Foot Function Determination: Agreement Between Tests?

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Abstract

Background:

Foot pronation is generally linked to musculoskeletal injuries, especially in relation to joint deviation caused by pronation during dynamic activities. However, no consensus appeared in the methodological way to determine foot function, and several tests propose to identify foot pronation under different conditions, from static testing to running. The aim of this study was to determine the level of agreement between different foot function classification measures.

Methods:

One hundred and six subjects completed 5-foot function tests at standing position, walking and running. Foot Posture Index (FPI) was undertaken to determine foot function during static posture. The Center of Pressure Excursion Index (CPEI) and 3 Foot Balance tests (FBs) were realized during walking and running trials to assess pronation during dynamic activities. Agreement between the measures was determined using the Cohen's Kappa coefficient (K) between 2 measures and the Fleiss Kappa (FK) between 3 or more measures.

Results:

Overall agreement between the measures reported a fair agreement ($K_f = 0.2$). Static and walking foot tests determination agreement was moderate ($K = 0.5$), while agreement between FPI and FBs tests were fair ($K < 0.4$). Fair results were also reported between walking and running tests ($K < 0.4$). The concordance between running tests classification was fair ($K_f = 0.2$).

Conclusions:

The lack of agreement between tests confirms the need for a consensus on an appropriate measurement of the foot function. Static foot tests are mainly used to determine foot function during dynamic activities. However, the lack of agreement between tests could question the relevance of the static foot function assessments. The FPI reported a moderate agreement with the walking classification test, but it should be accompanied by a dynamic test in order to limit the risk of misinterpretation.

Background

The relationship between foot and injury or musculoskeletal disorder is widely studied. Some foot posture (FoP) and/or foot function or motion are well-known as a risk factor for lower limb and back injury. Pes planus or flat foot, and foot pronation (FP) possibly increased the odds of injuries [1, 2]. FP is thought to

display abnormal biomechanical factors like moving medially the ground reaction force and create malalignment of the lower limbs like abnormal internal tibial and femoral rotation and knee valgus [3, 4].

However, all studies do not use all the same semantic to characterize FoP or foot motion. The FoP is mainly represented by the flat foot, the cavus foot or the physiological foot, without axis deviation. Unfortunately, these expressions are sometimes used in studies based on the foot function or foot movement. Nonetheless, for the foot function, three categories appeared: eversion and/or pronation, neutral and supination. Horwood and Chockolingam have published a study based on the FP definition [5]. Authors tried to clarify the confusion that appeared in the literature and proposed a definition of the FP, considering the entire part of the foot.

Determination of FP represents the first step of the studies which tried to find a relationship between foot motion and injury. Foot posture tests assess the foot by its shape, alignment, size, and mechanical properties of the soft tissues [6]. They are generally realized in a standing relaxing posture, where both feet stand on the ground. Foot posture assessments are used with the belief that they could offer some indications on the gait biomechanics [7]. This reinforces the uncertainty regarding the use of tests to assess foot function.

Nevertheless, all studies on this topic do not use all the same assessment to consider foot function. Indeed, several tests exist to classify the foot. The Foot Posture Index (FPI) is probably one of the most used in the actual literature. FPI has been reported to be simple, reliable and quick [8], and can classify foot from highly-supinated to highly-pronated foot. Other tests have emerged to evaluate foot function. These tests are realized during dynamic tasks, where the forces applied to the body complex are different compared to a static posture. The Centre of Pressure Excursion Index (CPEI) proposes to classify foot function as pronated, neutral or supinated. The CPEI could be resumed as a ratio representing a degree of mediolateral deviation of the center of pressure on the one-third trisection of the foot [9]. The CPEI was regularly used in the last few years in many investigations evaluating foot biomechanics and pathologies [10–12]. It is recognized that lower values of the ratio are associated with more medially directed ground reaction forces which suggest FP.

Foot Balance (FB) is a dynamic test to determine the running foot function that has been used several times in the literature [1, 13]. When the pressures are higher on the medial part of the foot, the foot is associated with FP. Several calculations of this ratio have been used in the literature and will be analyzed in this study.

The main objective of this study was to assess the concordance between the FPI-6, the CPEI et the FBs during standing, walking et running activities. It was hypothesized that: the FPI-6 test would show fair agreement with the CPEI and with the FBs tests [14]; the CPEI and FBs tests would show a substantial agreement; the FBs tests would be in substantial agreement.

