Greater Transfer to Walking of Lower Extremity Training with Robotics and Virtual Reality than Robotics Training Alone: Preliminary Findings

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Abstract— Virtual reality systems have been used to deliver goal directed repetitive training to promote rehabilitation of individuals post-stroke. Lower extremity training of individuals post-stroke who used a robot coupled with virtual environment has been shown to transfer to improved overground locomotion. To isolate the active components of training in this study we compared the outcomes of training with the robot-virtual reality (VR) system to the robot alone. Four individuals post-stroke participated in a four-week training protocol. One group trained with the robot-VR system and the other group with the robot alone. The improvement in walking speed and endurance for the robot- VR group was greater than the robot group alone. Adherence as well as the number of exercises performed in each session was comparable for the two groups. The duration of training sessions was comparable at the beginning of the study. However, subjects in the robot group reported higher fatigue and produced 16% fewer minutes of training towards the end of the study. These findings support the use of virtual environments coupled with a robot for transfer of training from the virtual to the real world environment.

I. INTRODUCTION

STROKE remains a major cause of disability in adults. People who have suffered a stroke may experience as much as 50% decrease in gait velocity, stride length and cadence as compared to age matched healthy adults [1]. This loss of gait velocity is useful as an indicator of a decrease in quality of life and functional status for both individuals post stroke and healthy adults [2],[3].

A growing body of evidence suggests that intensive, goal directed therapy improves function and cortical reorganization in individuals with both acute and chronic impairments post stroke [4]-[6]. As a result therapeutic interventions for individuals post stroke are emphasizing intensive practice of functional tasks rather than isolated movement pattern training [7].

Virtual Reality (VR) as a tool for rehabilitation has shown the ability to create a goal directed, repetitive treatment with intensity and feedback systematically manipulated and enhanced to create the most appropriate individualized learning experience [6]-[8]. Some of these applications have been designed to improve locomotion for people post-stroke [9]-[11]. VR walking interventions couple sophisticated hardware and task specific simulations. The work by Fung and colleagues [11] uses a treadmill placed over a Stewart platform to create variable walking conditions, in several environments. Our work with the Rutgers Ankle Rehabilitation System (RARS) consists of a Stewart platform used as a joystick for the affected foot to navigate in a virtual world. We have reported on transfer of training using the RARS system to improve walking and elevations for individuals’ post-stroke [10]. We speculate that several factors account for this positive transfer. These include the repetitive training that may be promoting endurance and strength as well as the task specific training that may be improving perceptual motor tuning and coordination. The system is composed of a robot, which delivers haptic feedback that may be enhancing proprioceptive processing as well as the simulations that drive and reward the motor behavior.

The purpose of this preliminary investigation was to explore the hypothesis that the coupling of the robotic device with VR produces greater transfer of training to overground walking and endurance than the use of the robotic device alone. Specifically, we wanted to evaluate the training effect of each protocol and the retention at three months post-training. We hypothesized that both groups would exhibit improvements but these would be greater, both immediately after training and at follow up, for those training with the robot coupled by the VR.

II. METHOD

A. Participants

Four community-dwelling individuals with chronic stroke (3 men, 1 woman) volunteered to participate in this pilot study. They were all in the chronic phase post-stroke, were able to follow instructions, exhibited residual gait deficits, had partial anti-gravity dorsiflexion and were able to walk 50 feet without the assistance of a person. None of them had motion sickness or were receiving concurrent therapy during the study.

Subject’s characteristics are summarized in Table I. Subjects ranged in age from 41-70 years and were at least 2.5 years post stroke. Motor recovery and balance were characterized using the Fugl Meyer (FM) [12] and Berg Balance Scale (BBS) [13]. BBS scores ranged from 39-54, and the average FM score was
randomly assigned to either the experimental or control groups. All subjects gave informed consent prior to the beginning of the study.

TABLE I

<table>
<thead>
<tr>
<th>Sub</th>
<th>Age</th>
<th>Gender</th>
<th>Affected Side</th>
<th>Use of Orthosis/AD</th>
<th>Time Since Onset (months)</th>
<th>FM Initial Score (34)</th>
<th>Initial Walking Speed*</th>
<th>BBS (56)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>55/M</td>
<td>R</td>
<td>AFO</td>
<td>80.4</td>
<td>22</td>
<td>0.8m/s</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>70/M</td>
<td>L</td>
<td>AFO</td>
<td>27.6</td>
<td>28</td>
<td>0.36m/s</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>60/F</td>
<td>R</td>
<td>AFO + cane</td>
<td>34.8</td>
<td>22</td>
<td>0.79m/s</td>
<td>54</td>
<td></td>
</tr>
</tbody>
</table>

*Walking speed averaged from three trials of walking at fast pace 3-meters.

