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Difference in static and dynamic stability between flexible flatfeet and neutral feet

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ABSTRACT

Different postural stability may be a contributor to secondary injuries in individuals with flexible flatfeet (FF) compared to those with neutral feet (NF). However, the differences between static and dynamic stability of FF and NF have not been examined. This study compared the static and dynamic stability of subjects with FF and NF and investigated the relationship between static and dynamic stability. Twenty-eight subjects (14 each in the FF and NF groups) performed three tasks (single leg standing with eyes open, with eyes closed, and the Y balance test). We quantified the center of pressure (COP) speed and Y balance test score (Y score) within the tasks. COP speed was significantly greater in the FF group than in the NF group under both conditions (eyes open and closed) and directions (anteroposterior and mediolateral). Y scores did not differ significantly between the two groups. No significant relationship was observed between the COP speed and Y score in either group. These results show that individuals with FF have different static stabilities, but not dynamic stabilities, compared with those with NF. This might indicate the absence of a relationship between static and dynamic stabilities.

1. Introduction

A low medial longitudinal arch during weight bearing status is a morphological characteristic of flexible flatfeet (FF) [1]. Although FF is morphologically different from neutral feet (NF), many studies have found secondary characteristics of FF. The low arch may cause mechanical imbalance such as tibialis posterior tendon dysfunction [2], pain [3,4], joint injuries, and even stress fractures [5].

One contributor to these secondary characteristics may be related with postural stability. Static stability is defined as the ability to minimize movement of the center of gravity within the base of support under a given condition [6]. Center of pressure (COP) has been used to characterize static stability [1]. Specifically, COP speed has been used to indicate the extent of sway moment during a task and has been suggested as the most sensitive COP variable for detecting the extent of sway [7].

Authors have hypothesized that FF and NF show different postural stability. Hertel et al. [8] supported this hypothesis by showing that subjects with FF have a greater COP area and faster COP velocity than those with NF. In contrast, Cote et al. [9] found no significant difference in the center of balance or postural sway between subjects with FF and NF. Tsai et al. [10] reported that subjects with FF have a significantly greater COP maximum displacement and standard deviation in the anteroposterior (AP) direction than those with NF, but not in COP average speed. Hence, a general consensus is lacking in terms of the difference in COP between FF and NF.

Tsai et al. [10] reported that FF might induce a loss of balance when individuals are required to stand unilaterally during functional activities. However, Cote et al. [9] suggested that only small differences in dynamic stability were observed between FF and NF as measured by the Star excursion balance test. Although other studies have used the test to compare pre- and post-data in subjects with FF [11,12], they did not compare their results with data of subjects with NF. Therefore, comparisons between FF and NF are needed to reveal functional differences in postural stability.

Furthermore, it is necessary to establish a relationship between static and dynamic stability. Since the both assessments require

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much time and effort from the investigators and are physically draining for the subjects, recent studies have investigated their relationship to verify whether one can be used as a proxy for the other [13,14]. However, there is still a lack of research on the relationship between COP speed and Y balance test score.

Therefore, the aims of this study were: to (1) compare static stability (COP speed) between FF and NF, (2) compare dynamic stability (Y score) between FF and NF, and (3) investigate the correlation between COP speed and Y score. We hypothesized that there would be (1) a difference in COP speed, (2) but not in Y score; therefore, (3) no relationship would be detected between COP speed and Y score.

2. Methods

2.1. Subjects

Sample size was calculated using the G*power 3.1.5 (Franz Faul, Kiel, Germany) based on our pilot experiment data. A required sample size of 12 was determined by achieving an estimated effect size of 1.89, alpha level of 0.05, and power of 0.80. Consequently, 28 individuals (14 in each of the two groups) were recruited.

Navicular drop (ND) and resting calcaneal stance position (RCSP) were measured for group allocation. ND was quantified as follows: while the subject was in the sitting position, an examiner gripped the subject's subtalar joint to put it in neutral position. The examiner marked the skin over the navicular tuberosity with a dot and made a mark on an index ruler at the level of the dot relative to the floor. While in the relaxed bilateral standing position, the level of the dot relative to the floor was measured again and the second spot was marked on the ruler. The distance between the two marks on the ruler was recorded [9,15]. RCSP was quantified as follows: the examiner drew a bisecting line on the skin over the calcaneus of the subject in the prone position. While in the relaxed bilateral standing position on a 20-cm-high box, RCSP was quantified by measuring the angle between the bisecting line and the vertical line to the ground in the frontal plane using a goniometer [16–18].

