

UTILIZING EMG BIOFEEDBACK TO MODIFY CORTICAL CONTRIBUTIONS TO  
POSTURAL CONTROL

by

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## **Abstract**

Electromyography Biofeedback (EMG-BF) is a clinical tool used by rehabilitation professionals to enhance patient awareness of muscular functions in real time. When used in conjunction with traditional rehabilitation exercises, it is believed that EMG-BF can enhance nervous system plasticity in control of postural muscles, potentially identifying new therapies for patients who suffer from neuromuscular disorders that weaken postural control muscles. I aimed to measure peripheral and cortical excitability before and after a balance intervention with or without EMG-BF intervention to evaluate its potential use in treating balance disorders. Nineteen healthy men and women between the ages of 19-24 participated in this study. The Hoffmann reflex (H-Reflex) and motor evoked potentials (MEP) were elicited for three postural control muscles: tibialis anterior (TA), peroneus longus (PL) and soleus (SOL) with electrical and transcranial magnetic stimulation before and after two sessions of 30-minutes of balance training using the Biodex Balance System. One group received EMG-BF of the PL during the balancing protocol, while one group did not. Reflexive excitability and MEP size was compared across muscles, intensity, time, and groups. Results indicated that EMG-BF eliminated differences in reflexive excitability between PL and SOL, potentially causing the PL to act as a postural muscle, increasing its ability to respond to changes in load. The control group demonstrated a synergy between the TA and PL following the intervention, suggesting that the PL may have a phasic role, potentially affecting reflexive strength during functional activity. Cortical excitability to the SOL decreased in the group that received EMG-BF; however, these differences were not demonstrated for the TA and PL. These findings potentially indicate that balance training with EMG-BF has the effect of inhibiting the SOL, which could be useful for the clinical treatment of dystonia in the lower extremity.

## **Introduction**

Neuromuscular deficits have been tied to an array of musculoskeletal and neurological disorders that range from ligamentous and musculotendinous injury to cerebrovascular accident. Manifestations of these deficits may exist across multiple systems, but is often present during the sensorimotor task of maintaining postural control (balance). Balancing is a unique task that integrates multiple modalities of sensory function and requires integration at the spinal cord and cortex in order to generate appropriate motor control. It is important to improve balancing mechanisms because decreased postural control ability is a significant risk factor for falling; ultimately putting patients at risk for fall-related injuries and their accompanying complications (Bang & Cho, 2016). A primary goal in neuromuscular disorder rehabilitation is improved balance ability: a precursor to walking ability (Bang & Cho, 2016). It has been shown that task-specific training with a focus on body awareness improves dynamic balance and postural control ability (Bang & Cho, 2016).

Postural control is regulated by sensory inputs, body geometry, kinetics, body orientation, and visual perception (Paillard & Noe, 2015). The nervous system controls feedback mechanisms to activate and inhibit the appropriate motor units in a coordinated sequence. Sensorimotor loops and vestibulospinal tracts receive, integrate, and initiate the execution of coordinated movement, especially posture (Patestas & Gartner, 2006). Afferent feedback from cutaneous, capsuloligamentous, and musculotendinous receptors send sensory messages from the muscle spindle. This information ascends the spinal cord via lower and upper motor neurons and is then integrated in the basal ganglia (Patestas & Gartner, 2006). Finally, the sensory input is received by the motor cortex and efferent signals for conscious muscle contraction are sent back down the pathway (Patestas & Gartner, 2006). Subconscious control is regulated by subcortical

mechanisms that include the vestibulospinal and reticulospinal tracts that coordinate movement between the brainstem and cerebellum (Patestas & Gartner, 2006). The vestibulospinal tract has ipsilateral fibers that descend the anterior funiculus and synapse with excitatory interneurons that innervate motor neurons that both activate the trunk and proximal limb extensor muscles while inhibiting limb flexor muscles (Patestas & Gartner, 2006).

One method to enhance the activating and inhibiting training effect is through the introduction of feedback, increasing body awareness. Electromyography Biofeedback (EMG-BF) is a method of retraining muscles by converting myoelectric signals in the muscles into auditory or visual cues (Giggins, Persson, & Caulfield, 2013). This rehabilitation technique helps patients to quantify a physiological event, thus aiding in their ability to achieve a desired level of neuromuscular control (Lepley, Gribble, & Pietrosimone, 2012). By converting myoelectric changes in the muscle fiber into signals that humans can perceive, conscious awareness of activation and inhibition at the neuromuscular level can be attained.