B. Design

A 2 factorial (group) repeated measures (time) design was employed. Subjects were tested before and after they participated in a four-week training program. Follow up testing occurred at three months.

Clinical outcome measures included gait speed over the middle three meters of a seven-meter walkway, time to ascend and descend one flight of stairs, as measured with a stopwatch, and walking endurance as measured by the six-minute walk test (6MWT). The Stroke Impact Scale (SIS version 3) was used to measure perception of recovery. Quantifying, frequency and type of cueing (manual or verbal) for every trial was used for comparison of group performance. The visual analog scale (VAS) was used to assess fatigue for both groups.

C. Intervention

Subjects trained on the RARS, which is a six-degree of freedom (DOF) Stewart-platform force feedback system that allows individuals to exercise the lower extremity in order to navigate through a virtual environment that is displayed on a desktop computer. Subjects were seated on a raised chair approximately 1 meter in front of a table with the computer screen at eye level. The affected foot was placed on the platform and strapped comfortably, with the ankle at neutral position and the knee and hip at 90° angles (Figure 1).

Using ankle movement subjects performed the task of navigating a plane or a boat through a virtual environment that contained series of targets. Training included discrete and combined ankle movements of pitch (dorsiflexion and plantar flexion) and roll (inversion /eversion). Training was performed three times a week for approximately one hour each visit for 4 weeks.

Each training session started with measuring performance of force, speed and excursion, and was stored as the baseline for all exercises during that session. The training regime between the two groups was comparable in all training parameters and included warm up trials, of sub maximal movement in all three directions (DF/PF, INV/EV and combination), endurance trials of low resistance, high repetition (increasing excursion) of the simulation and increase in duration (by increments of 1 min per session) as the training progressed. Speed trials gradually increased from 40-100% of maximal vehicle speed (set at 0.4 targets /s). Strengthening trials in which the resistance of the platform increased gradually from 40-100% of baseline force and coordination training with an emphasis on the directional movement and timing of segmental motion, targets appeared in different directions and changed time sequencing. Each session ended with a cool down section of the subject’s choice in sub-maximal intensity. Training intensity and progression protocol were designed based on previous studies [9], [10], [14] and were adjusted for individual subjects based on their observed performance and fatigue.

The experimental group (2 subjects) trained using the combination of the robotic device and the VR simulations. The control group (2 subjects) trained using the robotic device alone, without the VR simulation or the haptic feedback. The subjects were positioned as in the experimental group, on a height-adjusted chair, but the computer screen was turned away to block visual feedback. Auditory and haptic feedbacks were also turned off.

Training using the combined robot and simulation included knowledge of performance (KP) and knowledge of results (KR) provided by the system. The subjects in the control group did not receive KP or KR from the simulation; therefore a consistent rule for providing feedback was established. KP was given every 30 seconds in every trial by the therapist. In addition for the strength, and speed trials a metronome was used to provide auditory KP feedback.

For the strength exercise the subjects were told to hold the contraction until they heard the metronome, and for the speed trial the subjects were asked to perform the movement...
according to the pace of the metronome. During the
coordination trials the therapist gave a verbal cue to the
direction and timing of movement shift that was required
(using the word “switch” to indicate the need for directional
shifting).
Knowledge of results was given in the form of duration of
exercise. The visual analog scale (VAS) was used to assess
fatigue. A trial was terminated if the subject reported fatigue
≥8/10 on the VAS. In addition if the subject was unable to
produce movement for three consecutive targets, the trial was
either shortened or terminated.

D. Data Analysis

The clinical outcome measures were analyzed descriptively
using percent changes. The data were also graphed. The
magnitude of the treatment effect was determined by
calculating the effect size (Cohen’s r) [15] from the average of
the change pre and post training between the groups divided by
the pooled standard deviation.

III. RESULTS

Adherence in both groups was high. All subjects completed
every training session. However, subjects in the control group
reported fatigue earlier in the sessions compared to the subjects
in the experimental group. Those in the control group required
more verbal cues and manual cues to produce movement in the
required direction, and amplitude (Figure 2).

Training time for both groups in the first session was 24
minutes with 11 trials, each trial lasting 2 minutes on average.
Training time increased each week, reaching 56.5 minutes on
average for the VR group, with 20 trials each lasting between
3-10 minutes on the last training day and 48.5 min on average
for the control group with 18 trials lasting between 2-8 min.
Subjects in the control group trained 16% less time and
required more rest periods (9%) than the experimental group.

