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Arch Height and Maximum Rearfoot Eversion During Jogging in 2 Static Neutral Positions

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Context: Clinically, lowering of the medial longitudinal arch is believed to be closely related to rearfoot eversion. However, the relationship between arch height and rearfoot eversion during gait is unclear.

Objectives: (1) To examine the influence of 2 reference positions (weight-bearing neutral position [WBNP] and subtalar neutral position [STNP]) on maximum rearfoot eversion, tibial internal rotation, knee flexion, knee internal rotation, and dorsiflexion-plantar flexion of ankle joint measures during jogging and (2) to compare the relationships among static arch height, navicular drop, and the 2 maximum rearfoot eversion measures.

Design: Crossover study.

Setting: Gait laboratory.

Patients or Other Participants: Thirty-three volunteers between 18 and 40 years of age.

Intervention(s): Each participant stood on the treadmill in 2 static positions: WBNP and STNP. Kinematic data were obtained using a 10-camera motion analysis system (120 Hz) when participants jogged at 2.65 m/s on the treadmill in bare feet.

Main Outcome Measure(s): Rearfoot and shank angular kinematics, navicular drop, and static arch height.

Results: Maximum rearfoot eversion was greater (WBNP: 4.03° ± 2.58°, STNP: 10.91° ± 5.34°) when STNP was the static reference ($P < .001$). A strong correlation was seen between maximum STNP eversion and navicular drop ($r = 0.842$) but not between WBNP and navicular drop ($r = 0.216$). Differences were noted in dorsiflexion and knee kinematics during gait between the static references; however, the effect sizes were low, and the mean differences were smaller than 2°, which was less than 5% of total excursion during gait.

Conclusions: Using STNP rather than WBNP as the reference position affects estimates of frontal-plane rearfoot movement but not other ankle or knee motions in jogging.

Key Words: foot, lower extremity, biomechanics

Key Points

- Subtalar neutral static reference position resulted in greater maximum eversion motion during jogging than did weight-bearing neutral static reference position.
- The relationships among arch height, navicular drop, and maximum eversion were different for the 2 static neutral positions.
- Using subtalar neutral position rather than weight-bearing neutral position as the reference position affects estimates of frontal-plane rearfoot movement but not other ankle or knee motions in jogging.

The medial longitudinal arch of the foot provides both static and dynamic support to attenuate ground reaction force and decrease the amount of force transferred to the proximal lower extremity segments through linkage movement between the foot and the tibia.[1] Clinically, lowering of the arch is believed to be closely related to the motion of rearfoot eversion.[2,3] According to Sarrafian,[4] theoretically, arch height and rearfoot eversion motion are closely related in terms of movement transfer to the lower leg. He suggested that lowering arch height is associated with rearfoot eversion, which increases plantar fascia tension by lengthening the foot and transferring rearfoot eversion to tibial internal rotation. Therefore, medial arch support has been used clinically to control abnormal arch collapse[5–7] and abnormal rearfoot eversion[8,9] and for treatment of plantar fasciitis[10,11] and medial tibial stress syndrome.[12]

The navicular drop test is a clinical examination method that allows the clinician to estimate the amount of arch mobility.[13,14] The concept of this test is that people who show excessive arch collapse during the clinical test will exhibit an excessive amount of rearfoot eversion during gait. Therefore, this test has been used clinically to estimate the magnitude of foot pronation with inexpensive tools, such as a ruler or height caliper, instead of expensive devices, such as a multicamera gait analysis system. However, the relationship among static standing arch height and navicular drop measurements and the magnitude of rearfoot eversion during gait is unclear. Static standing arch height and navicular drop measurements were inefficient predictors of rearfoot movement at initial foot contact or at maximum rearfoot eversion during gait.[15,16] Nigg et al[15] and Kernozek and Ricard[17] demonstrated that maximum foot eversion was not influenced by standing arch height or navicular drop measures. McPoil and Cornwall[18] supported these findings by showing that among 17 static measures, including arch height and navicular drop measurement, only navicular drop substantially affected maximum rearfoot eversion angle during gait. However, it accounted for only 17% of variance of maximum rearfoot eversion. In contrast, Boozer et al[3] reported a relationship between medial longitudinal arch height and maximum eversion angle using radiographs to measure arch height in weight-bearing and 3-dimensional running analysis.