EMG-BF increases activation in dysfunctional and healthy muscles by increasing motor unit recruitment (Giggins et al., 2013; Lepley et al., 2012). It has also been shown to decrease tone in spastic muscles (Giggins et al., 2013). Thus, it is hypothesized that EMG-BF could positively affect the activation and inhibition of the lower extremity muscles involved in balance and postural control: tibialis anterior, peroneus longus, and soleus.

Current strategies to rehabilitate postural control and balance in patients with neuromuscular disorders include motor-skills training, strength exercises, and visual cueing; however, there have not been any investigations into the utilization of EMG-BF to enhance the neuromuscular effects of these strategies. While most of the initial steps in postural control happen subconsciously within the spinal cord and motor cortex, humans are still able to

consciously feel and control muscle contraction. However, the degree to which fast, automatic postural responses used to recover from challenges to postural equilibrium can be influenced by voluntary intention depends on the extent to which they are controlled by the cerebral cortex (Jacobs & Horak, 2007). While reflexive responses to postural perturbation are faster than any cued, voluntary response, it is suggested that cortical inputs, unlike spinal proprioceptive reflexes, are modifiable by learned balancing behaviors (Jacobs & Horak, 2007).

The purpose of this investigation is to determine how cortical and reflexive functionality changes in the postural control system with and without the use of EMG-BF. If EMG-BF is combined with balance training, there will be an increase in cortical and reflexive excitability and inhibition to the muscles involved in postural control. I hypothesize that EMG biofeedback combined with balance training will cause an increase in cortical and reflexive excitability to the tibialis anterior (TA), soleus (SOL), and peroneus longus (PL).

## **Methods**

### *Experimental Approach to the problem*

This study utilized a randomized pre-test post-test design with control group. Dependent variables included cortical excitability (MEP size), and reflexive excitability ( $H_{\max}:M_{\max}$  ratio). Independent variables included use of EMG-BF and test occasion.

### *Subjects*

Nineteen able-bodied individuals between the ages of 18-35 were recruited for this study (mean age:  $21.07 \pm 2.26$  yrs; mean height:  $183 \pm 80.1$  cm; mean weight:  $69 \pm 13.1$  kg, 8 females, 5 males). Participants were free of exclusion criteria for the safe practice of Transcranial

Magnetic Stimulation (TMS), including presence of metal in the body, history of brain or heart surgery, current medical treatment of psychological disorders, and any history of seizure or neurological disorders. Prior to participating, Appalachian State University Institutional Review Board approval was obtained (ID number: 16-02355) and each subject provided informed consent. Following baseline testing, participants were randomly assigned to one of 2 groups: EMG-BF or control.

### *Procedures*

Participants were asked to report to the Injury Neuromechanics Lab for a total of two testing sessions. During the first session, participants provided University-approved informed consent and questionnaires prior to being tested for all dependent measures at baseline. Those in the EMG-BF group were asked to complete a 2-day balance training task with the Biodex balance system (BBS), (Biodex Medical Systems, Shirley, NY) while using EMG-BF providing feedback from the peroneus longus. Those in the control group were asked to complete the Biodex motor learning task without EMG-BF intervention. Participants were asked to return to the lab 7 days following baseline testing to repeat all measures.

### *Pre & Post Testing*

Reflexive excitability was assessed using the Hoffmann Reflex (H-Reflex). Surface EMG electrodes were placed on the TA, SOL, and PL muscles using standard procedures (Basmajian, 1967). Skin over the muscle was palpated, shaved (if necessary), cleaned with isopropyl alcohol prep pad, and lightly abraded.

With participants laying prone on a padded table, the location of the sciatic nerve, prior to its bifurcation into tibial and common peroneal division, was identified at the level of the popliteal fossa. A bar electrode connected to a peripheral nerve stimulator (DS7AH, Digitimer, Hertfordshire, UK) was placed at this location and used to apply 1 ms pulses as EMG were collected from the TA, SOL, and PL muscles. The peak-to-peak muscle responses with the 10-40 ms window (M-wave) and the 50-120 ms window (H-wave) were extracted. The maximal H-wave was compared to the maximal M-wave, providing the dependent variable for analysis.

