Differences in Static- and Dynamic-Balance Task Performance After 4 Weeks of Intrinsic-Foot-Muscle Training: The Short-Foot Exercise Versus the Towel-Curl Exercise

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Context: Proper functioning of the intrinsic foot musculature (IFM) is essential in maintaining the integrity of the medial longitudinal arch (MLA). Improper functioning of the IFM leads to excessive pronation of the foot, which has been linked to various pathologies. Therefore, training the IFM to avoid excessive pronation may help prevent some of these pathologies; however, it is not clear how to train these muscles optimally.

Objective: To investigate the effects of 2 different types of IFM training on the height of the MLA and static- and dynamic-balance task performance.

Setting: University biomechanics laboratory for testing and a home-based training program.

Participants: 24 healthy, university-age volunteers (3 groups of 8) with no history of major lower limb pathology or balance impairment.

Interventions: One experimental group performed 4 wk of the short-foot exercise (SFE) and the other performed 4 wk of the towel-curl exercise (TCE). Participants were asked to perform 100 repetitions of their exercise per day.

Main Outcome Measures: Navicular height during weight bearing, the total range of movement of the center of pressure (COP) in the mediolateral (ML) direction for a static-balance test and a dynamic-balance test.

Results: There were no differences in the navicular height or static-balance tests. For the dynamic-balance test, all groups decreased the ML COP movement on the dominant limb by a small amount (~5 mm); however, the SFE group was able to decrease COP movement much more than the TCE group in the nondominant limb.

Conclusions: The SFE appeared to train the IFM more effectively than the TCE; however, there were differing results between the dominant and nondominant legs. These imbalances need to be taken into consideration by clinicians.

Keywords: biomechanics, medial-longitudinal arch, Y balance test, foot pronation
the calcaneus and inserts distally into the tarsal joints, giving it an optimal angle of pull to provide a stabilizing effect on the MLA. This theory is supported by research that has inhibited the IFM either through a tibial-nerve block or through fatiguing exercise. Both of those studies observed a significant increase in navicular drop (a surrogate measure of the height of the MLA) after inhibition of the IFM. Therefore, it appears that the IFM plays an important role in the integrity of the MLA. It can then be hypothesized that adequate strength, endurance, and neuromuscular control of the IFM may be crucial to the support the MLA, while dysfunction of these muscles could predispose individuals to pronation-related injuries.

Strengthening of the IFM is therefore logical as a possible intervention to help prevent pronation-related injuries. Common methods used in an attempt to strengthen the IFM have previously involved toe-flexion exercises (eg, towel crunches or marble pickups). However, those exercises are believed to recruit more of the extrinsic foot musculature, such as the flexor digitorum longus, and make these muscles dominant over the IFM in supporting the MLA. Recently, the “short-foot” exercise has gained popularity among clinicians due to claims that it may recruit the IFM independently of extrinsic foot musculature. Essentially, the short-foot exercise involves drawing the heads of the metatarsals toward the calcaneus without curling the toes. Isolation of the IFM using the short-foot exercise could potentially be a more effective method to reinforce the MLA. Although this concept makes sense intuitively, we are unaware of any research comparing the 2 methods of IFM training (toe-curl vs short-foot). Therefore, the purpose of this study was to compare the effects of traditional IFM-strengthening exercise (towel curls) with those of the short-foot exercise during both static and dynamic single-leg balancing tasks. Clinicians can use this information to better guide their efforts when designing lower extremity rehabilitation programs.

Methods

Design

A randomized controlled trial was used in this investigation. Participants were asked to come to the laboratory for initial testing, after which they were randomly assigned to 1 of 3 groups: a short-foot exercise (SFE) group, a towel-curl exercise (TCE) group, or a control group. After the intervention period, all participants were asked to return for subsequent testing. The independent variables were time (pre vs post) and group (SFE, TCE, control). The dependent variables were range of the mediolateral (ML) movement of the center of pressure (COP) during static and dynamic-balance tests, along with a modified version of the navicular drop test as only standing navicular height was measured before and after the exercise intervention.

