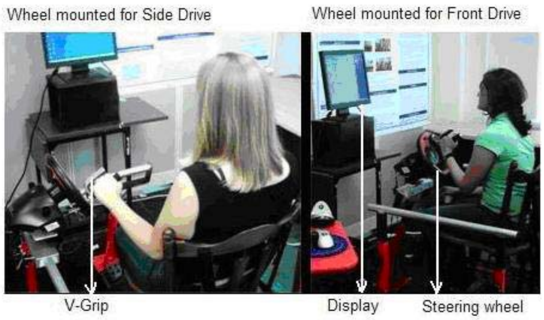


Fig.1The TheraDrive system for home-based rehabilitation with off-the-shelf force-feedback steering wheel. The systems embed therapy within steering activities. The front and side driving configurations are shown.

*B. Subjects and Protocol*

**Study 1:** Seven stroke survivors (five men, two women) gave informed consent and participated in this study. All were more than 6 months post-stroke with different motor and functional levels (Table 1). Motor impairment levels were measured in the impaired arm by the upper extremity fugl-meyer (UE-FM), a reliable measure of motor function (scores: 0-66), and functional disability levels were measured by the functional hand evaluation (UE-FT), a reliable measure of impaired arm functional ability on real activities (scores: in time and on levels 1-7). The users sat on a normal chair in front of the system and held onto the Logitech force-feedback steering wheel via an adapted handle while they performed tracking tasks displayed on a computer screen in front of them. The wheel was attached either to the front or to the side of the height adjustable frame with a tilt angle of 20 degrees (normal drive) or 90 degrees (bus driver mode). Different target acquisition and tracking tasks (3 trials each) were completed with the impaired arm. For example, subjects completed pseudo-random sine tracking where they moved the wheel to keep pace with a square box that moved in a randomized sine pattern.

Table 1.Raw clinical data for stroke subjects tested: Data shows impairment and disability scales. The subjects are divided as low and high functioning based on these scores.

| Subjects | Impaired hand | Age | Stroke type | Time since stroke(yrs) | Clinical scores | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | UE-FM | UE-FT | FIM | Vis Neg |
| | | | | | 66 | 7 levels | 7 | 0% |
| S Low | | | | | | | | |
| S3 | L | 62 | ischemic | 4 | 56 | 4 | 4 | 2.6 |
| S7 | L | 60 | ischemic | 2 | 24 | 4 | 6.6 | 2 |
| S11 | L | 55 | cortical | 15 | 56 | 5 | 6.8 | 0 |
| S High | | | | | | | | |
| S1 | L | 55 | ischemic | 3 | 66 | 7 | 7 | 0 |
| S5 | L | 58 | ischemic | 6 | 66 | 7 | 7 | 0 |
| S9 | R | 55 | ischemic/cortical | 1 | 66 | 7 | 7 | 0 |
| S10 | R | 58 | cortical | 2 | 66 | 7 | 7 | 0 |

Subjects trained on the system in day 1 and then completed assessment tasks in day 2; three levels of force-feedback: none, assistive forces and resistive forces in the front-driving mode and then no force-feedback with the wheel in side-driving mode. Steering position data were collected. The performance data on the pseudo-random sine-tracking task (at 20 degrees tilt) are discussed in terms of the effect of the configuration and the forces on motor performance. Subjects (Low:S7, S11 and High: S5) wore a harness in Day 2.

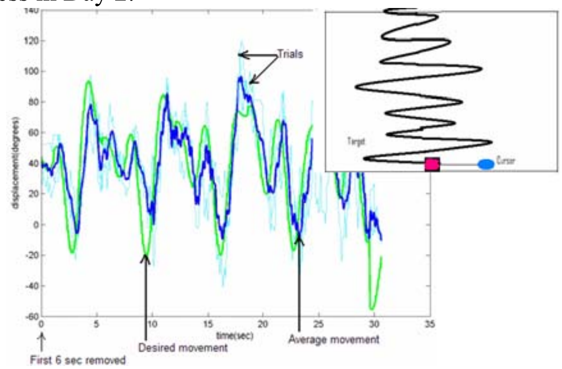


Fig 2: Example of tracking plot of the Sine tracking task (shows the subject's average and desired movements). The desired movement and the impaired arm response is given. The top right corner shows the task.