Cortical excitability was tested using TMS. After familiarization, the hotspot for targeting the test leg was found by searching in a 5cm radius starting from a point 2 cm anterior and 2 cm lateral to the vertex of the skull. The hotspot was identified as the location providing the largest MEP in the TA of the test leg. This location was marked and using this point, 50-60 pulses of intensities ranging below the motor threshold to the point above a maximal response were applied in random order. Using this stimulus-response curve, the resting motor threshold (RMT) was identified. Participants were then instructed to hold a contraction of their tibialis anterior equal to 15 % of maximal voluntary effort with visual feedback as 30 magnetic pulses equal to 90 and 110 % of RMT will be applied in a random order. Dependent variables include the average MEP size at 90 and 110% RMT during facilitated trials.

### *EMG-Biofeedback*

EMG-BF was performed with the Myotrac T4000P EMG unit (Patterson Medical, Montreal, Quebec, Canada). Surface electrodes were placed on the proximal two-thirds of the muscle belly of the PL. The subject was asked to relax their PL as much as possible and then perform a maximal contraction. The sensitivity range was set to the lowest value that did not

provide feedback. The subject was asked to relax again and the sensitivity was set to two-thirds of the no-feedback value. After, the subject was asked to contract the muscle until maximum feedback was obtained, and then hold the contraction for six seconds. Finally, the subject was asked to relax to return the meter to baseline (Starkey, 2004).

### *Balancing Task*

Subjects were invited to complete motor learning balancing games using the Biodex Balance System (BBS) (Biodex Medical Systems, Shirley, NY) for 30 minutes, with or without EMG-BF, depending on subject group. The Dynamic Balance Training screen of the BBS stresses the ability of the subject to maintain balance on the movable, unstable plate of the BBS (Ibrahim, Mattar, & Elhafez, 2016). Postural Stability Training mimics specific movement patterns by having subjects touch nine on-screen markers by moving a cursor with both feet (Eftekhari-Sadat, Azizi, Aliasgharzadeh, Toopchizadeh, & Ghojazadeh, 2015). “Limits of Postural Stability,” “Maze Control,” and “Limits of Stability” training programs were used during training as all three required the subject to activate postural control muscles. The level of difficulty was modified by adjusting the instability setting and changing the subjects’ base of support, as simply using a shoulder-width bipedal stance with difficulty level of six as identified by Eftekhari-Sadat, was not challenging enough to provide a demonstrable effect for all subjects (Eftekhari-Sadat et al., 2015). Each training program was completed for a total of 5 minutes with 3 minutes of rest between sets.

Min: 0-5	Warm up with stable platform, familiarize subject with Biodex system
Min: 5-10	Task 1: Static Balance on Unstable Surface. Ask subject to keep tracing inside the center circle. Level 4, two-legged stance, feet touching.
Min: 10-13	Rest
Min: 13-18	Task 2: Maze (highest difficulty setting, restart as needed). Instability level six, feet touching.
Min: 18-21	Rest
Min: 21-26	Task 3: Limits of stability (re-start testing as needed, hardest setting). Instability level 6, feet touching.
Min: 26-28	Rest
Min: 29-34	Task 4: Static Balance on Unstable Surface. One leg. Instability level 6.

Table 1: Training protocol for Biodex Balance System.

### *Data Analysis*

All dependent variables were assessed using 3-way factorial analyses of variance (ANOVA) with 1 between-subjects factor (group: BF vs. control) and 2 within-subjects factors (for H-reflex, muscle: 3 levels; time: 2 levels; for TMS, intensity: 2 levels; time; 2 levels). An a priori level of significance was set at 0.05. Three subjects were excluded from analysis due to incomplete data.

## Results

### *H-Reflex*

There was no significant effect of group on reflexive excitability ( $F_{1,13}=0.002$ ,  $p=0.962$ ) (Figure 1). For the experimental group, the TA excitability was lower than both PL and SOL for pre and post measures. For the control group, SOL excitability was lower than both TA and PL at pre and post measures.

