

MODIFYING ANKLE JOINT NEUROMECHANICS USING AN ANKLE FOOT ORTHOSIS WITH VIBROTACTILE FEEDBACK DURING HUMAN WALKING

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INTRODUCTION

Two common walking-related problems in impaired populations are the inability to propel the body forward during push-off at end of stance and/or clear the foot during forward leg swing (foot drop). A key factor contributing to these symptoms may be inadequate ankle joint control in the weakened limb. A potential solution to improve ankle joint control is through the use of biofeedback. For example, studies have investigated the capability of biofeedback in older adults with propulsive deficits, finding that this population has “considerable and underutilized propulsive reserve available” [1], making real-time biofeedback a promising method of rehabilitation. We have developed an ankle foot orthosis (AFO) with built-in vibrotactile biofeedback to provide dynamic feedback and encourage activation of ankle muscles during walking. The goal of this project was to test the effectiveness of this device in healthy subjects by asking the user to modify ankle kinematics by altering control of their own muscles based on biofeedback cues.

METHODS

A custom fabricated, unilateral carbon fiber/fiber glass composite AFO was created for eight healthy participants (age = 23.63 ± 3.29 years; mass = 74.72 ± 10.82 kg; height = $1.75 \pm .08$ m). The device uses a microcontroller with inputs from an encoder and pressure sensors to control biofeedback through the use of a buzzer and a vibration motor (Fig. 2a). Time series data between each step is shown in Figs. 2b,c. Each participant was asked to walk in four 7 minute conditions: (1) No AFO, (2) AFO – No Feedback, (3) AFO encouraging increased plantarflexion (i.e. improve push-off), and (4) AFO encouraging increased dorsiflexion (i.e. prevent foot-drop). An instrumented treadmill was used to record ground reaction forces (Bertec,

Columbus, OH) while a motion capture system (Vicon, Oxford, UK) was used to determine joint kinematics. A combination of the two was used in an inverse dynamic analysis to compute joint powers using Visual 3D software (C-Motion Inc., Germantown, MD). EMG was collected through surface electrodes (SX230 Biometrics Ltd.) processed and integrated while a portable indirect calorimetry system (Oxycon Mobile, Yorba Lina, CA) was used to measure inspired O₂ and expired CO₂ and compute metabolic power. Data was averaged over 10 steps and ANOVA with a Bonferroni adjustment was used to compare differences between No AFO and AFO with the different forms of biofeedback.

RESULTS AND DISCUSSION

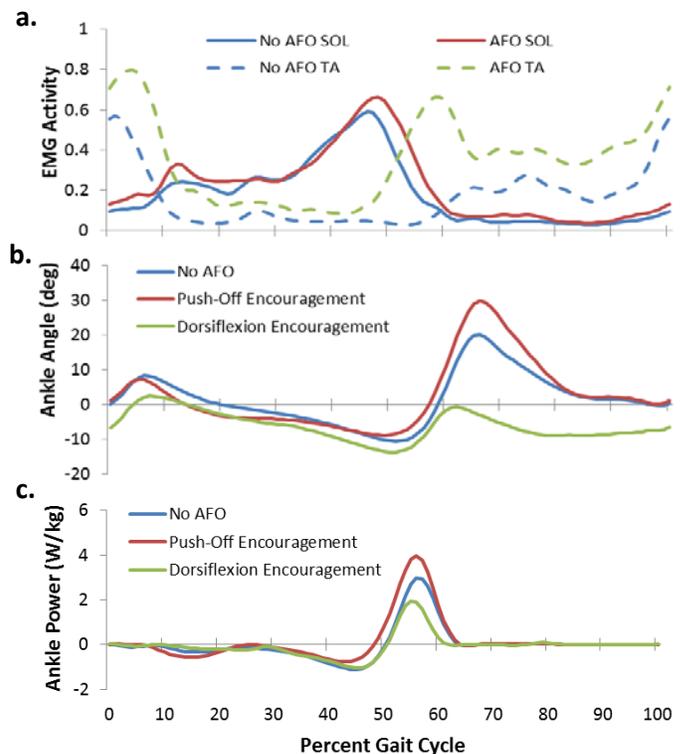


Figure 1: (a) Soleus (solid) and Tibialis Anterior (dotted) EMG ; (b) ankle angle ; (c) ankle power. Data are group means.