**Study 2:** One low functioning subject (S7) completed 12 additional sessions with the TheraDrive system. She chose her training environment from a battery of commercial steering games such as Need-for-Speed (www. needforspeed.com), MarioKart(www.internetgamebox.com), Trackmania(www.trackmania.com) and SmartDriver (BrainTrain). Driving tasks were completed under varying levels force feedback with the wheel in front and side configuration. These levels were determined at the beginning of each session was graded according to her ability and her previous performance. At each session, pseudo-random sine tracking without feedback was completed in order to assess her daily progress. She was asked to report pain and exertion levels during each session. A motivation survey was administered every third session [11]. The survey asked questions that were based on a validated intrinsic motivation measure by McAuley and colleagues. We used the measure to evaluate enjoyment, perceived value and effort (Scale 1 to 7).

C. *Data Analysis*

A custom-made, MATLab Graphical User Interface (GUI) was used to analyze the position data. Data for the three trials were averaged as shown in Figure 2. The root mean square error (Error) was the key performance metric used to evaluate the effect of changing configuration and force levels. It was calculated by taking the square root of the squared difference between the desired-position signal (track) and the actual-position signal (impaired arm movement). Based on the clinical scores for UE-FT (across harness), the subjects were divided into a high functioning (S1, S5, S9 and S10: UE-FT: level 7) and a low functioning (S3, S7, and S11: UE-FT: <= 5) group. We evaluated the effects of the harness on tracking and saw that the harness did not have a significant effect on tracking performance to affect the general grouping of subjects into low and high across the harness. Repeated measures ANOVAs were used to assess within and between stroke group differences due to force changes and wheel configuration.

## III. RESULTS

Table2. Error and Standard deviation (in parenthesis) on tracking performance for all subjects in the different driving modes (Front and Side drives)

| Subjects | UE-FM | UE-FT | Front Drive | | | SideDrive |
|---|---|---|---|---|---|---|
| | 66 | 7Levels | F Assist | NoForce | F Resist | NoForce |
| S Low | | | error in deg | error in deg | error in deg | error in deg |
| S3 | 56 | 4 | 35.33(12.50) | 29.07(2.40) | 75.15(5.44) | 36.92(7.59) |
| S7 | 24 | 4 | 13.72(0.16) | 41.61(13.90) | 81.40(2.62) | 32.4(3.61) |
| S11 | 56 | 5 | 9.25(0.72) | 19.31(1.10) | 81.50(19.42) | 39.54(6.79) |
| S High | | | | | | |
| S1 | 66 | 7 | 9.75(1.03) | 20.18(1.30) | 30.00(1.69) | 20.07(1.07) |
| S5 | 66 | 7 | 8.56(0.23) | 12.83(1.27) | 24.95(1.59) | 11.77(0.32) |
| S9 | 66 | 7 | 11.04(3.91) | 13.42(1.27) | 27.63(0.83) | 18.43(8.19) |
| S10 | 66 | 7 | 7.97(0.07) | 11.13(1.48) | 33.89(1.79) | 11.08(0.61) |
| Low Avg | 45.33 | 4.33 | 19.43(13.94) | 30.00(11.18) | 79.35(3.64) | 36.30(3.59) |
| High Avg | 66 | 7 | 9.33(1.36) | 12.46(3.98) | 29.12(3.79) | 15.34(4.57) |

### *A. Study 1: Graded therapy is possible with the force-feedback and the wheel position*

The TheraDrive system is able to grade therapy by manipulating force-feedback and wheel position (Fig. 3 and Fig. 4). Consistent accuracy trends were identified for low and high functioning subjects. Differences across force levels were significant for all subjects ($p<0.0001$). Both groups made greater errors when the tracking tasks progressed from easy (Force Assist mode) to more difficult (Force Resist mode). The differences between Force Assist and No Force modes were not significantly different ($p=0.113$). But errors in the Force Assist and No Force modes were significantly different from Force Resist ($p=0.006$ and $p=0.008$). For lower functioning subjects, side driving tended to lead to greater errors than front driving but the difference across wheel positions were not significant ($p<0.54$). These results imply that the side driving was not necessarily more demanding.