Methods

One hundred and fourteen subjects (age: 34.8 ± 8.5 years; height: 1.77 ± 0.15 m; weight: 77.9 ± 9.2 kg) were recruited for this study. All participants were volunteers and recreational runners (at least 15 km per week). They all read and signed a contentment sheet. All participants were injury-free and had no abnormalities affecting their ability to walk or run. Subjects younger than 20 or older than 50 were excluded. Pregnancy, lower limb abnormalities, apparent lower limb muscle weakness, and lower limb injuries older than one year were excluded.

All the measurement was realized on the right foot in accordance with a previous study considering only static measurement [15] and due to the statistical bias that could be performed by pooling both right and left foot as it was highlighted by Menz [16].

The FPI was used to classify each participant. The FPI is composed of 6 visual items. Each item is rated between -2 to +2, and the final score is between -12 and +12. A score above 5 is related to FP; a negative score is represented by a supinated FoP, and 0 to +5 is related to a neutral FoP.

The FPI-6 has been shown to possess good inter-examiner reliability between experienced clinicians (weighted kappa (K_w) = 0.86) [17] and high intra-examiner reliability [18]. All FPI assessments were rated by an experienced orthotist. Each subject was analyzed in a relaxed bilateral standing position and participants were classified into 2 groups: pronators (> 5) and non-pronators (< 6).

Two Zebris pressure distribution platforms (FDM-3, Zebris Medical GmbH, Germany, sampling frequency = 120 Hz, $2 \times 314 \times 62$ cm) were used to perform gait analysis. These 2 platforms were mounted flush in the middle of a 10m long carpet. This device running on capacitive force sensors and each platform is composed of 22 528 capacitive sensing elements. Zebris software was configured to measure plantar pressures (N/cm²).

After a familiarization test, participants were asked to walk barefoot at a self-selected speed between two lines positioned 4m before and 4m after the platforms. Ten trials were recorded and 15 stance phase were averaged in order to calculate the walking foot function test. The test was rejected if the foot was incompletely put on the platform.

Gait foot function was assessed by the CPEI. This test has shown high inter and intra-reliability.[9] CPEI is calculated by drawing a line connecting the first and last point in the foot's center of pressure, and then measuring the distance between this line and the center of pressure in the distal third tertile of foot length as a percentage of foot width. Then the distance between the center of pressure displacement and the reference line on the foot with is calculating as a percentage to obtain a value. A cut- off of 19.4% was used to determine the foot function; values below this percentage indicated FP and values above indicated a neutral or supinated foot. [19]

For the running analysis, each participant started and stopped at 6 meters from the platform. Each participant wore the same neutral running shoes (Adidas Supernova Classic). Measurements of foot pressure were realized between the shoe and the ground [1]. Participants were asked to run a minimum of

20 trials before the test. During the tests, subjects ran a total of 10 trials on the runway at a self-selected speed. Incomplete footprint on the platform was removed, and replaced by a new trial. For each trial, six anatomical pressure area were identified: medial heel (HM), lateral heel (HL), midfoot (MD), medial forefoot (MF), inner forefoot (IF) and lateral forefoot (LF).

Three-foot functionality tests were calculated for running. The Foot balance (Fb) proposed by Willems et al. [20] was adapted to the division proposed by the Zebris system: $(MF + HM) - (LF + HL) / \text{All pressure}$.

The second Foot Balance (FB) was calculated by separating the longitudinal axis of the foot, creating a medial side and a lateral side [1]. Longitudinal axis was projected from the first active contact cell to the last active contact cell. FB is a ratio between medial and lateral shoe-ground pressure. Moreover, heel rotation (HR) was calculated with the same pressure data by subtracting HM pressure by HL pressure. For these 3-foot function tests, the foot is pronating when the force is higher under the medial region, the foot is supinating when the force is higher under the lateral part.

In order to evaluate the agreement between foot function tests, subjects were classified as pronated-foot or non-pronated-foot in each test. Pronated-foot was coded by 1 and non-pronated-foot was assigned by 2. A first descriptive analysis was performed by calculating the observed percentage of agreement, which was the sum of the observed concordant counts divided by the total sample size. The agreement was then calculated using the Kappa coefficient. This coefficient expresses a relative difference between the observed proportion of agreement and the proportion of random agreement. The Kappa coefficient (K) is therefore a maximum percentage of agreement corrected for chance. K was evaluated in pairs between the different tests performed. In order to measure the overall between-measure agreement, the Fleiss Kappa (FK) was used. Kappa coefficients were interpreted as follows: < 0.4 = poor agreement; $0.41-0.6$ = moderate agreement; $0.61-0.8$ = good agreement; > 0.8 = excellent agreement.[21]

Results

Static versus dynamic measurement:

During the protocol, 8 subjects were excluded because of their running technique (forefoot foot strike). One hundred and six subjects were included and carried out all the tests.