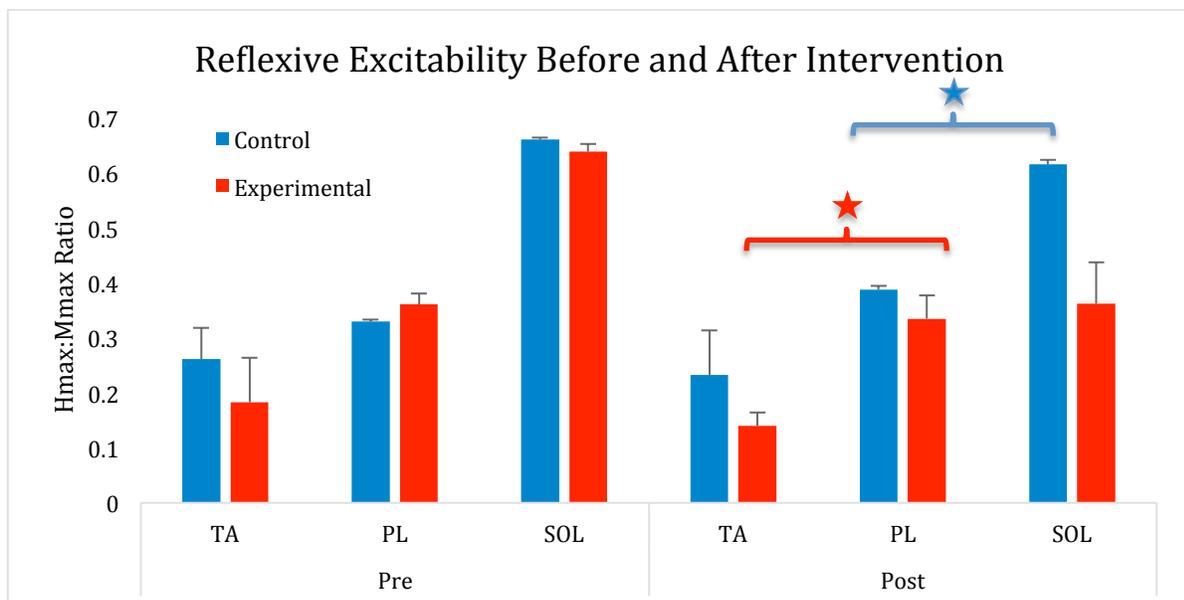


Figure 1: Reflexive excitability of the TA, PL, and SOL before and after intervention for EMG-BF group and control. Reflexive excitability is expressed as Hmax:Mmax ratio. Error bars indicate 1 SD.

### *Cortical Excitability: Tibialis Anterior and Peroneus Longus*

As expected, there was an effect of intensity between the 90% and 110% MEP measurements on the TA ( $F_{1,10} = 16.05$ ,  $p = 0.062$ ) (Figure 2) and PL ( $F_{1,11} = 8.61$ ,  $p = 0.014$ ) (Figure 3). However, there was not an effect between the experimental and control groups for the TA ( $F_{1,10} = 0.63$ ,  $p = 0.446$ ) (Figure 2) and PL ( $F_{1,11} = 0.533$ ,  $p = 0.481$ ) (Figure 3).

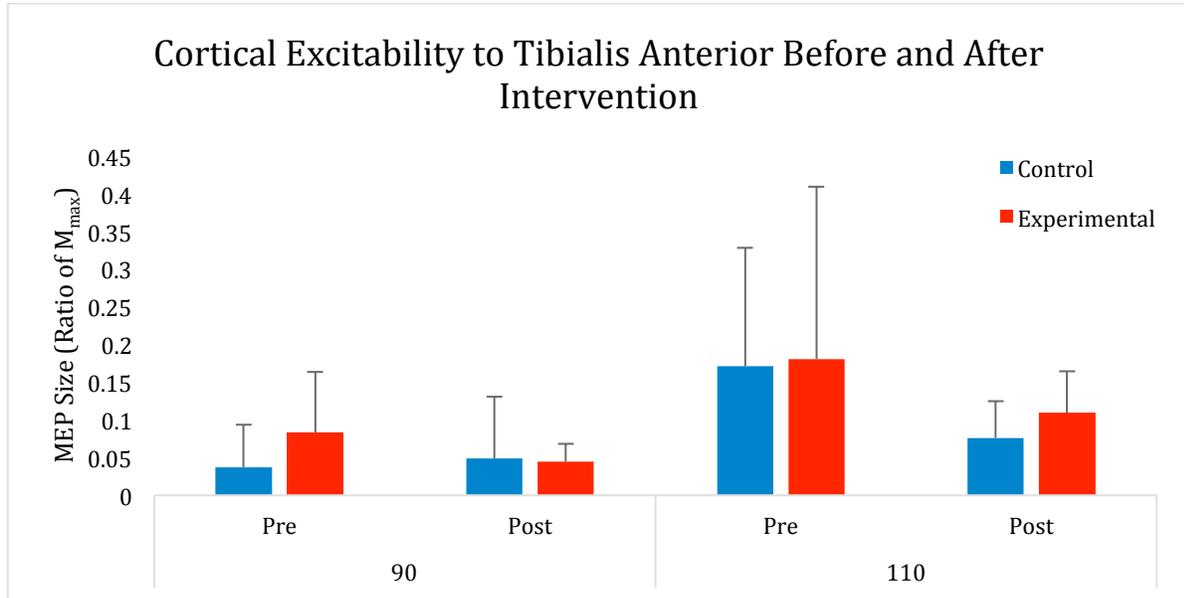


Figure 2: Cortical excitability to the TA before and after intervention for both EMG-BF group and control. 90 indicates motor evoked potential size (MEP) at 90% resting motor threshold (RMT). 110 indicates MEP size at 110% RMT. Error bars indicate one SD.