Initial averaged walking velocity per group was similar
(0.57m/s), for both the subjects in the VR group, walking
velocity increased by 98% from 0.36m/s to 0.71m/s and from
0.79m/s to 1.56m/s post training. An increase in velocity was
seen for only one of the subjects in the control group from
0.35m/s to 0.44m/s (21%) the other subject in this group had
no change in velocity post training. (Figure 3a) Effect size
between the groups was found to be r = 0.77. Gait speed
continued to improve at follow-up as compared to the post
training evaluation for three of the four subjects (increase of an
averaged of 0.25m/s and 0.04 m/s for the VR and control
respectively). Within-group evaluation showed considerable
improvement in speed from initial evaluation to follow up.
Treatment effect between the groups increasing to
r = 0.99 at follow-up from that observed at post training.

Both groups showed a decrease in time of descending and
ascending one flight of stairs (from 34s to 31.5s on average for
the control group and from 20.6s to 17s for the VR group)
these improvements account for 11.7%-16.9% for both the
control and the VR groups respectively with a small effect size
observed between the groups (r = 0.24). A slight improvement
in time to negotiate stairs at follow up was observed for only
one of the subjects in the VR group (4.2s) whereas the other
three subjects had a slight decrease in performance time (1.4s).

Endurance in the 6MWT was found to increase by 39.6%
for the subjects in the VR group (from 233m to 384m and from
396m to 463m). There was a decrease of 3% in the distance
walked for the subjects in the control group (from 110m to
117m and from 396m to 352m) (Figure 3c). The effect size
was large (r = 0.79). At follow up, endurance decreased by an
average of 22m from post training evaluation, for the VR
group, but only slightly for the control group (-2.25m),
treatment effect remained constant. (See Figure 3c)

Minimal improvement in the FM from an average of 23 to
24.25 (2-6%) was seen for both groups post training. The post
training self-report score of the perceived recovery from
stroke, showed a mean increase of 7% for all subjects (range 5-
12.5% increase). No change was seen in the scores of the BBS
post training.

IV. DISCUSSION

The findings of this pilot study suggest that a four-week
ankle-training program using a robotic-VR device resulted in
greater clinical effects than training without the VR simulation.
The protocol used for both the experimental subjects and the
control subjects has shown to have effects on walking speed,
stair climbing and endurance, although the magnitude of the
effect was greater for the VR group. The gains in the clinical
measures are in accordance to findings from previous studies
[9], [10]. Others have reported high adherence to exercise
training post stroke [16], which they attributed the collegiality
and support provided by group therapy. In this pilot the
training was not facilitated by a group and high adherence to
the training was evident in for all subjects. However, the
Fig. 3. Mean and standard deviations for each group pre-training, post-training and at 3-month follow-up: a) Velocity; b) Stair Climbing; c) Six-Minute Walk Test.

Control subjects trained less and required more rest periods. These findings could be explained by mental fatigue and the lack of purposeful training.

Performance based target level practice has been reported to affect patient motivation [17]. Subjects in the experimental condition seemed more motivated and enthusiastic about the training and often requested more challenging exercises. This finding supports patient reports about enhanced motivation when VR is incorporated into training [18],[19].

Both subjects in the VR condition had an increase of 98% in speed although their initial walking speeds were very different. These subjects continued to improve after training and have shown an increase in walking speed at the three month follow up. Subjects reported ambulating more, which suggest there might have been an increase in functional ability during real world activities that was achieved as a result of the training.

All subjects showed a decrease in time of descending and ascending stairs, although the difference between the groups was small and the gains were not maintained at follow up. Previous studies have shown improvement in this outcome measure 10, 14 therefore the limited change in stair negotiation could be related to the difference between the groups in the initial functional performance and to the small sample size.

Distance walked on the endurance test was greater for the VR subjects than the robot subjects. There was a larger decrease in endurance in the follow up evaluation for the VR subjects than the control subjects, however the decrease is proportional to the percentage of improvement between the groups. The gains in endurance were still considerably larger from the initial evaluation suggesting that motor function and capability improved.

It is interesting to note that functional gains of gait velocity were not related to improvements in either the FM or the BBS scores. This suggests that factors other than motor recovery and balance improvements account for the improvements in functional mobility. We speculate that force generation and coordination are two of the factors that could explain these findings, and will need to be elucidated in future studies. Finally, it is also worth mentioning that all subjects reported improvement in their recovery based on the SIS scores.

V. CONCLUSION

The results reported here support earlier findings that goal directed virtual reality training can improve ambulation for individuals with chronic stroke. Goal directed therapy produced a larger effect than lower extremity training alone. However, all subjects showed equal adherence and self-reports of improvements. Future research will use this technology to evaluate the underlying mechanisms of the improvements in gait. A follow up study with larger groups of subjects is underway. Sample size for the follow up study was determined using the effect size calculated here. Findings reported here are preliminary and should be interpreted with caution.

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REFERENCES