Participants

Thirty healthy participants volunteered for this study (15 male and 15 female, age 23.0 ± 1.6 years, height 1.72 ± 0.66 m, mass 68.2 ± 9.8 kg). After the initial testing the participants were assigned to 1 of 3 groups (SFE, TCE, control) of 10 participants each. However, 2 participants in each group (6 total) did not return for follow-up testing and were dropped from the study. The participants who were dropped either did not complete their required exercises during the intervention period or could not return for follow-up testing 5 weeks after their initial test. It should be noted that the reasons for dropout were not related to the study. Information for those who completed the study in each group is presented in Table 1.

All participants reported no history of lower extremity or low back injury in the last 6 months, nor had they ever been diagnosed with a neurological condition that would hinder their ability to balance. The study procedures were approved by the institutional review board, and all participants read and signed an informed-consent form before participation.

Instrumentation

During both the static- and dynamic-balance tests, participants stood with the test foot on an AMTI (Newton, MA) forceplate that was covered with an artificial turf surface. The plate measured the position of the COP on the plate. Tape was placed along the x-axis of the forceplate, and it was ensured that participants stood with their foot aligned straight along this tape line. This ensured that any movement of the COP in the y direction of the forceplate corresponded to ML movement of the COP under the foot.

There was also a single retroreflective marker placed on top of the participant’s moving foot during the dynamic-balance task so that different phases of these trials could be identified and any excess frames before or after the actual balance test could be cut. The position of the retroreflective marker was captured with a 9-camera Qualisys (Gothenburg, Sweden) Oqus 300 motion-capture system. Marker motion data (at 100 Hz) along with forceplate data (at 2000 Hz) were collected simultaneously using Qualisys Track manager (QTM) software (Gothenburg, Sweden).

Table 1 Participant information for the Short-Foot-Exercise (SFE), Towel-Curl-Exercise (TCE), and Control Groups, Mean (SD)

<table>
<thead>
<tr>
<th>Group</th>
<th>Age, y</th>
<th>Height, m</th>
<th>Mass, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFE, 3 men and 5 women</td>
<td>23.7 (2.1)</td>
<td>1.72 (0.10)</td>
<td>69.9 (9.8)</td>
</tr>
<tr>
<td>TCE, 4 men and 4 women</td>
<td>22.8 (1.2)</td>
<td>1.69 (0.13)</td>
<td>66.0 (11.2)</td>
</tr>
<tr>
<td>Control, 3 men and 5 women</td>
<td>22.6 (1.7)</td>
<td>1.74 (0.10)</td>
<td>68.8 (9.4)</td>
</tr>
</tbody>
</table>
Procedure

During the initial visit, the participants’ age, height, and weight were recorded and they were asked which limb was their dominant limb (the limb with which they would kick a ball). After this, MLA height was measured for both feet using a modified version of the navicular drop test. The navicular tuberosities were palpated and marked on the foot with a marker. The height of the navicular tuberosity above the floor was then measured with the participant standing, legs straight, and an equal amount of weight on both feet. The same examiner performed all these measurements to eliminate the potential for interrater variability, and previous research has demonstrated good reliability for measuring navicular height.

Participants were then asked to perform 2 balance tests (static and dynamic) while standing in single-leg stance on the forceplate. Three trials were performed on both legs for both tests, and the order of the trials was randomized. For the static-balance test, participants stood on 1 foot for 30 seconds. They were instructed to keep their hands on their hips and to stare at an X marked on the wall in front of them. The trial was considered invalid if the participant’s arms came away from the body or if the other foot touched the ground, in which case a replacement trial was performed.

For the dynamic-balance test, participants performed the Y balance test (a modification of the Star Excursion Balance Test) using the methodology outlined by Plisky et al. Previous research has demonstrated good reliability (ICC = .67–.87) of this test. Participants were asked to stand on 1 foot while reaching with the other leg out in 3 different directions in the following order: anterior, posterolateral, and posteromedial (Figure 1). They were asked to reach a distance equal to a percentage of their leg length (floor to greater trochanter) based on previously published data of average reach distances in each of these directions for a similar sample population. This was to ensure that the task was the same for both preexercise and postexercise testing for each participant. The distance from the floor to the greater trochanter was measured, and then tape was placed on the floor at a specified percentage of that distance (depending on gender and direction of movement) in each direction. The participant was then asked to reach the foot over the top of the tape without touching the ground, then return to the starting position before reaching in the next direction. If the participant did not reach the tape mark in any direction, if the moving foot touched the ground, or if the heel of the stance foot came off the ground, the trial was repeated. A structured practice protocol was not used, as participants were given practice ad libitum, with most subjects practicing the task 1 or 2 times. Once the participant indicated he or she was

![Figure 1](https://example.com/figure1.png)

**Figure 1** — The modified Star Excursion (Y-Balance) Test. Subject reaches in the (A) anterior, (B) posteromedial, and (C) posterolateral directions.
comfortable with the task, data were collected on the next 3 trials on each limb. The order of limb tested was randomized for all participants.