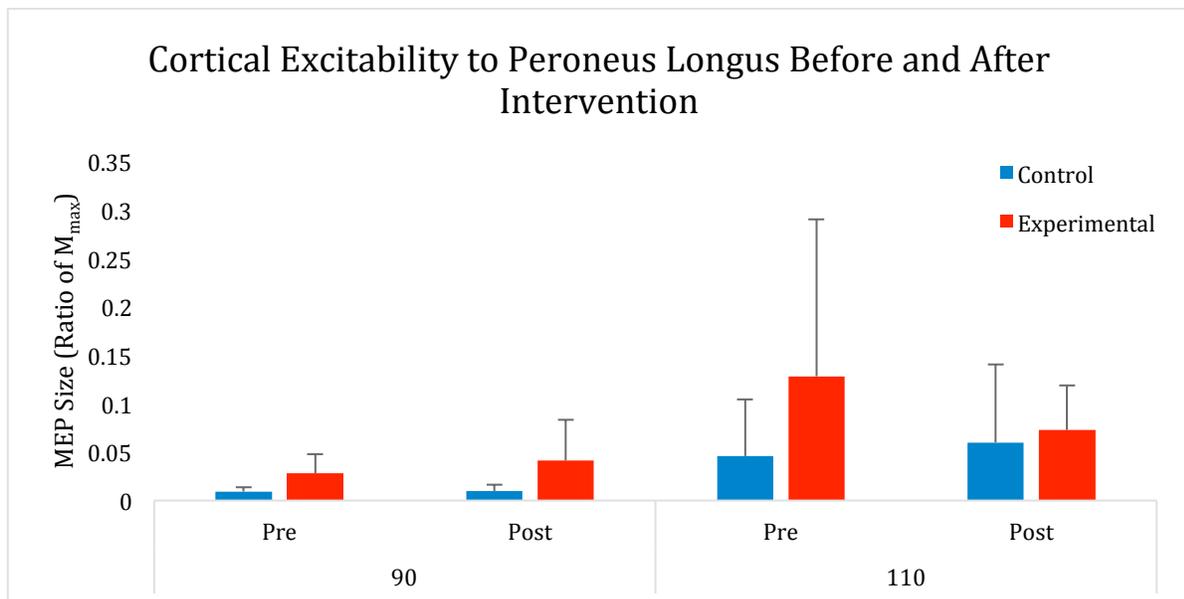


Figure 3: Cortical excitability to the PL before and after intervention for EMG-BF group and control. 90 indicates motor evoked potential size (MEP) at 90% resting motor threshold (RMT). 110 indicates MEP size at 110% RMT. Error bars indicate one SD.

### Cortical Excitability: Soleus

There was a nearly significant effect between time, intensity, and group for SOL ( $F_{1,10} = 4.59$ ,  $p = 0.058$ ). There was a significant effect between time and group ( $F_{1,10} = 5.316$ ,  $p = 0.044$ ) exhibited by a decrease in excitability between pre and post tests for the experimental group. After the EMG-BF intervention with balance training, there was a decrease in cortical excitability to the SOL.