One possible reason for these inconsistent results is the use of static weight-bearing neutral position (WBNP) as a reference position for calculating eversion motion during gait. All authors who investigated this relationship used WBNP as a reference. To put the foot in the clinically meaningful position and increase reliability, various methods have been used, including WBNP and subtalar neutral position (STNP). In these neutral positions, the offset that is created is canceled by the joint kinematics. However, because of a large amount of variability in the standing postures assumed by volunteers, WBNP often misrepresents the excursion and end range of joint kinematics.[19] In WBNP, the arch is already lowered because of the gravitational burden of body weight. Subsequently, arch collapse leads to rearfoot eversion, coupled with rotation of proximal segments[20–22] and potentially changes in lower extremity static alignment.[23] Pierrynowski and Smith[24] examined the effect of using different standing neutral positions on rearfoot eversion and reported that eversion motion during gait has been underestimated throughout the gait cycle as a result of using WBNP as a reference position. In order to place the foot in the same position and make valid comparisons across different foot postures, a reliable and clinically meaningful neutral position (STNP) should be used.[19] If STNP is the reference position, the cancellation of rearfoot eversion that results from arch collapse should be minimized. Using STNP as a reference to quantify lower extremity kinematics during gait may provide more clinically accurate kinematic measures of foot movement than does WBNP. To our knowledge, no previous authors have published data on the relationship between arch height and rearfoot eversion during jogging using different static reference positions.

Using STNP to standardize the reference position more truly represents the behavior of interest. However, if this reference position affects other joint angular kinematics, it indicates that the lower extremity may be capturing the behavior of interest, which is not expected to happen. Therefore, examining the effect of STNP as a reference not only on frontal-plane rearfoot movement but on sagittal-plane and transverse-plane movement at the foot and sagittal-plane and transverse-plane movement at the knee is necessary to more fully understand the implications of using different reference positions.

Our primary aim was to examine the influence of 2 reference positions, WBNP and STNP, on other joint kinematics such as dorsiflexion–plantar flexion, tibial internal rotation, knee flexion, and knee internal rotation in order to see whether different static reference positions alter maximum rearfoot eversion and other joint kinematics during barefoot jogging. We hypothesized that no difference would be seen between the reference positions in knee angular kinematics and dorsiflexion and that maximum rearfoot eversion angle would be greater with STNP than WBNP. Our secondary aim was to compare the relationships among static arch height, navicular drop, and the 2 maximum rearfoot eversion measures during jogging. We hypothesized that correlations would be strong between maximum rearfoot eversion measured with respect to STNP and arch height and navicular drop compared with the WBNP-referenced rearfoot eversion measurement.

METHODS

Participants

Power analysis (G*Power 3; Heinrich Heine University, Kiel, Germany) was performed using means and standard deviations (maximum rearfoot eversion angle) from the results of McPoil and Cornwall.[18] With $\alpha = .05$ and $1-\beta = .8$, the power analysis revealed that 5 participants were sufficient to detect statistically significant differences between conditions. Because of the large standard deviations in 3-dimensional joint kinematics, we decided to recruit more than 6 times that number of volunteers. A total of 33 volunteers participated: 12 men and 21 women (age $= 22.33 \pm 8.4$ years; age range, 18–40 years; height $= 173.33 \pm 7.11$ cm; mass $= 62.33 \pm 5.32$ kg). All measures (ie, navicular drop, static arch height, and gait kinematics) were collected from both limbs; thus, 66 limbs from 33 participants were analyzed. However, we analyzed separately left limbs, right limbs, and pooled limbs (average of left and right limbs). Because the arch height and navicular drop measures were important variables in this study, we specifically tried to recruit participants with a range of foot types (hypomobile, normal, hypermobile) (Table 1). Eighteen feet (10 left, 8 right) were hypomobile (navicular drop <4 mm), 20 (10 left, 10 right) were hypermobile (navicular drop >10 mm), and 28 (13 left, 15 right) showed normal range (4 mm $<$ navicular drop $<$ 10 mm). Volunteers had no injury to or chronic pain in either lower extremity for the past 6 months and no history of lower extremity surgery. The University of Virginia's Institutional Review Board approved the study procedures. Data collection was explained to all participants and informed consent obtained from them.

