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Visual EMG Biofeedback to Improve Ankle Function in Hemiparetic Gait

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Abstract—**Spasticity in stroke patients interferes with coordinated muscle firing patterns of the lower extremity leading to gait abnormalities. The goal of this study was to improve ankle function during walking by augmenting treadmill gait retraining with a visual EMG biofeedback technique. Eight stroke patients who could ambulate between 0.5 and 0.9 m/s participated in the study. The training consisted of 12 sessions of treadmill walking during which the activity of the tibialis anterior and gastrocnemius lateralis muscles of the affected side was displayed on a computer screen. Targets were shown to indicate to the subject when to activate the monitored muscles. Gait evaluations were performed before and after the training period to test the hypothesis that ankle mechanics improved following the intervention. Improvements in gait function were characterized by changes in temporal gait parameters and lower extremity kinematics and kinetics. Subjects showed an increase in gait speed, time of single leg support on the affected side, ankle power generation at push-off and a reduction in knee extensor moment. These results indicate that treadmill gait retraining augmented via visual EMG-biofeedback facilitates improvements in hemiparetic gait.**

Key Words- **Stroke, biomechanics, electromyography, motor retraining.**

I. INTRODUCTION

There are over 4.5 million stroke survivors in the United States making it the leading cause of acquired disability in adults [1]. Following a stroke, alterations in muscle firing patterns often occur throughout the lower extremity leading to gait abnormalities. Gait disorders negatively impact the performance of activities of daily living and a person's quality of life [2]. A frequent goal of stroke rehabilitation is therefore the restoration of a normal gait pattern in order to increase mobility in these patients.

Patients with stroke often ambulate at slow speed and display gait patterns including spastic paretic stiff-legged gait, genu recurvatum and hip circumduction. Many of the gait abnormalities observed in post-stroke patients are related to inappropriate dynamic voluntary activation of the ankle plantar/dorsi-flexors [3]. Ankle plantarflexion during stance aids heel rise at push-off, while ankle dorsiflexion combined with knee flexion ensures foot clearance during mid-swing. These actions assist in minimizing the excursion of the center of mass (COM) during the gait cycle, and enhance overall gait efficiency. Kerrigan et al. have recently suggested that heel rise at the end of stance accounts for the majority of the reduction in center of mass excursion during gait [4]. Ankle plantarflexors contribute to heel rise at push off and the appropriate activation of these muscles during terminal stance and pre-swing is an important contributor to walking efficiency [4]. These findings suggest that the retraining of these muscles and related ankle function should be incorporated into a gait-retraining program.

Gait retraining tools employed by clinicians such as partial weight support gait retraining, functional electrical stimulation and dynamic EMG biofeedback often attempt to reproduce normal gait and retrain muscle activity. Using EMG biofeedback, spastic muscles have been retrained to be less active and muscle firing has been demonstrated in previously flaccid muscles. Early studies showed promising results in EMG biofeedback [5, 6]. However, despite success in retraining muscles to fire appropriately in isolation, the facilitation of isolated movements often demonstrates little transfer into activities of daily living [7, 8]. This observation increased interest for dynamic EMG biofeedback procedures to overcome limitations of retraining muscles in isolation. In a study by Colborne et al, EMG biofeedback of the soleus muscle and kinematic feedback of the ankle joint was used to retrain gait in 8 hemiparetic stroke patients. After training, subjects demonstrated significant increases in stride length, walking velocity, gait symmetry, and push off impulse [9]. These results demonstrated that biofeedback systems enhance specific quantitative gait parameters. However, the experimental setup, including overground walking on a 9-meter walkway, limited its scope of clinical application.

Treadmill walking is often used as a substitute to level ground walking since it requires less space and is possible to apply this techniques in less functional patients with the use of weight support. Studies have shown that walking on a treadmill does not significantly change the gait pattern compared to level ground walking [10]. With this in mind, it was hypothesized that gait retraining on a treadmill using visual EMG biofeedback could be beneficial to the stroke population.