Previous studies investigating balance have focused on the path of the COP to evaluate performance, with less dispersion of the COP considered to be a better performance. In addition, because the current study concentrated on the maintenance of the MLA with the IFM, only the ML dispersion of the COP was examined, as pronation and supination of the foot would show up as ML movement of the COP on the forceplate. The maximum and minimum values achieved in the position of the ML COP during each balance test were found and subtracted from one another (max ML COP – min ML COP). The resulting value represents the total range of movement of the COP in the ML direction during these balance tests. Since this study investigated the ability of the IFM to maintain the integrity of the MLA, this measure is most relevant. For each participant, the total ML COP movement distances from the 3 trials were averaged to give 1 score for each limb in the 2 balance tests.

After the processing of the initial test data, participants were randomly divided into 1 of 3 groups: SFE, TCE, or control. A one-way ANOVA demonstrated no significant differences between the 3 groups before the exercise intervention.

The SFE and TCE groups were instructed to return to the laboratory 1 week after initial testing to receive training on exercises that were to be performed during the training phase of the study. The SFE participants were instructed to raise the MLA of the foot by drawing in the metatarsal heads toward the calcaneus without flexing the toes and holding an isometric contraction for 5 seconds during each repetition. The TCE participants were instructed to place a towel on a slick surface (tile, hardwood floor, etc) and place their toes on the edge of the towel. They were then instructed to drag the towel under their foot by flexing their toes, generating a strong grip on the fabric for 5 seconds per repetition.

Participants in both the SFE and TCE groups were instructed to perform 100 repetitions of their prescribed exercise on a daily basis for 4 weeks. This protocol was based on previous work. These exercises were also progressed for both groups during the intervention period to increase the difficulty of the prescribed exercise as participants become more familiar with them. In the first 2 weeks, participants performed their prescribed exercise in a seated position. In the third and fourth weeks, they performed it in a standing position. Participants in the 2 exercise groups were contacted by phone once a week to check on their progress and were asked to return to the laboratory before the start of the third week to receive instruction on the next progression (exercise while standing). All participants were then asked to return to the laboratory 5 weeks after their initial testing session to be retested on all dependent measures. Testing procedures during the follow-up testing were identical to the initial testing, and the order of trials was again randomized.

Data Analysis
All data were analyzed using Predictive Analytics SoftWare (PASW) Statistics version 18.0 (SPSS Inc, an IBM Co, Chicago, IL). Mixed-model repeated-measures ANOVAs were used on each dependent variable or leg, with the within-subject factor being the time (pretesting vs posttesting) and the between-subjects factor being group (SFE, TCE, control). If there was a main effect for time and also a significant interaction (time × group), post hoc tests in the form of repeated-measures T-tests were run on individual group data to determine in which groups there were differences between pretesting and posttesting. The level of significance for all statistical tests was set at $P < .05$ for the main effect and interactions. To adjust for the 3 comparisons made on each variable for post hoc testing, a Bonferroni correction was used ($P < .017$).

Results
All results (means, SDs, and effect sizes) are shown in Table 2. Significant main effects for time were observed in the dynamic-balance test only (both the dominant and nondominant legs). There were no main effects in the static balance test—dominant leg $P = .309$, nondominant leg $P = .650$. There were also no main effects in navicular height during static standing—dominant leg $P = .264$, nondominant leg $P = .752$.