For the increase dorsiflexion/prevent foot drop biofeedback framework, users exhibited increased tibialis anterior muscle activity (Fig. 1a) and dorsiflexion of the ankle (Fig. 1b) during the swing phase of gait. However compensations such as decreased ankle power (Fig. 1c) and increased hip power were observed during swing, contributing to increases in metabolic cost while walking with the AFO turned on (Table 1). These results lead us to believe that this type of rehabilitation will be best for users with foot drop not accompanied by other neuromuscular impairments by strengthening their tibialis anterior muscle and increasing ankle dorsiflexion. However, for those who suffer from foot-drop and propulsion deficits (e.g., post-stroke), intensely focusing on using ankle dorsiflexors to keep a lifted toe would negatively impact propulsion performance. In these cases, strategies that focus more on knee flexion to achieve toe clearance, might be better.

In the second framework, increase plantarflexion/improve ankle propulsion deficiencies, increases in propulsive ankle power (Fig. 1c) and soleus muscle activity (Fig. 1a) were observed, as well as decreases in peak hip power (Table 1), indicating that users could recruit unused reserves of ankle ‘push-off’ power for limb

advancement by trading off with power at the hip. Slight increases in metabolic cost were observed, however this was expected as enforced gait patterns can elicit higher metabolic energy cost [2]. If an impaired population, such as those with hemiparesis following stroke can attempt to replicate these results, we are hopeful that gait symmetry and walking economy could be restored, leading to improved quality of life.

CONCLUSIONS

This study lays the groundwork for future testing on a vibrotactile biofeedback AFO to prevent foot drop and assist push-off in impaired populations. This targeted, on-line biofeedback approach, could positively impact rehabilitation practices if impaired populations can recruit muscle activity that they are not using on a daily basis.

REFERENCES

1. Franz JR., et al., Real-time feedback enhances forward propulsion during walking in old adults. *Clinical Biomechanics*. 2014; **29**: 68-74.
2. Wezenberg D., et al. Mind your step: Metabolic energy cost while walking an enforced gait pattern. *Gait & Posture*. 2011; **33**: 544-549.

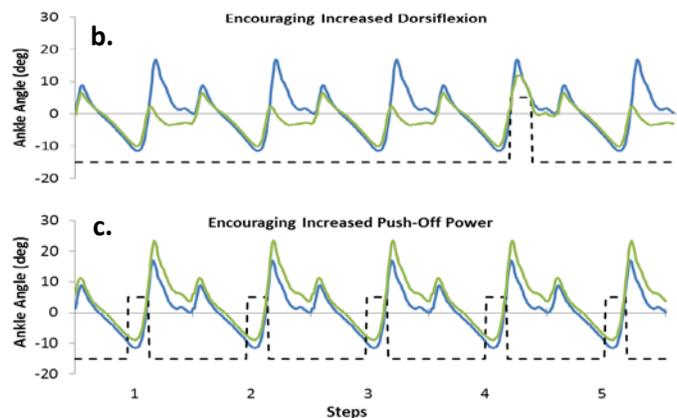
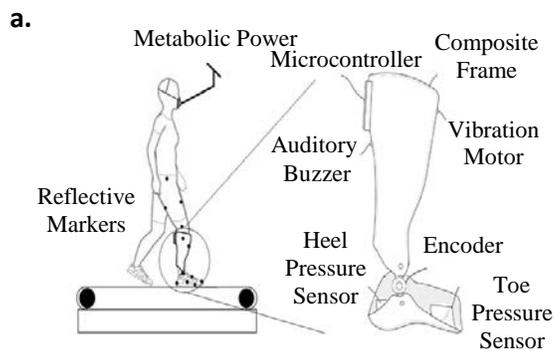


Figure 2: (a) Vibrotactile AFO; and time series demonstrating (b) dorsiflexion encouragement (i.e., decrease foot drop) and (c) plantarflexion encouragement (i.e., increase push-off power)

Table 1: Comparison of peak values for foot drop and push-off paradigms to no AFO condition

Foot Drop	<u>No AFO</u>	<u>AFO</u>	Push Off	<u>No AFO</u>	<u>AFO</u>
Peak TA Activity	0.19	0.26	Peak SOL Activity	0.21	0.23
Peak Ankle Dorsiflexion*	20.66 deg	-0.244 deg	Peak Ankle Plantarflexion*	20.66 deg	30.45 deg
Peak Positive Ankle Power*	3.15 W/kg	2.04 W/kg	Peak Positive Ankle Power*	3.15 W/kg	4.07 W/kg
Peak Positive Hip Power	0.76 W/kg	0.96 W/kg	Peak Positive Hip Power	0.26 W/kg	0.17 W/kg
Metabolic Cost	2.71 W/kg	3.45 W/kg	Metabolic Cost	2.71 W/kg	3.13 W/kg