The Effect of a Short Foot Eccentric Endurance Exercise on Foot Center of Pressure: A Pilot study

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PURPOSE: This study aimed to investigate the effect of a 5-week short foot eccentric endurance training program on the foot center of pressure measures in healthy university graduate students.

METHODS: Eleven healthy students between the ages of 18 and 35 years ($n=11$, 3 males, 8 females; mean age 26.5 ± 2.5 years; BMI 23.9 ± 2.6 kg/m²) were included in the study. The participants volunteered in a 5-week progressive eccentric contraction short foot exercise program performed three times per week. The main outcome pressure measurements pre- and post-intervention in static double leg stance were measured using a MatScan® Pressure Mapping System.

RESULTS: Statistically significant differences were found in the base of support ($p=.002$, $ES=2.59$), time to boundary ($p=.024$, $ES=1.63$), and overall minima measures ($p=.05$, $ES=1.36$) pre- and post-intervention.

CONCLUSIONS: A 5-week progressive eccentric contraction short foot exercise program significantly decreased the center of pressure excursion measures, demonstrating improved postural control.

Key words: Intrinsic foot muscles, Short foot, Exercise, Eccentric

INTRODUCTION

The foot is a complex structure with multiple articulations, degrees of freedom, along with extrinsic and intrinsic muscles that play an important role in static posture and dynamic activities [1]. Components of the intrinsic foot muscles (IFM) are the Abductor hallucis (Abdh), flexor digitorum brevis, quadratus plantae and flexor hallucis brevis muscles. The IFM help contribute to foot arch stability under loads that are routinely seen with ambulation [2-5]. During adaptation to ambulation over irregular ground, the IFM provide afferent information and a stable base for balance when loading the foot, and in transmission of force during propulsion [2-4]. Deficiencies in IFM may result in foot overpronation contributing to a number of musculoskeletal conditions such as patellofemoral pain, medial tibial stress syndrome, posterior tibialis tendinopa-

thy plantar fasciitis and chronic ankle instability [6-8].

Numerous musculoskeletal pathologies have been associated with deficits in IFM activation [1]. An exercise showing promise in emphasizing the plantar IFM is the short foot exercise (SFE) [9]. The SFE pulls the metatarsal heads towards the calcaneus without flexing the toes which engage the extrinsic muscles surrounding the foot. The Abdh is a specific intrinsic foot muscle positioned medially and has a mechanical advantage in maintaining the medial longitudinal arch, making it a target for training [2]. When the Abdh muscle suffered from fatigue, the navicular drop measure significantly increased [10]. The SFE demonstrated being more effective than other commonly used exercises in activating the Abdh muscle [11] and decreasing navicular drop measures for 4-weeks post-exercise cessation [12].

During gait activities, the IFM function eccentrically at the midstance

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Received 29 Jan 2021 Revised 22 Jul 2021 Accepted 25 Jul 2021

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phase to absorb energy from loading and shorten at toe off to assist in propulsion [5]. Focusing on eccentric activities of the IFM through specific exercises, such as the SFE, may provide an increase in foot stability and improve postural control. This is relevant, as it was suggested that eccentric exercise-induced adaptations include muscle hypertrophy, increased cortical activity, and changes in motor unit behavior, all of which contribute to improved muscle function [13]. Center of pressure (COP) measurements can be acquired using a MatScan pressure mat which has demonstrated acceptable validity [14] and reliability [15]. Specific measures using COP provide outcome data useful for determining the degree of postural stability. A measure such as time-to-boundary (TTB) suggests the estimated time it takes for the center of pressure to reach the boundary of the base of support (borders of feet) [16].

The SFE can be viewed as a foundational exercise for foot and ankle rehabilitation similar to how the abdominal drawing-in maneuver is foundational to lumbar spine motor control [1]. Advancing the effectiveness of exercise interventions that optimally provide restraint to the extent and rate of medial longitudinal arch deformation during the stance phase of gait where the IFM are acting eccentrically is critical. The short foot eccentric endurance exercise may have a significant effect on the prevention and treatment of pronation-related musculoskeletal conditions. To date, studies inquiring the effect eccentric endurance training of the IFM has on postural control measures have not been conducted. Therefore, the purpose of this study is to investigate the effect a 5-week short foot eccentric endurance program has on COP measures in healthy, University students. Based on previous inquiry regarding the SFE [9-12], we hypothesize that this intervention will have a significant effect on COP measures consistent with improved postural control.

METHODS

A nonrandomized, pre-post intervention study was conducted where the independent variable was time of endurance exercise program consisting of the SFE with a focus on the eccentric muscle action phase of the movement. The exercise was performed with a device created to help provide resistance only during the eccentric phase of the SFE. The outcome data consisted of COP measurements from the MatScan® Pressure Mapping System.