Anthropomorphic Measurements

Anthropomorphic measurements consisted of height, mass, and bilateral leg lengths and knee and ankle joint widths. Joint width of each knee and ankle was measured with calipers. *Knee joint width* was defined as the distance between the lateral and medial femoral condyles, and *ankle joint width* was defined as the distance between the lateral and medial malleoli according to the Vicon System recommended procedures (Vicon-UK, Oxford, United Kingdom). We then used these measurements to find the joint centers of the ankle and the knee using the algorithm embedded within Vicon Plug-in Gait (Vicon-UK).

Arch Height and Navicular Drop

After anthropomorphic measurements, arch height measurement and navicular drop test were performed using a Vernier height gauge. To assess arch height, we measured navicular tuberosity height when the feet were placed shoulder-width apart in upright bilateral standing, weight-bearing position. For navicular drop, the change in navicular height from standing STNP to WBNP was calculated.[25] The *STNP* was defined as the position in which the medial and lateral portions of the talar head were palpated equally with the thumb and index finger.[26]

Previously reported[27] reliabilities of static weight-bearing arch height and navicular drop measurements were intraclass correlation coefficients (ICC) (2,1) = 0.98 and 0.94. For consistent measurement of static weight-bearing arch height and navicular drop, the study tester's day-to day intratester reliability (sessions within 10 days of each other) was established before data collection at ICC (2,1) = 0.98 and ICC (2,1) = 0.93, respectively.

Kinematic Data Collecting Procedure

The modified reflective marker sets were attached to the participant's pelvis and lower extremity per the recommendations

Table 1. Descriptive Statistics of Static Weight-Bearing Arch-Related Measures

Side(s)	Measure	n	Minimum, mm	Maximum, mm	Mean, mm	SD
Pooled	Navicular height	66	2.20	5.60	4.10	0.75
	Navicular drop	66	−0.10	2.30	0.81	0.50
Right	Navicular height	33	2.50	5.60	4.12	0.74
	Navicular drop	33	−0.10	2.30	0.83	0.51
Left	Navicular height	33	2.20	5.50	4.09	0.78
	Navicular drop	33	0.00	2.10	0.79	0.49

of Pohl et al[28] and included a combination of markers from the Vicon Plug-in Gait model and additional shank and foot markers. A total of 24 markers were placed on the following landmarks: posterosuperior iliac spine, anterosuperior iliac spine, mid-lateral thigh, lateral tibiofemoral joint line, and lateral mid-shank. Three additional markers formed an array on the shank, lateral calcaneus, calcaneal tuberosity, sustentaculum tali, and second metatarsal head. The foot markers were placed according to the instructions of Pohl et al,[28] who reported that they accurately measured frontal-plane rearfoot and transverse-plane shank motion.[28]

To determine WBNP and STNP, the investigator asked the participant to stand in the middle of the treadmill, with the feet shoulder-width apart and the first and second rays of the foot aligned forward. The examiner then placed both feet in WBNP and then in STNP. The *WBNP* was defined as the position of the subtalar joint when the participant distributed the weight equally to the medial and lateral sides of the foot using 2 force plates embedded in the treadmill. The *STNP* was defined as the position in which the medial and lateral portions of the talar head were palpated equally with the thumb and index finger. All reference positions were determined by the same certified athletic trainer. Because participants had difficulty maintaining STNP in bilateral stance, a 5° wedge was slid under the plantar surface of the foot the appropriate amount to maintain STNP (Figure 1). A 5° wedge was enough to hold the STNP for no more than 10 seconds. The tester adjusted wedge placement by sliding the wedge deeper under the foot if subtalar joint neutral was high and vice versa if subtalar joint neutral was low.

Kinematic data were obtained using a 10-camera Vicon 624 motion analysis system (Vicon Peak, Lake Forest, CA). To determine initial foot contact and toe-off, we collected ground reaction force data with synchronized conventional force plates (customized model; Advanced Mechanical Technology, Inc, Watertown, MA) embedded in the treadmill. The sampling rates were 120 Hz for kinematic data and 1080 Hz for ground reaction force data.

