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Short communication

Test–retest reliability and descriptive statistics of geometric measurements based on plantar pressure measurements in a healthy population during gait

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ABSTRACT

Previous studies have demonstrated that pressure, force, area, and time measurements can be reliably collected from pedobaragraphic platforms, but no studies have analyzed geometric measurements. The purpose of this study was to establish the test–retest reliability of geometric measurements obtained during gait at a self-selected speed using a two-step approach. Data were collected on both feet for 10 healthy participants using the emed-x platform. Reliability of 15 geometric measurements was assessed using intraclass correlation coefficients (ICC). All 15 measurements were demonstrated to be reliable (ICC > 0.8), with 12 measurements ICC > 0.90. Collection of geometric measurements at a self-selected pace with the emed-x platform was found to be reliable and can be used for investigation in research settings.

1. Introduction

Static, geometric measurements have previously been used in both clinical and research settings to describe and classify foot structure, but recent prospective studies have demonstrated that assigning running shoes based on such classifications does not reduce musculoskeletal injuries [1–3]. The use of geometric measurements during gait from a pedobarographic platform may provide clinicians and researchers valuable information about the geometry and alignment of the foot. Since the foot is dynamically loaded during gait and sport activities, it may be more appropriate to classify foot structure based on geometric measurements during gait rather than static measurements. Pressure, force, area, and time measurements can reliably be collected using pedobarographic devices [4,5], but the reliability of geometric measurements has not been established. Therefore, the purpose of this study was to establish test–retest reliability of geometric measurements obtained during gait at a self-selected speed using a two-step approach.

2. Methods

2.1. Participants

Ten healthy males ($n = 8$) and females ($n = 2$) from the University participated in two identical sessions for this study (age: 27.7 ± 4.1 years; mass: 77.6 ± 10.7 kg; height: 174.3 ± 7.0 cm). Participants were between the ages of 18 and 45 years, physically active, and were excluded if they had current lower extremity musculoskeletal pain and/or injury or any disorder affecting sensation in the lower extremity that may affect balance or gait. The mean number of days between test sessions was 10.8 days (range: 6–17). This study was approved by the University's institutional review board and written informed consent was obtained prior to participation in the study.

2.2. Instrumentation

The emed-x platform (Novel GmbH, Munich, Germany) was set flush within a 4 m walkway. The emed-x platform is comprised of 6080 capacitive sensors within a sensing area of 475 × 320 mm (sensor resolution of 4 sensors/cm^2) and has a pressure range of 10–1270 kPa, accuracy of ±5%, and hysteresis <3%. The sampling frequency was 100 Hz.

2.3. Protocol

A two-step approach at a self-selected speed was utilized for all trials, which has been demonstrated previously to be as reliable as the mid-gait approach [6]. Participants stood on the platform and took two steps forward to determine the starting position. At the starting position, subjects were instructed to take four steps, striking the platform on the second step. Subjects were instructed to use their usual gait while looking straight ahead and not targeting the platform. After a demonstration from the researchers, subjects practiced walking across the platform until he/she was comfortable with the procedures. Subjects performed five trials with the right and left feet, until a total of 10 successful steps were recorded. A trial was successful when only one foot contacted the platform, contact was made on the second step, and participants did not target the platform. Trials not meeting these criteria were excluded and another trial was collected.

2.4. Data reduction

Data were analyzed using the Novel Database Medical software program (version 15.2.3, Novel GmbH). Fifteen geometric measurements were automatically

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calculated utilizing the software algorithms for each trial. All measurements were calculated from the maximum pressure picture of the step during gait. The maximum pressure picture is an image of the foot that represents the maximum pressure value recorded by each sensor. The geometric measurements calculated for this study are defined in Table 1 and the angles are illustrated in Fig. 1. Definitions of the geometric measurements during gait are as defined by the platform manufacture [7]. For each subject, means of the five left and right foot trials were calculated for each geometric measurement and used for statistical analyses.

2.5. Statistical analysis

Test–retest reliability for left and right feet was assessed by calculating intraclass correlation coefficients (ICC) using a two-way random effects model (ICC [2,k]). Mean, median, standard error of measurement (SEM), interquartile range (IQR), and minimum/maximum values were calculated using right foot data from the first session. All statistical analyses were performed using PASW (version 18, SPSS Inc., Chicago, IL).

3. Results

The ICC values ranged 0.818–0.992 and the SEM ranged 0.004–2.65 indicating geometric measurements can be obtained reliably at a self-selected speed using a two-step approach (Table 2). Descriptive statistics of these measurements are presented in Table 2.

4. Discussion

Previous studies have demonstrated that pressure, force, area, and time measurements can be reliably obtained using pedobarographic devices [4,5], but this was the first study to assess geometric measurements during gait. The purpose of this study was to establish the reliability of geometric measurements obtained during gait. Geometric measurements can be collected reliably (ICC $\geq$ 0.818) and can be used in future research, including classification of foot structure/type.