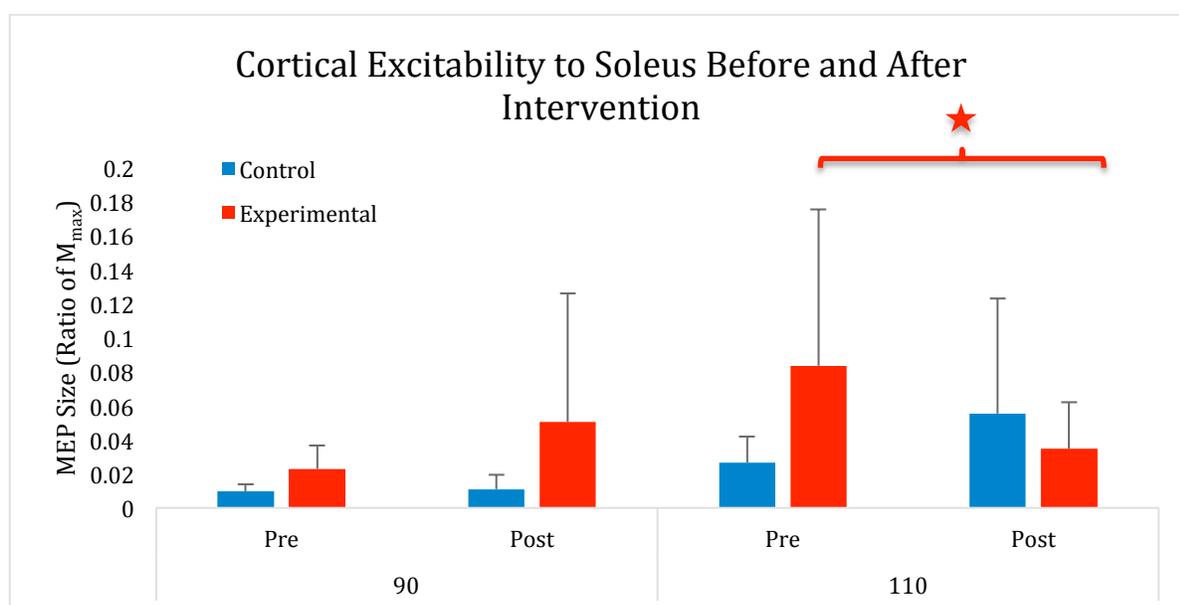


Figure 4: Cortical excitability to the SOL before and after intervention for EMG-BF group and control. 90 indicates motor evoked potential size (MEP) at 90% resting motor threshold (RMT). 110 indicates MEP size at 110% RMT. Error bars indicate one SD.

### Discussion

Overall, the use of EMG-BF did not significantly alter reflexive excitability and cortical excitability measures of the TA and PL. As expected, sizes of muscle responses increased with TMS stimulus intensity; however, there were no differences between groups or times for the TA

or the PL. SOL excitability decreased in the group that completed the balance training with EMG-BF, but not in the control group.

### *H-Reflex*

Multiple studies have demonstrated that the H-Reflex decreases, specifically in the SOL, with dynamic, acute, and long-term balance training (Kawaishi & Domen, 2016; Mynark, Koceja, & Lewis, 1997; Taube et al., 2007; Trimble & Koceja, 2001). Acute studies consisted of 3 training periods over 1 week and 2 hours on 1 day, respectively. Long-term balance training studies utilized 16 sessions over 14 weeks. It has been shown that the down regulation of alpha motor neuron pool excitability in the soleus is a hallmark of dynamic balance, and researchers hypothesize that this allows for supraspinal centers to recruit more motorneuronal activity to allow for more precise movements (Kawaishi & Domen, 2016). While this is the first study to evaluate the efficacy of utilizing EMG-BF to enhance reflexive excitability during balance, Place et al. observed changes to the activation patterns of plantar flexors including SOL during EMG-BF facilitated contraction (Place, Duclay, Lepers, & Martin, 2009). Thus, I may have expected to see a significant change in the H-Reflex following balance training protocols, especially in the experimental group which utilized both balance training and EMG-BF; however, EMG-BF has been shown to increase motorneuron pool excitability, so there could have been some sort of compensatory effects, forcing changes to occur at the cortical level (Giggins et al., 2013; Lepley et al., 2012).

While increasing volitional feedback during a balance task did not induce a reflexive change in this study, several factors could explain this discrepancy. My findings are consistent with Lepley et al. who did not see changes in H-reflex after a similar EMG-BF intervention at

the knee (Lepley et al., 2012). However, their intervention involved an isometric strength assessment, as opposed to balance. Maintenance of postural control has been described to modify reflexive excitability in paradigms where the stimulus is provided during dynamic balance (Schubert et al., 2008). I measured H-reflex after a 2-day intervention, hypothesizing that I would see changes due to modifications in corticospinal and reflexive inputs that would be present at rest; however, perhaps these changes would only be seen during task-specific interventions, as suggested by Beck et al. (Beck et al., 2007). Furthermore, as the H-reflex has decreased in previous balance interventions, it is possible the use of two sessions separated by seven days may not have been a sufficient stimulus to decrease motoneuron pool excitability (Schubert et al., 2008).