### *B. Study 1: Performance outcome measures on steering tasks relate to clinical outcome measures*

Subjects' performance on all tracking tasks was sensitive to clinical outcome measures for impairment and function. Error performance on pseudo-random sine tasks was sensitive to motor impairment levels. Low functioning subjects performed with more errors than higher functioning ones. The two group's performance on the task was significantly different across force conditions ($p<0.0003$) and between driving positions in the no force-feedback condition ($p<0.0018$). In general, lower functioning subjects tended to overshoot the target (higher errors). There was a significant interaction between subject group and force levels ($p = 0.0011$). These results imply a non-uniform reaction to the increasing forces. When we examine the individual trends in Fig. 5, we see that S3 had higher errors when assistive forces were applied than when none was applied.

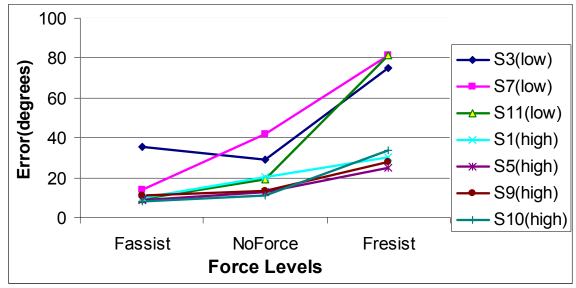


Fig.3 Error for all subjects during the pseudo-random sine tracking task with different forces on the wheel. See Table 2.

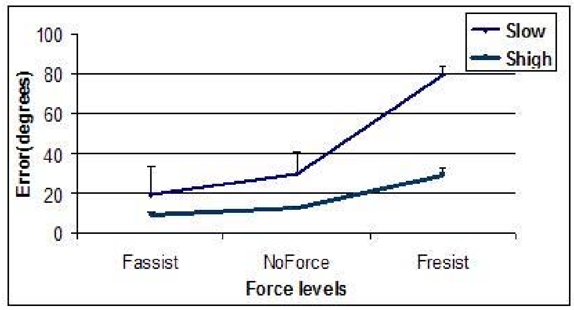


Fig.4. The average errors of low and high functioning subjects during the SineTracking task with different type of forces on the wheel. See Table 2

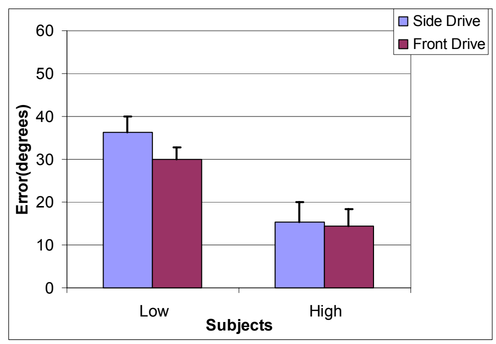


Fig.5. The average errors of low and high functioning subjects during the SineTracking task with different positions of the wheel. See Table 2.

### *C. Study 2: Significant performance changes did not induce change in clinical measures so higher dosages of the therapy maybe needed*

The representative low subject's (S7) performance on tracking tasks stabilized during therapy and improved; the subject was able to tolerate progressively higher levels of force feedback (progressing from 0% to 65% of maximum effort). Pain experienced was consistently low (about 1-2 of 7) while perceived effort and intensity of arm use was consistently high (5-6 of 7). In Fig. 6, we see that as a result of the 12 training sessions, her before and after errors on pseudo-random sine tracking in the No Force mode decreased for both front and side driving wheel positions.