Table 1 summarizes the agreement results between the static foot function determination (FPI) and the dynamic foot function determination (CPEI, FB, Fb and HR). The concordance analysis showed the best results between the FPI and the CPEI. Eighty-two percent agreement was observed between the 2 measures.

Kappa score reported a moderate agreement between these measures ($K = 0.5$). The results between the FPI and the running tests showed lower percentage of agreement. FB and HR reported 64% and 68% of perceived agreement with the FPI, while FB and FPI exposed 55% of agreement. All the Kappa scores were fair ($K < 0.4$).

Table 1
Agreement between the static and the dynamic foot function tests

	Tests	Perceived accordance	Kappa interpretation	Kappa	p value
Static - walking	FPI-6 - CPEI	82%	Moderate	0.5	<0.001
Static - running	FPI-6 – FB	51%	Fair	0.0	0.99
Static - running	FPI-6 – Fb	64%	Fair	0.0	0.90
Static - running	FPI-6 - HR	68%	Fair	0.1	0.55

Walking vs running measurement:

Table 2 shows accordance results between walking foot function test and running foot function tests. Comparison between CPEI and Fb and CPEI and HR revealed 62% and 63% of perceived accordance while the agreement between CPEI and FB was lower (52%). Kappa agreement between all the measure were fair.

Table 3 discloses the percentage of accordance between running tests determination of the foot function. HR and Fb reported the best percentage of perceived accordance (90%). FB was in fair agreement with Fb (58% of perceived agreement; K = 0.1) and HR (55% of perceived agreement; K = 0.1). Fleiss Kappa reported a fair agreement (Kf = 0.2).

Table 2
Agreement between the walking and the running foot function tests

Tests	Perceived accordance	Kappa interpretation	Kappa	p value
CPEI vs FB	52%	Fair	0.0	0.82
CPEI vs Fb	62%	Fair	0.1	0.84
CPEI vs HR	63%	Fair	0.1	0.51

Table 3
Agreement between the running foot function tests

Tests	Perceived accordance	Kappa interpretation	Kappa	p value
FB vs HR	55%	Fair	0.1	0.35
FB vs Fb	58%	Fair	0.1	0.11
HR vs Fb	90%	Substantial	0.7	<0.001

Discussion

The present study tried to assess the agreement between foot function tests. The results indicate mostly a fair agreement between tests. Contrary to our hypothesis, FPI and CPEI reported a moderate agreement.

Contrary to our hypothesis, the FB tests and the CPEI reported a fair agreement.

Several tests for determining the foot function profile exist in the current literature. However, there is no consensus between the use of static or dynamic foot tests. The FPI appears to be the most widely used [15], probably because of its ease of use and low requirement for high-cost equipment. Hence, several studies tried to assess the relationship between FPI and dynamic motion of the foot. Chuter worked on the relationship between FPI and rearfoot kinematics [22]. Forty subjects were assessed on barefoot walking trials and correlation score was strong between these two tests. Sanchez-Rodriguez et al. also reported a correlation between FPI and foot biomechanics according to plantar pressure assessment [23]. These results were shared with other studies [11, 24]. However, several studies contradicted the existing relationship between FoP and dynamic motion of the foot. Paterson et al., studied the prediction of FoP assessment on dynamic foot function [25]. The authors worked on the correlation between FPI results and kinematics assessment of the foot during walking and results showed a weak correlation. Buldt et al., realized a systematic review on this topic [24]. Authors found that FoP could explain only a small amount of variance in plantar pressure variables.

Our findings did not confirm our hypothesis and showed moderate agreement between the static and gait tests in the classification of foot function ($K = 0.5$). However, the agreement does not seem strong enough, despite the 82% perceived agreement between tests, to refer only to this test in assessing foot function. Indeed, errors of determination could substitute in the classification of the foot. Our results highlighted changes in foot function between the static test and the gait test that could indicate, in some cases, a lack of link between static foot posture and foot function in dynamic situations. The FPI should therefore be combined with a dynamic test or used with caution when studying FP during walking.