For ML COP movement during the dynamic-balance task on the dominant-leg side, there was a significant main effect ($P < .01$) but no interaction ($P = .812$). Therefore, all 3 groups (control group included) had a significant decrease in the amount of ML movement of the COP after the intervention or control period. Although there were statistical differences in each group, the effect sizes were all in the small to moderate range. However, for the dynamic-balance test in the nondominant limb, there was a significant main effect ($P < .01$) and a significant interaction ($P = .02$). T-tests then revealed that only the SFE ($P < .017$) and TCE ($P < .017$) groups had a significant decrease in ML COP movement after the intervention, while there was no difference in the control group ($P = .906$). It should also be noted that the effect size of the change in the TCE group was similar to the changes seen in the dominant side limb (ie, small), while the effect size of the change in the SFE group was much larger.

Discussion
The main findings of this study were as follows: (1) The results of the static-balance test and navicular-height test were not affected by training the IFM, (2) in the dominant limb, we observed a small improvement in performance for all 3 groups during the second testing, and (3) in the nondominant limb, dynamic-balance test performance only improved in the 2 exercise groups, and the SFE group improved much more than the TCE group.
The static-balance test and the navicular height test were both performed with the participant remaining motionless and standing unilaterally and bilaterally, respectively. It appears that both of these tests are not difficult enough to reveal changes that may have occurred as a result of IFM training. Our results are similar to those of Dewes et al, in whose study a single group of participants with lower limb pathology performed an SFE intervention. In that study, there were no differences in any of the static measures after the intervention. Perhaps the muscle-activation requirements of the IFM during such simple tasks are so small that all participants have sufficient strength or neural drive to these muscles before performing the exercise intervention. Therefore, it appears that if future studies want to investigate the effects of IFM training with a similar population, more challenging dynamic tasks need to be used to determine whether training programs are effective. However, it is not known whether static tasks would be sufficient to reveal differences in older or pathological populations.

The results of the dynamic-balance task were interesting, as the dominant and nondominant limbs responded differently to the intervention protocol. The results on the dominant-side limb were unexpected, as all groups, including the control group, had a small improvement (less movement of ML COP) after the intervention period. In addition, the magnitude of improvement was relatively similar across all 3 groups, indicating that the IFM exercises (SFE, TCE) had an effect on performance similar to that of doing no exercises (control group). This may signify that in a population of young, healthy individuals, the dominant-side limb IFM is capable of functioning properly and may not require direct IFM training to improve performance. This explanation would suggest that simply performing complex dynamic tasks in single-limb stance may provide sufficient stimulus to improve the performance of the IFM in the dominant-side limb. It could also be that the dynamic-balance task used in this study was not challenging enough to reveal differences in the dominant-side leg. Perhaps even more dynamic tasks such as running, cutting, or jump landings would be needed to reveal differences in the dominant-side limb of a young, healthy, active population.

In the nondominant limb, the results of the dynamic-balance test were in accordance with the ideas suggested by Newsham. There was no change in the control group across the intervention period, while both the SFE and TCE groups had a significant improvement. This may indicate that the IFM was not performing adequately in the nondominant limb in these participants, and they

### Table 2  Average Mediolateral (ML) Center-of-Pressure (COP) Movement and Navicular Height for the 3 Groups Before and After the Exercise Intervention or Control Period, Mean (SD)

<table>
<thead>
<tr>
<th></th>
<th>Dominant Stance Leg</th>
<th>Nondominant Stance Leg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preintervention, mm</td>
<td>Postintervention, mm</td>
</tr>
<tr>
<td>Dynamic balance</td>
<td></td>
<td>Effect size&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>ML COP movement all</td>
<td>51.0 (5.1)</td>
<td>46.9 (5.1)&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>short-foot exercise</td>
<td>53.4 (6.2)</td>
<td>49.3 (7.1)&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>towel-curl exercise</td>
<td>48.1 (2.1)</td>
<td>44.8 (2.6)&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>control</td>
<td>51.4 (5.1)</td>
<td>46.7 (4.2)&lt;sup&gt;‡&lt;/sup&gt;</td>
</tr>
<tr>
<td>Static balance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ML COP movement all</td>
<td>37.8 (5.5)</td>
<td>39.0 (5.2)</td>
</tr>
<tr>
<td>short-foot exercise</td>
<td>37.5 (3.8)</td>
<td>40.3 (6.1)</td>
</tr>
<tr>
<td>towel-curl exercise</td>
<td>38.1 (4.4)</td>
<td>38.2 (5.5)</td>
</tr>
<tr>
<td>control</td>
<td>37.7 (8.1)</td>
<td>38.7 (4.3)</td>
</tr>
<tr>
<td>Navicular height</td>
<td></td>
<td></td>
</tr>
<tr>
<td>all</td>
<td>41.8 (6.6)</td>
<td>40.9 (5.0)</td>
</tr>
<tr>
<td>short-foot exercise</td>
<td>44.7 (3.2)</td>
<td>42.9 (4.6)</td>
</tr>
<tr>
<td>towel-curl exercise</td>
<td>39.5 (8.3)</td>
<td>39.5 (5.8)</td>
</tr>
<tr>
<td>control</td>
<td>41.3 (7.0)</td>
<td>40.9 (4.3)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Effect size = (post mean – pre mean)/(pre SD).<sup>25</sup>