Before jogging, each participant was asked to stand in the middle of the treadmill using 2 static positions: WBNP and STNP. Five seconds of each static trial were captured and used for reference in the calculation of dynamic trials. Joint kinematics during jogging were obtained by the motion analysis system. Four trials, each lasting 15 seconds, were captured while participants jogged barefoot at 2.65 m/s on the treadmill with embedded force plates.

Data Processing

In order to obtain 3-dimensional kinematics, raw data were processed using algorithms implemented in LabVIEW (National Instruments, Austin, TX) and Vicon Plug-in Gait.[29] The definition of global axis system was as follows: X, anteroposterior axis (+anterior); Y, mediolateral axis (+right lateral); and Z, vertical axis (+upward). The Vicon Plug-in Gait system used Euler and Cardan angles to calculate joint kinematics. Sequences of rotation were Y, X, Z (Y, mediolateral axis of knee joint coordinate system; X, anteroposterior axis of knee joint coordinate system; and Z, longitudinal axis of knee joint coordinate system) for knee joint kinematics and Y, Z, X (Y, mediolateral axis of ankle coordinate system; Z, longitudinal axis system; X, vertical axis of ankle joint coordinate system) for ankle joint kinematics. Ankle and knee joint kinematics of dynamic trials were calculated with respect to the proximal segment reference system (knee joint and hip joint reference system, respectively), and then the offsets of all angular kinematics were calibrated with respect to the reference systems constructed with both WBNP and STNP static reference trials. All the kinematic data were filtered by a Woltring filtering routine with a mean squared error prediction value of 20.

Only the stance phase of the gait cycle was considered for angular kinematic analysis. The stance phase was determined from the events starting with initial heel contact and ending with toe-off and was interpolated to 100% to match the time windows across strides and trials. The ensemble average of the stance phase from 4 consecutive strides from each trial and 4 trials was used for statistical analysis. For both conditions

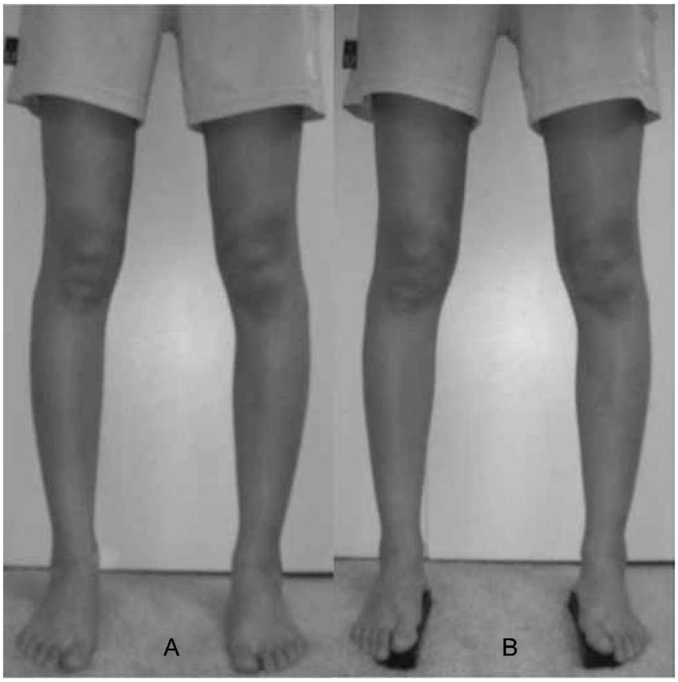

Figure 1. A, Weight-bearing neutral position. B, Subtalar neutral position with wedges in place.

(WBNP and STNP), average curves were formed for the kinematic variables of interest (eversion, dorsiflexion, tibial internal rotation, knee flexion, and knee internal rotation). The maximum values for each variable were extracted using a custom LabVIEW program.

The maximum differences of joint kinematics measured by WBNP and STNP were also calculated. Subsequently, the ratio between the difference between the maximum joint angle and total excursion was calculated to determine the percentage difference of maximum joint motion with respect to the total excursion measured during jogging. *Total excursion* was defined as total movement ranges measured during jogging in each plane (ie, maximum eversion−maximum inversion).