Multiple studies have demonstrated that changes to the H-Reflex are task-specific, implicating that the reflex will not change unless it is measured during the task (Beck et al., 2007; Schubert et al., 2008). Both studies only observed changes in the H-Reflex during dynamic balance and motor control, respectively, but only when the stimulus was provided during the task, not at rest. Our study measured H-Reflex excitability in a prone position before training and after a 10-minute rest period following training on the second day. Kim et al. have shown decreased modulation of the SOL during movement from prone to unipedal standing in healthy and chronic ankle instability populations, so further studies could include evaluating modulations in the H-Reflex while using the BBS (Kim, Hart, & Hertel, 2013).

While I did not see a significant change in the overall effect of the EMG-BF on H-Reflex modulation, I saw that the use of EMG-BF to facilitate the PL caused the excitability to become similar to that of the SOL. This muscle has higher excitability because of its role as a postural muscle that maintains more consistent levels of activation throughout daily tasks. It has been

shown that uninjured patients use different stabilizing muscles during perturbation compared to those with functional ankle instability (Needle et al., 2017). In the current study, experimental subjects used the PL for ankle stability in a way that potentially resembled those of pathological populations. In addition, several studies have indicated that changes to postural control during balance are the result of enhanced cortical, not spinal, excitability (Mouthon, Ruffieux, Walchli, Keller, & Taube, 2015; Schubert et al., 2008; Taube et al., 2007).

#### *Cortical Excitability to the Dorsiflexors and Evertors*

There was not a significant change in the cortical excitability to the TA and PL muscles based on the EMG-BF intervention. Since the EMG-BF intervention was directing the subjects' attention to the PL muscle during balance, it was a reasonable hypothesis that enhanced awareness to the muscle would increase muscle activation, and therefore excitability of the corticospinal tracts to these muscles. Similar studies, through interventions such as body awareness or motor skills training that provide feedback to a patient through means other than EMG-BF have caused increased motor excitability in both able-bodied and neurologically impaired populations (Bang & Cho, 2016; Perez, Lungholt, Nyborg, & Nielsen, 2004). A study by Bang et al. utilized motor skills training that did not include dynamic balance; however, it did incorporate visual inputs by having the subject plantar and dorsiflex the ankle to control a cursor on a screen, similar to the task required by the BBS (Bang & Cho, 2016). They found significant increases in recruitment of MEPs in the leg motor area following 32 minutes of motor skills training compared to passive and non-skill training. The findings of Perez et al. also indicate that plasticity changes are related to the degree of difficulty of the motor task (Perez et al., 2004). Through pilot testing and anecdotal reports from participants, the balance training task was

highly challenging in task and length, making the lack of change in excitability from training surprising. As such, similar interventions have demonstrated that short-term motor learning in the lower extremity may be occurring in the cerebellum, and not the cortex (Floyer-Lea & Matthews, 2004; Muellbacher, Ziemann, Boroojerdi, Cohen, & Hallett, 2001; Pascual-Leone, Grafman, & Hallett, 1994; Puttemans, Wenderoth, & Swinnen, 2005).

One reason why there may not have been significant changes between groups is that both experimental and control groups received some form of visual feedback in addition to the experimental group receiving auditory feedback. To complete the balance training exercises using the BBS, subjects were instructed to use the real-time tracing lines that corresponded to their changes in center of pressure to complete the maze, limits of stability, bipedal and single leg static balance tasks. Roche and O'Mara have reported that training visuomotor associations enhances performance on subsequent trials of the task by involving the parts of the brain that are involved with arbitrary association matching (Roche & O'Mara, 2003). While subjects in the experimental group of our study did understand that increases in muscle activity corresponded to the increasing intensity of the auditory feedback, subjects in both groups were predominately focused on the visual inputs of completing the balancing tasks. Thus, changes between groups might have been more evident if the balancing tasks did not include a visual input component.

The PL activates during natural balancing tasks, but has not been shown to increase activation to provide additional stability in patients with chronic ankle instability (Louwerens, van Linge, de Klerk, Mulder, & Snijders, 1995). Thus, it is hypothesized that the PL serves to maintain balance during static tasks. While the TA does serve to assist in balance control, this is not its primary function. Cortical inputs have been shown to significantly modulate TA activity in patients with bilateral instability, and not in uninjured populations, suggesting that the muscle

can alter its firing to adapt to increased balance control demands (Louwerens et al., 1995). More recent studies in stroke populations have demonstrated an increase in cortical excitability in the TA of the paretic leg, and decreases in the non-paretic leg after balance training (Omiyale, Crowell, & Madhavan, 2015). As such, the TA and PL both function as phasic muscles; they fire when they are needed, for example, during the precise timing of walking and other functional activities.