<sup>*</sup>Significant main effect (P < .05) for time (pre vs post). †Significant interaction (P < .05) time × group. ‡Significant paired-samples T-test with Bonferroni correction (P < .017).
needed focused training to improve performance. In most people, the right leg is the dominant leg and the left leg is the nondominant leg, so this result accentuates the need for clinicians to identify and correct right–left imbalances.

The identification and correction of right–left imbalances in the IFM may have effects in decreasing injury rates in other joints, as well. This is supported by research demonstrating a strong trend (P = .06) toward more noncontact anterior cruciate ligament (ACL) injuries in the left leg than the right in females. Many studies have also linked excessive pronation to an increased risk of noncontact ACL injury, but those retrospective studies could not determine if the excessive pronation preceded or was a result of the ACL injury. However, the fact that increased pronation results in increased valgus loading of the knee and increased tibial translation suggests that those who pronate excessively may be at increased risk of ACL injury. Clearly, future research needs to elucidate the relationship between limb asymmetries, IFM function, and lower extremity injury.

While both the SFE and TCE groups improved after the intervention in the nondominant leg, the SFE group had a much greater improvement, as they were able to decrease ML COP movement by an average of 9.3 mm. In comparison, the TCE group only decreased the movement of the ML COP by an average of 3.6 mm. The change seen in the SFE group has an effect size with a “large” magnitude of change, compared with the TCE, for whom the effect size indicated only a “small” magnitude of change. This suggests that the SFE was more effective in training control of the MLA than the TCE in the nondominant limb. This could be due to the explanation suggested by Newsham: that the SFE isolated the IFM much better, while the TCE involves a large contribution from the extrinsic muscles such as the flexor digitorum longus. However, it should be noted that although this decrease in ML COP movement is statistically significant and has a large effect size, the clinical significance of the change is unknown. Future research should examine whether the magnitude of change that is induced with IFM training could produce positive clinical outcomes.

Several studies have examined the difference between the dominant- and nondominant-side lower limbs in various tasks with mixed results. Some found superior performances in the dominant limb, others found superior performances in the nondominant limb, while still others found no differences between limbs for various different tasks. This may be due to the populations selected in each of these studies. If participants regularly perform unilateral activities on the same side of the body as part of their fitness regimen, sporting activities, or simple activities of daily living, this could lead to more imbalances between the dominant and nondominant sides. Clearly, further research is required to determine how muscle functions and movement patterns differ between limbs in a variety of populations so that this can be related to a better understanding of injury mechanisms, which can then be used to develop better injury-prevention strategies and rehabilitation exercise prescriptions.

This study had several limitations that include the relatively small sample size and short intervention period (4 weeks). We also assumed that the static structure of the foot would not change after the intervention, so we did not measure the unloaded navicular height needed to calculate navicular drop as was done by Fiolkowski et al. In addition, a structured practice protocol was not used for the Y balance test, and data regarding participants’ normal activity patterns or injuries that occurred more than 6 months before participation in the study were not collected.

**Conclusion**

It appears that the SFE is more effective than the more traditional TCE at training the IFM to maintain the height of the MLA during dynamic-balance tasks. However, the results differed between the dominant and nondominant limbs, as simply practicing some complex single-limb balance tasks on the dominant limb improved performance in all groups. Therefore, clinicians should be careful to identify imbalances between limbs in terms of IFM function and attempt to remedy this with exercise. It appears that an effective training program for the IFM in a young, healthy population should include both the SFE and complex single-limb balance tasks to ensure the best results.

**References**