Statistical Analysis

We used SPSS (version 14; SPSS Inc, Chicago, IL) for statistical analysis. Pairwise *t* tests and effect sizes and accompanying 95% confidence intervals (CIs) were calculated to determine the differences between the ankle and knee kinematic measures during jogging as calculated from the 2 reference positions. The following equation was used to calculate effect size:

$$ES = \frac{Mean_{WBNP} - Mean_{STNP}}{SD_{POOLED}}.$$

A Cohen d effect size of less than 0.3 was considered small; between 0.3 and 0.5, moderate; and greater than 0.8, large. Additionally, Pearson product moment correlations were computed to examine the relationships between static arch height, navicular drop, and the 2 maximum rearfoot eversion measurements. The α level was preset to <.05 to determine statistically significant differences between groups.

RESULTS

Means, standard deviations, *P* values, and effect sizes are shown in Table 2. Maximum eversion increased when STNP was used as the static reference when compared with WBNP, regardless of side. Maximum eversion had a large effect size (pooled: Cohen d = 1.64, left: Cohen d = 1.61, right: Cohen d = 1.65), and the CIs did not cross zero, which indicates certainty in the meaningfulness of these differences. Although statistically significant increases were seen in maximum dorsiflexion, maximum tibial internal rotation, maximum knee flexion, and maximum knee internal rotation when STNP was used as the static reference, the mean differences were smaller than 2° and less than 5% of total excursion. Additionally, the effect sizes for these measures were all less than 0.19, which is small according to Cohen's definition.[30,31] The CIs of the effect sizes for the 4 variables also crossed zero, regardless of side, indicating uncertainty in the meaningfulness of these differences.

Total excursion, mean differences for each maximum joint kinematic measure determined with the STNP and WBNP, and mean differences expressed as a ratio of total excursion during jogging are provided in Table 3. Maximum eversion differences were 6.77° ± 2.31° (pooled), 6.69° ± 2.47° (right), and 6.85° ± 2.16° (left), with the STNP method producing greater values. This magnitude of difference represented more than a 100% difference in total eversion excursion. Differences for the other 4 variables were less than 2° between STNP and WBNP, which accounted for less than 5% of total excursion during jogging.

Pearson product moment correlations between static arch measurements and maximum eversion measures in the 2 static references are reported in Table 4. The navicular drop test results and maximum STNP eversion were strongly correlated, whereas the navicular drop test results and maximum WBNP eversion were weakly correlated. Scatterplots for navicular drop measures and maximum eversion in the 2 reference positions are displayed in Figure 2.

DISCUSSION

Our results demonstrated greater maximum angles of rearfoot eversion, dorsiflexion, tibial internal rotation, knee flexion, and knee internal rotation during jogging as determined

Table 2. *t* Test Results and Effect Sizes for Kinematic Data (Pooled, Right, and Left Sides) Using 2 Static Neutral Positions

		Maximum Motion, ° (Mean ± SD)			
Side(s)	Motion	Weight-Bearing Neutral Position	Subtalar Neutral Position	*P* Value	Effect Size (95% Confidence Interval)
Pooled	Eversion	4.03 ± 2.58	10.91 ± 5.34	<.001	1.64 (1.07, 2.18)
	Dorsiflexion	31.54 ± 5.38	32.24 ± 5.34	<.001	0.13 (−0.35, 0.61)
	Tibial internal rotation	17.06 ± 10.03	19.00 ± 10.28	<.001	0.19 (−0.29, 0.67)
	Knee flexion	40.66 ± 8.18	40.98 ± 8.17	<.001	0.07 (−0.44, 0.52)
	Knee internal rotation	4.04 ± 8.78	4.35 ± 8.8	<.001	0.03 (−0.45, 0.52)
Right	Eversion	3.69 ± 2.38	10.72 ± 5.54	<.001	1.65 (1.07, 2.19)
	Dorsiflexion	31.23 ± 4.36	32.02 ± 4.29	<.001	0.18 (−0.30, 0.66)
	Tibial internal rotation	15.84 ± 10.25	17.81 ± 10.48	<.001	0.19 (−0.30, 0.67)
	Knee flexion	42.05 ± 5.16	42.44 ± 5.24	.002	0.07 (−0.41, 0.56)
	Knee internal rotation	4.16 ± 6.75	4.37 ± 6.90	.006	0.03 (−0.45, 0.51)
Left	Eversion	4.37 ± 2.76	11.09 ± 5.20	<.001	1.61 (1.04, 2.15)
	Dorsiflexion	31.86 ± 6.29	32.46 ± 6.28	<.001	0.10 (−0.39, 0.58)
	Tibial internal rotation	18.28 ± 9.80	20.19 ± 10.10	.001	0.19 (−0.29, 0.67)
	Knee flexion	39.27 ± 10.26	39.51 ± 10.20	.003	0.02 (−0.46, 0.51)
	Knee internal rotation	3.92 ± 10.54	4.32 ± 10.47	<.001	0.04 (−0.44, 0.52)