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II. PROCEDURES

A. Subjects

Eight post-stroke adults (7 male, 1 female) participated in this study. The subjects had a mean age of 54 years (range, 47 - 59 years), mean mass of 79.7 kg (range, 47.2 – 91.0 kg) and a mean height of 171.8 cm (range, 157.5 – 185.0 cm). Patients were all greater than 2 years post-stroke, community dwelling, had residual ankle plantar/dorsiflexion strength (MRC $\geq$ 3), limited spasticity (Ashworth <2), and were not receiving other types of physical therapy at the time of the study. All subjects could ambulate between 0.5 and 0.9 m/s prior to training. Patients with severe neurologic problems other than those from stroke, with cardiovascular or musculoskeletal disorders or patients that received botulinum toxin or phenol injections in the lower extremity within four months from the beginning of the study were excluded. Prior to participation in the study, written informed consent was obtained from each subject.

B. Equipment

Lower extremity kinematic and kinetic data were obtained during gait evaluations using an 8 camera Vicon motion capture system (VICON 512, Oxford Metrics, Oxford, UK) and two AMTI force platforms (AMTI, MA). Gait training was performed on a Biodex RTM500 treadmill (Biodex Medical Systems, NY).

C. Procedures

All testing and training was performed at the Motion Analysis Laboratory, Spaulding Rehabilitation Hospital. Two gait analyses were performed: the first one before initiating gait retraining to establish a baseline of gait performance; the second one, after completion of the 12-session training period, to assess related changes in gait patterns. During each gait analysis, patients walked at a comfortable self-selected speed on a level walkway. Three-dimensional positional data (120 Hz) of reflective markers attached to the pelvis and lower extremities were captured synchronously with ground reaction forces. Five trials including complete motion analysis data were collected. Temporal parameters were obtained using the force platform and kinematic information to define foot contact times and distance parameters. Joint kinetics in each plane was calculated using a lower body inverse dynamic model (Vicon BodyBuilder, Oxford Metrics) and data was normalized for body weight.

A prototype version of a visual EMG biofeedback system was developed which included a screen display positioned at head height in front of the subject. During the training sessions, the subject ambulated on the treadmill at a comfortable walking speed and was instructed to keep looking forward at the screen and concentrate on the task (Figure 1). The gastrocnemius lateralis and tibialis anterior muscle EMG from the affected side were processed through a moving average window of 250 ms applied to the rectified EMG signal. When a heel strike was detected (via a foot-switch positioned to detect heel contact), the computer display screen reset by blanking the screen and then displaying the target EMG pattern for the entire stride. The X-axis of the screen corresponded to the stride duration. The Y-axis of the display was an ON/OFF indication of EMG amplitude, with ON corresponding to a target window derived from the normative activation intervals. Throughout the stride the real-time muscle EMG was drawn over the displayed targets. During each training session, the subject walked for five trials of four minutes each. Data were collected for the last two minutes. After each trial, the subject was allowed to rest for four or more minutes as necessary.

Figure 1. Experimental set-up with subject walking on treadmill watching screen for visual biofeedback.

D. Statistical Analysis

The statistical analysis was performed on a subject-by-subject basis due to the variability in compensatory patterns developed by different individuals. Kinematic and kinetic parameters describing ankle and knee mechanics before and after treatment were compared using a two-tailed Mann-Whitney U test. Differences observed by comparing data from pre- and post-intervention gait evaluations were deemed significant if estimated p-values were found smaller than 5%. P-values between 5 and 10% were considered indicative of a trend.

III. RESULTS

All the 8 subjects completed the 12 training sessions and underwent pre- and post-training gait evaluations. The estimated p-values for the comparison of temporal gait parameters and lower extremity mechanics between pre- and post-training are shown in Tables 1-3. Parameters showing a statistically significant change at a 5% confidence level are displayed in bold and those where the post-training value was further from a normative behavior than the pre-training value are shown with a downward arrow. P-values are also shown for estimates between 5 and 10% to indicate a trend.