The bony structure of the foot, specifically the navicular bone, functions as a vital support for the arch [19]. As one of the most extensively used clinical measures for foot type classification [20], ND provides the amount of vertical navicular excursion between subtalar joint neutral and standing positions [15] and serves as a composite measure of the mobility of the arch [21]. Also, RCSP has been evaluated to determine how much the calcaneus deviates from the vertical line [17]. In this study, the intra-rater test-retest reliability was determined for ND [intraclass correlation coefficient $(ICC)_{3,1} = 0.930$] and RCSP ($ICC_{3,1} = 0.826$).

The NF group included subjects whose feet had a 5–9 mm ND and a RCSP within 2° of inversion and eversion. The FF group included subjects whose feet had >10 mm of ND [9] and >4° of eversion in RCSP [16]. Subjects were excluded if they had <5 mm ND, non-symmetric feet [10], >10 mm discrepancy in leg length (*i.e.*, the distance between the anterior superior iliac spine and medial malleolus in the standing position) [22], continuous pain or surgery on a lower extremity within the past 6 months, an orthopedic malady, a neurological condition that affected the ability to maintain balance [11], more than 10 failures in the single leg standing position for 15 s, and engagement in training related to postural stability [10]. Except for ND and RCSP, no statistical differences in characteristics were observed between the groups (Table 1).

2.2. Measurements

A six-component force plate (AMTI-OR6-7-2000, AMTI, Inc., MA, USA) was used to assess static stability (COP speed) by recording ground reaction forces at a sampling rate of 1500 Hz. The Y balance test was used to assess dynamic stability (Y score).

Table 1
Participant characteristics.

Parameters	Flexible flatfeet	Neutral feet	p
No. of participants, feet	$n = 14$, 14 feet	$n = 14$, 14 feet	
Gender (men/women)	9/5	9/5	
Age (year)	22.8 ± 1.9[a]	23.6 ± 4.0	0.479
Height (cm)	170.8 ± 7.8	171.6 ± 7.5	0.788
Weight (kg)	62.5 ± 10.5	65.9 ± 14.2	0.473
BMI[b] (kg/m^2)	21.3 ± 2.1	22.2 ± 3.9	0.432
Foot width (mm)	89.9 ± 9.5	93.8 ± 9.9	0.616
Foot height (mm)	243.6 ± 21.0	240.0 ± 16.8	0.303
ND[c] (mm)	12.2 ± 2.5	6.1 ± 1.1	<0.001[*]
RCSP[d] (°)	5.6 ± 1.7	1.6 ± 0.4	<0.001[*]

[a] Mean ± standard deviation.
[b] Body mass index.
[c] Navicular drop.
[d] Resting calcaneal stance position.
[*] Significantly different between groups: $p < 0.05$.

2.3. Experimental procedure

All procedures were approved by the University Institutional Review Board. Each subject provided written informed consent prior to the experiment. Each subject practiced three tasks (single leg standing with eyes open, with eyes closed, and the Y balance test) twice before the recording. The order of the tasks was randomized, and all subjects performed the tasks three times in bare feet with a 10-min rest between tasks.

The single leg standing with both eyes open and closed started on a linear line placed on the force plate to control foot position. Each subject positioned both legs on the ground, crossed the arms on their chest, and focused the eyes on a circle placed on the wall 3 m from the subject. With a verbal cue provided by a metronome, the subject began flexing a non-dominant leg for 4 s to the level of a target bar set at 90° while maintaining single leg standing with a dominant leg. The leg used to kick a ball was defined as the dominant side. After arriving at 90°, the subject was instructed to maintain the position as motionless as possible while avoiding bringing the flexed leg in contact with either the ground or the dominant leg [23]. After maintaining this position for 7 s, the subject lowered the flexed leg to the ground for 4 s. The test was performed three times with a 2-min rest between trials. The COP *x*- and *y*-coordinates were recorded to the nearest millimeter for each time. If a subject dropped a hand from a chest or the flexed leg from the target bar or moved the standing leg from an initial position, the data were discarded, and the subject repeated the task.

The Y balance test started from the intersection point of three pieces of tape placed on the ground. The subject positioned both legs on the ground and both hands on the hips. With a verbal cue, the subject lifted the non-dominant leg and extended it over the tape as far as possible, and then touched the tape lightly with the distal-most part of the first toe while maintaining single leg standing on the dominant leg. The distance reached was marked on the tape using erasable ink at the point touched [24] and recorded to the nearest millimeter. This test was performed in three directions in the order of anterior, posterolateral, and posteromedial [25]. The test was performed three times with a 2-min rest between trials. If a subject dropped a hand from a hip or added weight to the first toe of the extending foot or moved the standing leg from the initial position, the data were discarded, and the subject repeated the task [26]. In this study, the intra-rater test-retest reliability was determined for the anterior ($ICC_{3,1} = 0.940$), posterolateral ($ICC_{3,1} = 0.917$), and posteromedial ($ICC_{3,1} = 0.932$)