Table 3. Total Excursion and Differences Between Motions for Static Weight-Bearing Positions

Side(s)	Motion	Total Excursion, °	Subtalar Neutral Position Maximum − Weight-Bearing Neutral Position, × (Mean ± SD)	Difference/Total Excursion × 100, %
Pooled	Eversion	6.77 ± 2.31	6.84 ± 4.90	101
	Dorsiflexion	28.88 ± 8.10	0.70 ± 0.93	2
	Tibial internal rotation	49.29 ± 10.74	1.94 ± 1.85	4
	Knee flexion	25.49 ± 9.61	0.32 ± 0.56	1
	Knee internal rotation	11.47 ± 6.01	0.31 ± 0.50	3
Right	Eversion	6.69 ± 2.47	7.03 ± 4.68	105
	Dorsiflexion	28.60 ± 9.36	0.79 ± 0.96	3
	Tibial internal rotation	49.98 ± 10.81	1.97 ± 1.85	3
	Knee flexion	26.78 ± 6.11	0.39 ± 0.66	4
	Knee internal rotation	10.55 ± 3.95	0.21 ± 0.42	2
Left	Eversion	6.85 ± 2.16	6.73 ± 3.92	98
	Dorsiflexion	24.20 ± 12.11	0.61 ± 0.90	3
	Tibial internal rotation	49.77 ± 10.84	1.91 ± 1.88	4
	Knee flexion	12.38 ± 7.49	0.24 ± 0.44	2
	Knee internal rotation	29.15 ± 6.73	0.39 ± 0.56	1

with the STNP reference compared with the WBNP. Although the results for dorsiflexion, tibial internal rotation, knee flexion, and knee internal rotation were statistically significant, the mean differences for maximum dorsiflexion, tibial internal rotation, knee flexion, and knee internal rotation were each less than 2°. Additionally, only the difference in maximum eversion measure had a strong effect size of 2.67 (95% CI = 2.05, 3.29). Maximum eversion in STNP and navicular drop measures were strongly correlated, accounting for 71% of the variance,