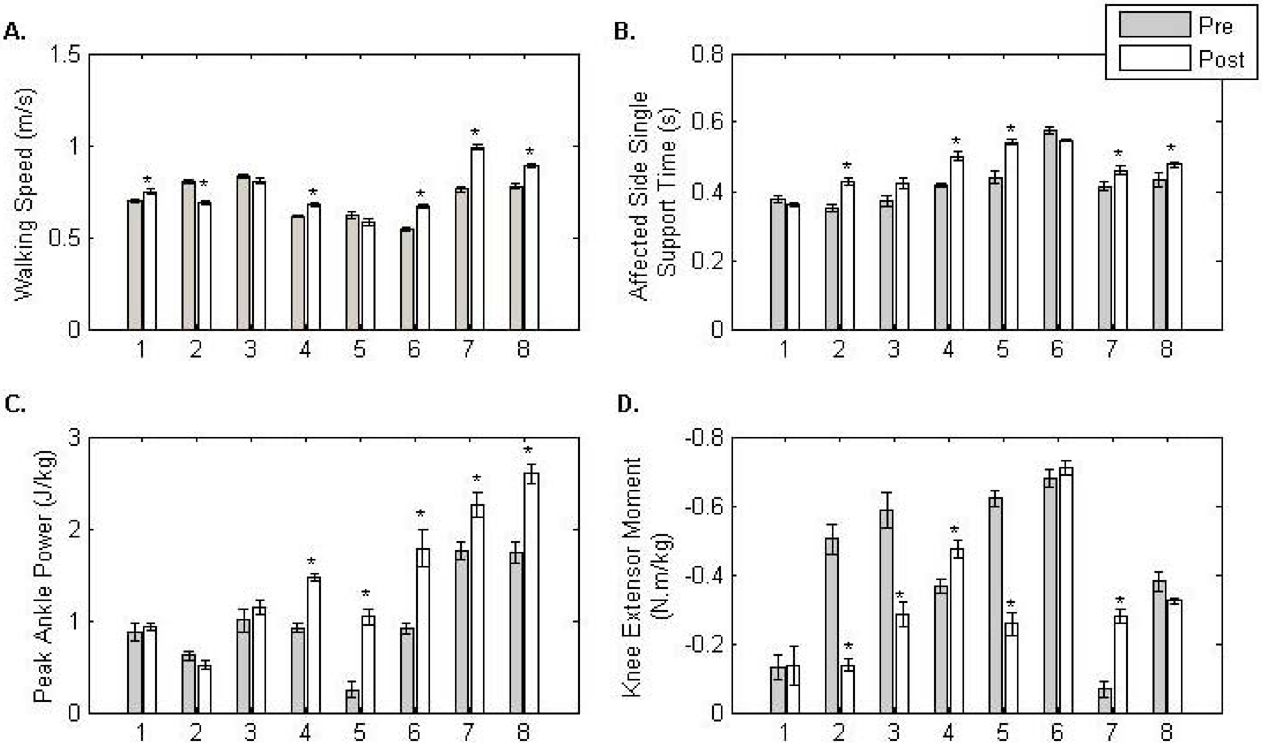

Figure 2. Mean (±standard error) of select temporal and kinetic gait parameters from gait evaluations for each subject (1-8) pre- and post-training. For each subject and parameter, the bar on the left represents the results from the pre-training evaluation, while the one of the right relates to the results from the post-training evaluation. Mean values are of 5 trials and significant changes at a 5% confidence level are indicated with a star (*).

Table 1 summarizes the results for the temporal gait parameters. Walking speed increased significantly in 5 of the 8 subjects, decreased significantly in 1 of them (Figure 2a), and showed a trend toward a decrease in 1 subject. The time of single support on the affected side increased significantly in 5 subjects (Figure 2b) and showed a trend toward an increase in 2 other subjects, while on the unaffected side it increased significantly in 4 subjects and decreased in 1. Significant increases in stride length of the unaffected side were shown by 6 subjects and 1 subject showed a significant decrease, while on the affected side 4 subjects significantly increased their stride length and 1 subject showed a trend toward an increase in stride length.

Table 1. P-values for changes in temporal gait parameters.

Subject	Walking speed	Affected side single support	Affected side stride length	Unaffected side single support	Unaffected side stride length
1	**0.016**	NS	NS	NS	**0.008**
2	**0.008**↓	**0.008**	NS	**0.008**	NS
3	NS	0.056	0.095	**0.016**	**0.016**
4	**0.008**	**0.008**	**0.008**	**0.016**	**0.008**
5	0.056↓	**0.008**	NS	**0.008**↓	**0.032**↓
6	**0.008**	0.056	**0.008**	NS	**0.008**
7	**0.008**	**0.032**	**0.008**	**0.008**	**0.008**
8	**0.008**	**0.032**	**0.008**	NS	**0.008**

Changes in ankle mechanics after training are outlined in Table 2. All but 1 subject showed an increase in peak ankle power generation at push off (Figure 2c), but in only 5 of the subjects were the increases statistically significant. About half of the group showed an improvement in ankle plantar and dorsiflexion during stance. Also, an increase in plantarflexion corresponding to push-off was observed. These changes were significant at a 5% confidence level in about 30% of the cases and a trend was shown in another 30% of the comparisons.