1. Participants

Eleven healthy, University graduate students between the ages of [18-

35] were included in this study. The participants were recruited from an allied health profession campus ($n=11$, 3 males, 8 females; mean age of 26.45 ± 2.53 years; BMI $23.85 \text{ kg/m}^2 \pm 2.56$). Exclusion criteria were the following: Surgical procedure of the lower extremities performed within the past 12 months, fracture in either lower extremity within the past 12 months, an injury to the knee or hip in the previous 3 months that forced limitation of physical activity for at least 2 days, a current injury to either leg that caused swelling, discoloration, heat, pain, or loss of range of motion or strength, pregnancy, or a diagnosis of a vestibular disorder, Charcot-Marie-Tooth disorder, Ehlers-Danlos disorder or other nerve or connective tissue disorders. One participant dropped out following one intervention session citing scheduling conflicts and time constraints. Participants who met the inclusion criteria provided informed consent. Data was collected in a University laboratory. The study was approved by the University Institutional Review Board.

2. Testing Procedures

Participants provided demographic information, including age, gender, health and injury history. Height and weight measurements were taken with a physician's balance beam scale with height rod. Center of pressure was measured while the participants were instructed to assume a relaxed, static, double leg stance on the MatScan® Pressure Mapping System (TekScan Inc., South Boston, MA) ($\text{ICC}=0.77-0.95$) [17].

The intervention procedure began with the participants being verbally instructed, provided demonstrations, and guided through ten practice repetitions of the eccentric SFE without the device created to provide resistance. The device used for the exercise was comprised of one Harbinger ankle strap, 2 in. twisted and braided nylon rope, 2 Coleman Deluxe Link hooks, and a variety of weightlifting plates (2.5 lbs., 5 lbs., and 10 lbs.). The nylon rope was cut to an appropriate length so that each end was able to be tied to each individual hook. The hook was then attached to the ankle strap and the other hook was placed through the center of weight plates and attached to the ankle strap to ensure that the added weight was easy to remove and add, as well as ensuring that the weight would not detach from the ankle strap. The participants were positioned in a non-weight bearing foot posture while seated on an electric high-low plinth with the dominant lower extremity placed in a hip to knee 90°/90° position. The dominant foot was placed on an elevated platform that allowed adequate room for the weighted plates to hang from the strap and not touch the floor. The dominant foot was positioned so that the lateral plantar aspect was on the platform while the medial plantar

surface of the foot was off the platform which is depicted in Fig. 1.

The participants were provided with verbal cues in order to emphasize a three second duration of control during the eccentric phase of the exercise while allowing the investigator (sec) to passively position the foot with the IFM and medial longitudinal arch in a shortened position to prevent the performance of the concentric phase of the traditional SFE. The participants began with a resistance between 10 and 12.5 lbs. Once thirty repetitions were accumulated with a weight, 2.5 lbs. would be added to the device. The repetition goal range was between twenty and thirty for 3 sets per session. The participants were instructed to complete as many repetitions as possible until failure, cramping or fatigue causes

completion of the set.

3. Statistical analysis

The statistical analysis was computed using Microsoft Excel (Microsoft Corporation, Redmond, WA) and SPSS (version 20.0; IBM Corporation, Armonk, NY) with a pre-determined alpha level of 0.05 ($p = 0.05$) [18]. A paired sample t-test was applied at the conclusion of the intervention. The paired sample t-test compared relaxed, static double leg stance pre-intervention foot center of pressure using the Matscan® Pressure Mapping System to post-intervention values. Effect size were calculated using a Cohen d and interpreted as small (≤ 0.10), medium (0.11-0.39), and large (≥ 0.40) [18].

RESULTS

Significant differences were present in BOS ($p = .002$, $ES = 2.59$), TTB ($p = .024$, $ES = 1.63$) and in total minima ($p = .05$, $ES = 1.36$) between pre and post intervention values. The differences in pre- and post-intervention values are summarized in Table 1.

DISCUSSION

The purpose of this study was to inquire the effect a 5-week SFE eccentric endurance program would have on center of foot pressure measures with healthy, University graduate students. As hypothesized, significant differences were present in BOS ($p = .002$), TTB ($p = .024$) and in total minima ($p = .05$) between pre and post intervention measures demonstrating improved postural stability.

The theoretical role of the intrinsic foot muscles in function has been suggested by inquiry of muscle activation using fine wire EMG [4,5]. A study assessing the IFM activation response to increases in postural challenge found the recruitment of these muscles increase going from a double to single stance [4]. It was also interesting to note that the peaks in muscle activation occurred prior to the recording of medial COP ex-

Fig. 1. Exercise Foot Position.