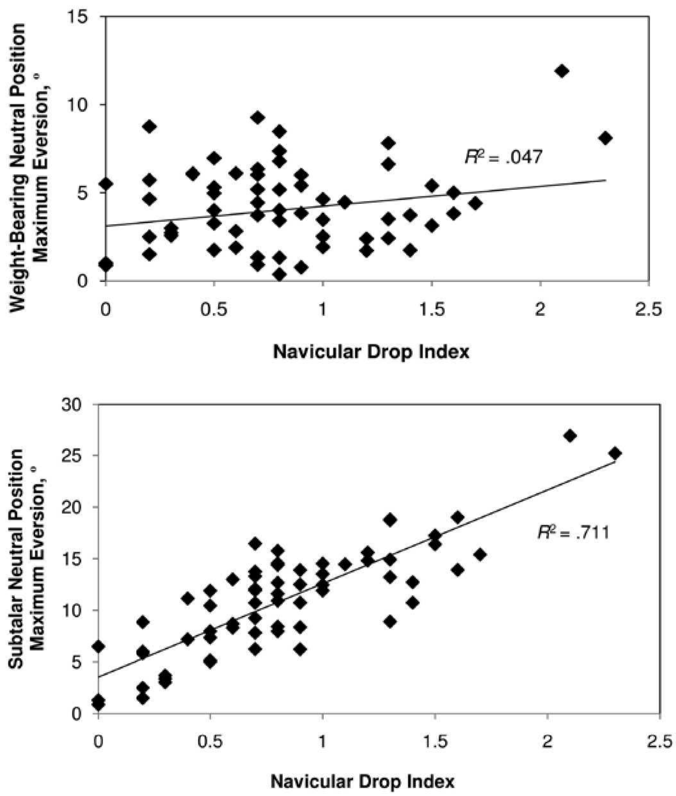

Figure 2. Scatterplots. A, Weight-bearing neutral position maximum eversion and navicular drop index. B, Subtalar neutral position maximum eversion and navicular drop index.

but maximum eversion in WBNP and navicular drop measures were weakly correlated, accounting for only 4% of the variance.

Our first hypothesis was that maximum rearfoot eversion angles would be greater with STNP than WBNP, and it was supported by our results. Similar to our maximum rearfoot eversion angle result (6.84 ± 4.90° differences between WBNP and STNP), McPoil and Cornwall[32] and Pierrynowski and Smith[24] found approximately 6° of difference in maximum rearfoot eversion calculated with 2 reference positions. During weight bearing, arch height usually drops because of the continuous burden of body weight. The amount of arch collapse depends on a person's plantar fascia elasticity, extensibility of the intrinsic foot muscles, and lower extremity alignments.[2,3,33–35] Subsequently, collapse of the arch during standing changes the position of the calcaneus and leads to rearfoot eversion.[36,37] Because the rearfoot is typically placed into a more inverted position in STNP than in WBNP, the amount of maximum rearfoot eversion motion during jogging was 6.84 ± 4.90° greater when the STNP reference position was used. Interestingly, this difference is 101% of the total range of motion during gait, which is a large amount. Therefore, because of the high correlation between the navicular drop and STNP maximum rearfoot eversion and the large difference in maximum rearfoot eversion between STNP and WBNP, the STNP more accurately captures the behavior of interest than does the WBNP.

We also hypothesized that no differences would be seen in ankle dorsiflexion–plantar flexion, tibial internal rotation, knee flexion, or knee internal rotation during gait between the STNP and WBNP methods. We examined these factors to see whether the different static references affected joint kinematics other than rearfoot eversion. This hypothesis was not supported: Significant differences were found, but the mean differences between the reference positions in knee motion and ankle dorsiflexion were smaller than 2°, which is less than 7% of the total excursion of each angular motion during gait. We recruited 6 times more participants than were indicated according to the a priori sample size estimate of *t*. Because a *t* test is more likely to demonstrate significant differences with a small mean difference when the analysis is overpowered, effect size may provide a better means of analysis. We found low effect sizes,

Table 4. Pearson Product Moment Correlations for Static Arch Height Measurements and Maximum Eversion Measurements During Jogging

Side(s)	Measure	Static Arch Height	Navicular Drop Test	Maximum Weight-Bearing Neutral Position Eversion	Maximum Subtalar Neutral Position Eversion
Pooled	Static arch height	—			
	Navicular drop	−0.343[a]	—		
	Maximum weight-bearing neutral position eversion	−0.155	0.216	—	
	Maximum subtalar neutral position eversion	−0.328[a]	0.842[a]	0.608[a]	—
Right	Static arch height	—			
	Navicular drop	−0.436[b]	—		
	Maximum weight-bearing neutral position eversion	−0.299	0.202	—	
	Maximum subtalar neutral position eversion	−0.500[a]	0.858[a]	0.548[a]	—
Left	Static arch height	—			
	Navicular drop	−0.254	—		
	Maximum weight-bearing neutral position eversion	−0.037	0.244	—	
	Maximum subtalar neutral position eversion	−0.155	0.829[a]	0.671[a]	—

[a] $P<.01$.
[b] $P<.05$.

with CIs that crossed zero in ankle dorsiflexion–plantar flexion, tibial internal rotation, knee flexion, and knee internal rotation during jogging. Therefore, we assert that no meaningful differences were identified for kinematic measures other than rearfoot eversion.