Static foot tests are also used in running studies. In fact, several studies which tried to find a relationship between sports injuries and lower limb kinematics used these tests, in particular, to compare pronated and neutral foot function. Nielsen and al., reported that FP is not associated with injury rate in novice runners [8]. In their study, 927 novice runners were included and classified according to the FPI. They were followed 1 year, and injuries were compared between groups. Pronated-foot reported a lower incidence of injury compared to neutral runners. Other studies have concluded on the same results [26, 27]. In 2014, Neal et al., realized a systematic review on the relationship between FoP and lower limb injury [7]. Only 2 injuries were found to be in relation with FP with strong and very limited evidence. However, our results showed fair agreement between the FPI and running foot function tests. Our results therefore question the ability of the FPI to predict the movement of the foot during running and are in line with Behling et al. which did not show a correlation between the FPI and the kinematics of the foot during running [14]. Langley et al., studied the relationship between FoP and foot function at running gait. In this study, authors compared FPI, medial longitudinal arch posture angle (MLA), and rearfoot angle posture during running with an optoelectronic system. Results showed that none of the static foot classification measures was significant predictors of MLA deformation during the stance phase of running [28]. Moreover, a previous study, found that dynamic measures were predictive of foot orthoses outcome for patellofemoral pain while measures of static FoP were not [29]. Thus, our results recommend that the

studies studying foot function in running should use dynamic analysis of foot function and be cautious about FPI prediction when used in isolation.

Contrary to our hypothesis, the walking test was not in agreement with the running test. These agreement results could suggest that it may exist a difference in foot function between walking and running that would mean that neutral foot at walking could be changed to a pronated foot at running and inversely. Thus, foot function test should be carried out according to the activity that is investigated. Another explanation could lie in the measurement technique of these tests. The CPEI considers the functionality of the foot according to the displacement of the center of pressure while the running tests are based on a medio-lateral cut-out of the foot. A consensus in the calculation method could therefore be envisaged in order to establish a concordance between the walking and running tests.

Finally, running classification reported disparity in their agreement results. FB compared to Fb and FB compared to HR, reported only fair results while Fb and HR reported a substantial agreement ($K = 0.7$).

The substantial agreement between HR and Fb seems logical in view of the calculation of Fb including the calculation of HR. Nevertheless, this result appears interesting since it suggests an agreement between the measurement of the hindfoot and the whole foot. With 90% of perceived agreement, the measurement of the hindfoot could allow a visualization of the functionality of the whole foot. This result highlights the importance of the hindfoot and the impact that early pronation (at the beginning of the stance phase) could have on the foot. The fair agreement between the overall running foot function tests could be due to the calculation method. They all consider plantar pressure, but Fb and HR only take localized foot pressure area (medial/lateral side) while FB considers a foot cutting-line based on active baropodometric cells at the beginning and the ending of the foot contact with the platform. Finally, this cutting-line considers only 2 areas of the foot, but with a larger area.

The disagreement between studies which tried to find a relation with FoP and foot function, or also between FP and injuries, could be due to the methodological classification of the foot function. Our study revealed a lack of agreement between the different foot function tests. Based on these results, we recommend a classification of the foot with a foot function assessment performed in the condition in which the foot will be evaluated.

Some limitations must be acknowledged. No control of the velocity was performed in the walking or running tests which could have an impact on the plantar pressure. In addition, the plantar pressure during running comes from the sole of the shoe, which could have inhibited certain areas of the foot. This possible reduction could have an impact on the calculation of pressure tests or influence the results.

Conclusions

Dynamic foot function tests, and especially the assessment of FP, are commonly utilized in clinical practice, and our findings highlighted a fair agreement between tests. The FPI showed moderate agreement with the walking test but fair agreement with the running tests. These results enroll the need

for a consensus on the FP definition and determination. The foot function determination should be adapted to the activity being studied.

Abbreviations

CPEI : Center of Pressure Excursion Index

Fb : Foot Balance (Willems et al., technique)

FB : Foot Balance (Brund et al., technique)

FoP : Foot Posture

FP : Foot Pronation

FPI : Foot Posture Index

HR : Heel Rotation

Declarations

Ethics approval and consent to participate

All participants provided written informed consent before participation, in accordance with the declaration of Helsinki. The study was approved by the university ethical research committee of Rouen.

Consent for publication

Each subject signed a consent form before participating in the study.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request

Competing interest

None

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Conflict of interest

None.

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Authors' contribution

Damien Dodelin: Conceptualization, Methodology, Software, Writing – Review & Editing

Claire Tourny: Validation, Methodology, Resources

Maxime L'Hermette: Supervision, Validation, Conceptualization

Authors' information

DD is a PhD, working as biomechanics engineer in a Podiatry Center. The function of the foot appears to be a factor that favors the development of musculoskeletal pathologies. However, the literature has mainly focused on the determination of pronation in a static position. Nevertheless, it would seem that the posture of the foot does not always allow for the determination of the function (dynamic movement) of the foot, which has been observed more and more in the literature, but also in the practice here on the different patients of the center (on the last 6 years). It would seem that the dynamic analysis of the function of the foot would make it possible to specify the function of the foot during walking or running.

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