Table 1. Statistical Analysis Results

Outcome	Mean	Standard Deviation	Standard Error Mean	95% CI of the Difference		t	df	Sig. (2-tailed)
				Upper	Lower			
BoS (in ²) PRE – BoS (in ²) POST	40.3	30.6	9.7	18.4	62.2	4.2	9	0.002*
Min. TTB (L-R) PRE – Min. TTB (L-R) POST	2.4	2.8	0.9	0.4	4.5	2.2	9	0.024*
Total Minima PRE – Total Minima POST	-62.8	87.7	27.7	-125.5	-0.05	-2.3	9	0.05*

*Significantly different ($p < 0.05$).

BoS, Base of Support; TTB, Time-to-Boundary.

cursions [4]. This evidence would suggest a possible central, feedforward motor control mechanism to activate the foot core muscles as an anticipatory postural adjustment providing foot stability in preparation for postural challenges. Other research investigated the activation of IFM during gait [5]. It was found that the intrinsic muscles provided a stiffening effect during gait and were the primary factor in creating a rigid link to effectively propel during the push-of phase [5].

Research specific to the SFE demonstrated it achieved greater activation of the Abdh muscle than other traditional foot core strengthening exercises [11]. Additionally, it was found that the Abdh muscle (eccentric action) increases in activation possibly providing a bolstering effect to support the longitudinal arch that is responsible for slowing the rate of pronation [19]. A study comparing the effect the SFE and toe-curl exercise have on COP found the SFE training program decreased medial-lateral movement of COP significantly more than a toe curl training program on the nondominant leg during a dynamic-balance task [20]. It was argued that the SFE was more effective in isolating the IFM than the toe-curl which includes extrinsic muscles [19]. Other studies [21,22] have found significant improvements in both antero-posterior and mediolateral stability after SFE training with hyperpronated and chronic ankle instability participants respectively, using dynamic balance testing. These results are similar to our findings. Another study [23] compared the effect the SFE with a visual feedback gauge had on healthy vs. hyperpronated populations using a static balance Metscan instrument, as used in this study. The findings were an improvement in sway area with the hyperpronated group only. These results would suggest the SFE may only be effective in populations of foot core strength deficiencies, however, the small population may have minimized the power of the study and influenced the findings. With our study, participants suffering from hyperpronation is unknown but the consistent improvement in postural sway throughout the population may suggest an emphasis on the eccentric muscle action, as in our protocol, could facilitate greater muscle stiffness and postural improvement then the traditional SFE regardless the foot posture.

Several theoretical mechanisms in postural stability improvement from the SFE have been suggested. With an increase in joint position sense found after a SFE protocol [22], the exercise may stimulate the IFM proprioceptors resulting in an increase in sensory input followed by accurate and efficient motor activation. Another theory [22] is the increased integrity of the medial longitudinal arch secondary to the SFE resulting in a restraint from a medial shift of the COP during arch col-

lapse and increased postural control. With this study, in theory, the mechanism for improvement in postural stability was most likely secondary to an increase in foot core stability. In turn, greater stability provided by the IFM may facilitate minimizing medial longitudinal arch deformation during weight bearing. Additionally, this exercise not only targets the IFM but emphasizes the eccentric muscle action. Consequently, it could be argued this type protocol may also be effective in lowering the rate of loading during the midstance phase of gait.

There were several limitations to this study. The population was limited, reducing its power. An a priori sample size estimation was performed (G*Power, Version 3.1.5, Universität Kiel, Kiel, Germany) with statistical power = 0.80, $p \leq 0.05$ for the future study. Eight participants will be needed with effect size 1.29 using mean and standard deviation data presented in the current study. The training protocol in this study asked each participant to go to failure with each set. The ability to continue the exercise may vary per individual causing inconsistency in training intensity between participants. Activity levels outside of the training protocol were not monitored or controlled and there was not a control group included in this study. The concentric phase of the SFE was assisted by the authors manually, which may not have been universal for all repetitions.

CONCLUSION

An eccentric IFM endurance exercise protocol appears to increase postural stability in the frontal plane in University graduate students indicated by COP measures. These results suggest using this exercise may be beneficial for populations engaged in activities challenging balance and postural control.

Further investigation into this exercise is recommended using RCTs with additional outcome measures using various populations.

CONFLICT OF INTEREST

The authors declare no conflict of interest. All authors indicate that no benefits in any form have been received or will be received from a commercial party related directly or indirectly to the participant of this article.

AUTHOR CONTRIBUTIONS

Conceptualization: J Schilling, JP Ko; Data curation: B Gragston, B

Dunlvey; Formal analysis: J Schilling, JP Ko; Methodology: B Gragston, B Dunlvey; Project administration: J Schilling, JP Ko; Visualization: J Schilling, JP Ko; Writing-original draft: B Gragston, B Dunlvey; Writing-review & editing: J Schilling, JP Ko.

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