Table 2. P-values for changes in ankle mechanics.

Subject	Max Plantar., Stance	Max Dorsi., Stance	Max Plantar., Push-off	Peak Ankle Power
1	NS	NS	**0.032**↓	NS
2	**0.008**↓	NS	0.095	NS
3	**0.008**	**0.008**	0.056	NS
4	0.056	NS	0.056	**0.008**
5	**0.008**	**0.008**	NS	**0.008**
6	**0.008**	NS	0.095	**0.008**
7	NS	0.095	**0.008**	**0.016**
8	0.095	NS	**0.008**	**0.008**

Finally, Table 3 summarizes the observed changes in the knee mechanics. An important finding was the significant change in the knee extension pattern for 5 of the subjects, reflected by changes in knee extensor moment (Figure 2d) and maximum knee extension angle during stance. Most subjects showed non-significant changes in knee flexion and in the knee flexor moment during stance (weight acceptance phase). Three subjects showed an increase in maximum knee flexion during swing and 1 subject demonstrated a trend toward an increase in peak knee flexion during swing.

Table 3. P-values for changes in knee mechanics.

Subject	Max Flex, Stance	Max Ext, Stance	Max Flex, Swing	Max Flex. Mom., Stance	Max Ext. Mom., Stance
1	NS	NS	NS	NS	NS
2	**0.016**	**0.008**	NS	NS	**0.008**
3	NS	**0.016**	**0.008**	0.095	**0.008**
4	NS	NS	**0.008**	NS	**0.008**
5	**0.008**	**0.008**	NS	**0.008**	**0.008**
6	**0.008**	**0.008**	**0.008**	0.095	NS
7	NS	**0.008**	NS	NS	**0.008**
8	NS	NS	0.056	**0.008**	0.095

IV. DISCUSSION

Overall the group responded positively to the treadmill training and EMG biofeedback intervention. Post-training gait evaluations revealed significant improvements in gait function characterized by increases in walking speed, time of single support on the affected side, and ankle power at push-off. Also, a decrease in maximum knee extensor moment during stance was observed. We consider these changes to be related to a better-coordinated firing pattern of the ankle plantarflexor and dorsiflexor muscles, as targeted by the visual EMG biofeedback training program.

The significant increase in walking speed and timing of single support on the affected side is expected to be associated with an improvement in gait symmetry and increased weight-bearing capability of the affected side.

By training the gastrocnemious lateralis muscle, subjects achieved timing and magnitude of muscle activity that led to an increase in ankle power at push off. This is an important change because it leads to an improvement in the efficiency of gait [4].

The training of the tibilias anterior muscle enabled subjects to dorsiflex the ankle during swing and attain heelstrike at ground contact. Combined with an increase in knee flexion during swing, we see these changes as aiding foot clearance and lessening circumduction as typically observed in stiff-legged gait of stroke patients.

Three subjects showed a reduction in a hyperextension pattern of the knee leading to a lower likelihood of damage to the knee joint in the long term. Two subjects showed an increase in knee extensor moment, however this could be due to a corresponding increase in walking speed. It is encouraging to note that improvements in knee function were observed, especially considering that the intervention was primarily focused on rehabilitating ankle function. The benefit to knee mechanics may be explained by the bi-articular nature of the gastrocnemius muscle which was targeted during the treadmill training. Subject 5, in particular, showed a significant change in gait pattern, with an augmented time of single support on the affected side, decreased time of single support on the unaffected side, decreased stride length on the unaffected side, increased peak ankle power, and decreased knee extension moment. These changes appeared to provide the subject with an increased symmetry in gait and an important reduction of the hyperextension of the knee during stance.

V. Conclusion

This preliminary study was aimed to determine the efficacy of a visual EMG biofeedback technique to improve ankle function in hemiparetic gait of post-stroke individuals. Significant changes were seen in most of the group, which we interpret as a general indication of the positive response to the intervention. These results are encouraging to those who hope to use biofeedback as a form of therapy and indicate that improvements in gait function can be achieved even several years post-stroke.

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