### *D. Study 2: Motivation and intensity of arm use trends were measurable and repeatable.*

Motivation as measured by levels of enjoyment was consistently high (Fig 7). The subject enjoyed playing the driving games and felt driven to play to score more. She was satisfied with the technology, operability and comfort of the system. This sentiment was echoed by the other subjects in Study 1.

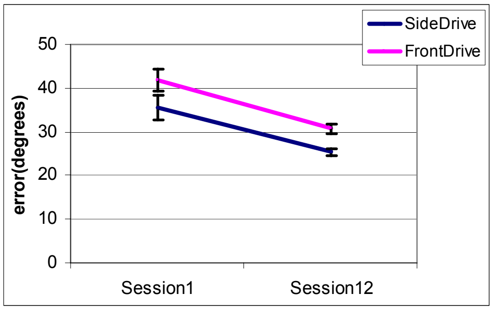


Fig.6. Tracking errors on pseudo-random sine task on FRONT and SIDE driving tasks over the 12 sessions. Ses1.Side: 38.59(5.51), Front:41.83(4.96),Ses12.Side:25.41(1.65),Front:30.71(2.02)

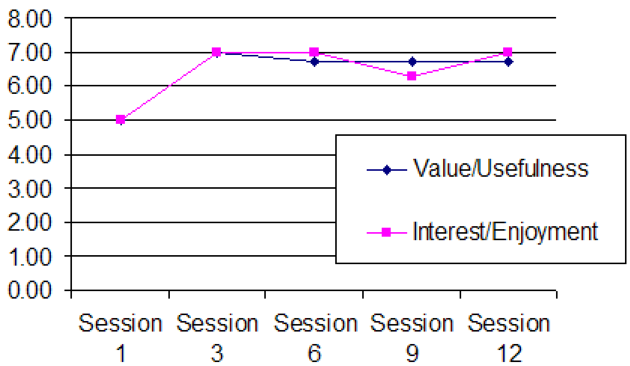


Fig.7. Motivation trends during fun, functional steering on TheraDrive. Each subscale was measured out of 7.

## IV. Discussion and Conclusions

We evaluated the relationship between performance errors and the ability of TheraDrive to create more or less challenging therapy through force-feedback and by varying wheel positions. We also examined how a stroke survivor would experience therapy using the system, whether exposure would lead to improved function and whether the game-based therapy environment was able to maintain task engagement and motivation.

The system was able to grade therapy. The force-feedback methods used affected low and high functioning stroke subjects in similar ways. In general, assistive forces caused the least errors and resistive forces the most in both front and side driving. This suggests that as game tasks are learned, more challenging tasks can be created by increasing resistance on the wheel. Lum et al. [8] showed that modulating forces during therapy is a viable method for building strength in the impaired arm. Changing the configuration of the TheraDrive system from front to side driving was intend to increase task difficulty, thus resulting in an increase in performance errors. A trend was seen but it was not significant. This was surprising because we expected that side driving would require larger arm movements and more movements out of synergy. Therefore, it should have been more challenging. Further investigations are needed. One possible reason may be due to the fact that we did not control for trunk compensation.

We also established that the system was sensitive to motor function levels by evaluating the accuracy differences across low and high functioning strokes. These results support previous work done by Jones and Donaldson [9] that demonstrated that performance on steering tasks could measure upper arm motor impairment. Therefore, the recovery of motor function induced by the TheraDrive system should be detectable.

Finally, we established that the TheraDrive has potential as a tool for administering game-based, upper arm therapy after stroke over the long-term. The therapy was considered fun and motivating by our subject. Interactions with the TheraDrive were also positive across all seven subjects. Although, our subject showed improved motor performance without clinically measurable gains in motor function, we believe that this may have been due to insufficient exposure to the system or to lack of training of her hands. Further study is needed. And, perhaps the TheraDrive system could include games that require more use of the hands.

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