Our second hypothesis was that stronger correlations would be present between arch height, navicular drop, and measures of maximum rearfoot eversion in the STNP than in the WBNP. This hypothesis was partially supported. Correlations were strong between maximum STNP eversion and navicular drop (navicular drop accounted for 68% to approximately 71% of STNP eversion in pooled, right, and left legs), correlations were moderate between maximum STNP eversion and maximum WBNP eversion (WBNP eversion accounted for 30% to approximately 45% of STNP eversion in pooled, right, and left legs), and correlations were weak for WBNP eversion and navicular drop (navicular drop accounted for 4% to approximately 6% of WBNP eversion in pooled, right, and left legs) and static arch height (static arch height accounted for 1% to approximately 9% of WBNP eversion in pooled, right, and left legs). Similar to the results of our study, previous authors[16,38,39] found that when WBNP was used as a reference, arch type was not a significant predictor of rearfoot eversion motion during gait. Butler et al[40] compared rearfoot eversion of high-arched and low-arched people and concluded that frontal-plane rearfoot movement during running did not differ. McPoil and Cornwall[18] also supported this finding: Of 17 static measures, navicular drop was the only one that affected maximum rearfoot eversion. In order to standardize the reference position, several investigators[37,41] used different reference positions, such as a calibration bracket, which aligns the rearfoot and tibia with an imaginary vertical line to the ground. However, rearfoot eversion and arch height were not significantly correlated. This result might occur when the rearfoot is aligned to the vertical line without consideration of individual differences in STNP. These findings further support the importance of the standing reference, which is anatomically meaningful and represents lower extremity alignment properties.

Clinically, this information is most important for clinicians who are interpreting gait analysis results in an effort to design intervention programs for patients with rearfoot eversion-related overuse injuries. The clinician might be inclined to use an intervention that controls arch collapse in overpronating patients; however, eversion kinematic results using WBNP as a reference underestimate the magnitude of maximum rearfoot eversion. This factor may change the clinician's decision-making process to avoid applying any interventions to prevent foot overpronation. Therefore, STNP as a reference may help the clinician to better capture the motion of interest, especially rearfoot eversion, and elucidate the links between this motion and injuries such as medial tibial stress syndrome, patellofemoral pain syndrome, and stress fractures. Alternatively, if STNP is used as a reference position, the cancellation of rearfoot eversion that results from arch collapse should be minimized. Even though the differences in lower extremity kinematics between orthotic and nonorthotic conditions measured with respect to STNP and WBNP references would be the same, the STNP may be a more effective reference position to enable comparisons across participants with different foot postures (eg, pes planus, pes cavus). In addition, foot orthotics are usually fabricated when the foot is in STNP. Therefore, using WBNP as a reference underestimates the amount of rearfoot eversion during gait, and the rearfoot pattern may stay in an inverted position throughout the stance phase of the gait cycle, potentially leading to misinterpretation of the results.

From this we draw two conclusions. First, incorporating STNP as a reference for gait analysis appears to be very promising. Second, based on the relationship between navicular drop and STNP maximum eversion, the interventions that are associated with alteration of navicular drop might be the most appropriate to investigate using STNP as a reference for gait analysis. However, further study should be conducted to verify all the relationships we described using STNP and WBNP to determine the clinical meaningfulness of STNP.

The limitation of this study is as follows. We measured angular kinematics during treadmill jogging. In a previous study[42] conducted at the same gait laboratory, maximum angular kinematics between treadmill jogging and overground jogging for all ankle and knee motions except knee flexion were similar. However, those authors suggested that the difference in knee flexion may vanish after a familiarization period. In our study, participants started with walking, followed by at least 5 minutes of familiarization. Therefore, we assume that the difference in knee flexion will vanish after 5 minutes of familiarization.

CONCLUSIONS

The two neutral positions, WBNP and STNP, resulted in different estimates of maximum eversion motion during jogging. The magnitude of the difference and strong effect sizes demonstrate the certainty of the difference when these reference positions are used. The STNP seemed to capture the behavior of interest more accurately. We conclude that using the STNP rather than the WBNP as the reference position will affect estimates of frontal-plane rearfoot movement during jogging. In addition, the relationship among arch height, navicular drop, and maximum eversion is very different between the STNP and WBNP methods.

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