### *Cortical Excitability to the Plantarflexors*

Unlike the other muscles, EMG-BF caused a decrease in cortical excitability to the SOL. Without intervention, the SOL relies more on reflexive loops than cortical input for activation, causing the muscle to be in a constant “on” state as a postural control muscle. After the EMG-BF, cortical inputs to SOL significantly decreased compared to the control group, potentially representing turning the muscle “off.” The SOL (a plantarflexor that performs ankle extension) is regulated by the medial reticulospinal tract, which activates extensor muscles and inhibits flexor muscles to keep the body erect, suggesting that changes to the tract would not be evident by measuring cortical excitability (Patestas & Gartner, 2006).

Multiple hypotheses could support why the change from postural to phasic would occur. First, reciprocal inhibition of the soleus may serve to facilitate TA and PL activation. Matsugi et al. evaluated SOL Ia presynaptic inhibition and reciprocal inhibition after cerebellar TMS and found that cerebellar TMS facilitated a decrease in Ia presynaptic inhibition, but not reciprocal inhibition (Matsugi et al., 2015). Seeing as the SOL plantar-flexes the foot, while the TA dorsi-flexes and inverts, and the PL plantar-flexes and everts the foot, it would be a logical hypothesis

that the SOL cortical inputs would be down-regulated, in effect, enhancing TA and PL activation without changing their cortical excitability.

Another theory could be that the SOL became fatigued with the balancing tasks. Crupi et al. have demonstrated that protracted exercise can decrease primary motor cortex excitability, even when subjects did not experience acute neuromuscular fatigue (Crupi et al., 2013). While fatigue should have theoretically been similar across groups, the H-Reflex data show that the EMG-BF facilitated PL contraction through the SOL. Thus, the additional awareness of the PL and SOL muscles could have lead to increased fatigue in the SOL. Anecdotally; many subjects complained that metabolite buildup was occurring in the SOL during the single-leg static balance task. As such, Coco et al. demonstrated an inverse relationship between lactate buildup and MEP amplitude in a fatigue task (Coco et al., 2014). This data may also serve as evidence that the rest period was not long enough to overcome fatigue.

Finally, the motor cortex is not the only brain area that is responsible for postural control. The basal ganglia and cerebellum are two brain areas influential in maintaining balance. Taube et al. showed that a decrease in cortical excitability occurred after balance training; however, they include in their discussion that other studies have shown an increase in cortical excitability during skill acquisition and a decrease in cortical excitability during the automatization phase with subsequent training (Floyer-Lea & Matthews, 2004; Muellbacher et al., 2001; Pascual-Leone et al., 1994; Puttemans et al., 2005). Furthermore, activity of the cerebellum and basal ganglia increased; however, the present study did not obtain intermediate cortical excitability measurements, so I can only speculate that neural control may have been increasingly regulated to subcortical areas (Floyer-Lea & Matthews, 2004; Puttemans et al., 2005).

Clinically, EMG-BF combined with training could be beneficial in the treatment of patients with dystonia. In *The Dystonia Patient: A Guide to Practical Management*, the authors recommend that EMG-BF be used by physical therapists as an intervention to train patients to inhibit erroneous muscle contractions at rest and during movement, facilitate posture and positioning, and as an aid for pain management (Okun, 2009). It is specifically recommended for patients with cervical dystonia to both reduce spasms in agonists and enhance activation of antagonists. Dystonia in the lower extremity often manifests as plantar flexion and eversion of the foot; however, adult-onset lower extremity dystonia is rare and has not been well studied (Okun, 2009). Our findings indicate that using EMG-BF with training decreased cortical excitability to the SOL, potentially activating reciprocal inhibition to activate the PL and TA. Since dystonia manifests as plantar-flexion and eversion, turning the SOL “off” to enhance the effect of the TA could be a beneficial addition to antagonist-strengthening protocols.

## **Conclusion**

EMG-BF combined with short-term balance training created a decrease in cortical excitability to the SOL, and effectively generated an increase in PL reflexive excitability. Patients with dystonia typically suffer from excessive plantarflexion and eversion of the foot. Since this training protocol caused changes in the way the SOL behaves, this information could be utilized to enhance the TA through reciprocal inhibition. While this study utilized EMG-BF to increase subject awareness to the PL to facilitate contraction in healthy populations, perhaps EMG-BF could be used to increase patient awareness to erroneous sustained contraction to the PL and facilitate decreased contraction. More research is still needed to establish consistent protocols to achieve the desired effects; however, EMG-BF with balance training could

potentially be useful to clinicians for treating foot-drop disorders in patients with dystonia of the lower extremity.

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