Running shoes are typically recommended to individuals based on the plantar shape of the feet that have been classified and defined by static measurements. Motion control shoes are recommended for individuals with low-arches, stability shoes for individuals with normal-arches, and cushioning shoes for individuals with high-arches [8,9]. However, recent prospective studies have demonstrated that selecting a running shoe based on static plantar surface measures does not reduce injuries in recruits during basic training in the Air Force [1], Army [2], or Marine Corps [3]. In these studies, trained evaluators examined the plantar surface of the foot in contact with an acrylic surface and rated the foot as low, normal, or high arched. Recruits were randomized into experimental and control groups. The experimental group received shoes based on their plantar shape (as described above) and the control group received stability shoes. In all three studies, it was found that assigning shoes based on a static plantar shape had little influence on injury rates.

The primary limitation to these studies is the selection of a static instead of a dynamic measure. Dynamic loading will change the characteristics of the foot, especially when comparing rigid and flexible feet [10]. In a pilot study comparing static and geometric measurements during gait from the emed-x platform, significant differences were found, including subarch angle (Table 1). An increase in the subarch angle from static to dynamic measurements, or subarch excursion, may provide a quantifiable dynamic measure of midfoot flexibility. This measure and other dynamic measures may provide a better method in recommending running shoes. The comparison between static and dynamic geometric measures is currently being investigated using a larger sample size.

Reliable dynamic assessment of foot geometry can be obtained using the emed-x pedobarography platform and the descriptive statistics may be used as normative data in a healthy population. These findings support the use of dynamic foot geometry assessment in future research to classify foot structure/type and to determine the relationship between foot geometry and lower extremity injuries.

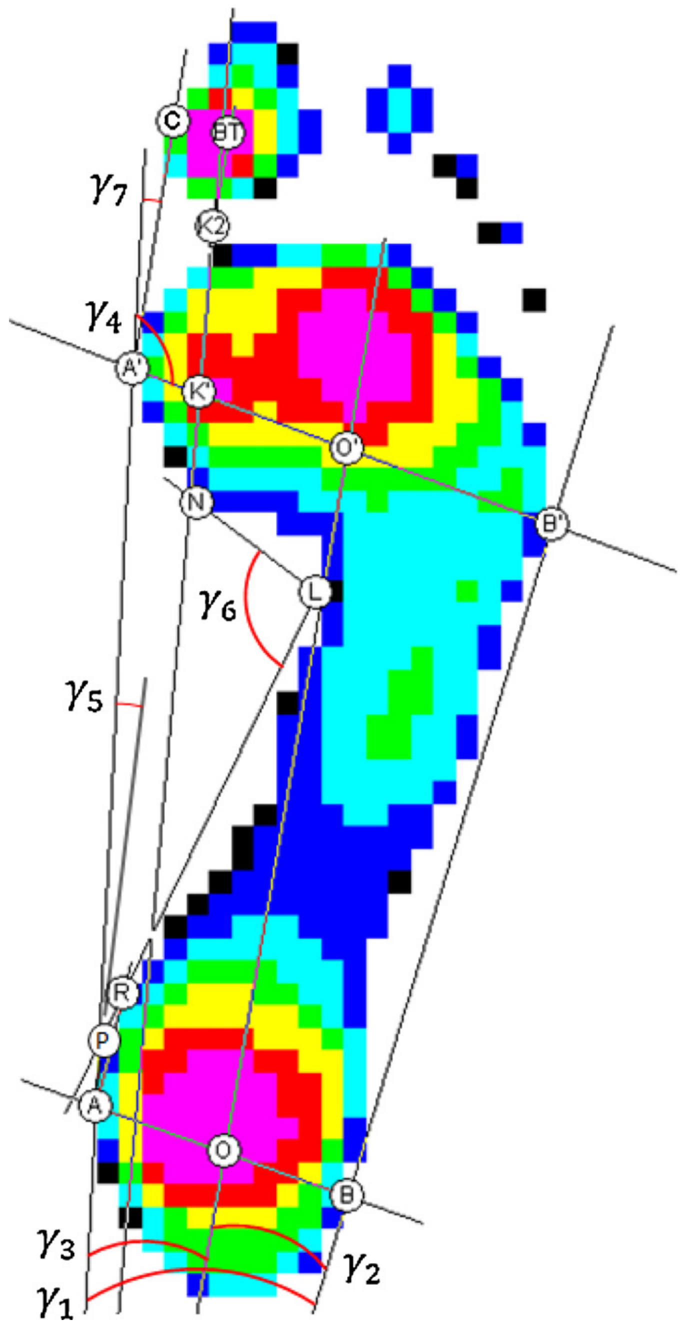

Fig. 1. Geometric measurements during gait. AA′ and BB′: drawn from the medial and lateral aspects of the foot, respectively; OO′ is formed by the bisection of AB and A′B′; P: point of contact of the tangent from A towards the heel; L: most lateral displacement of the medial midfoot border; N: point of contact of the tangent from L towards the forefoot; R: point of contact of the tangent from L towards the heel; C: point of contact of the tangent from A′ to the hallux. Figure adapted from platform manufacturers literature [7]. All measurements were calculated from the maximum pressure picture. The maximum pressure picture is an image of the foot that represents the maximum pressure value recorded by each sensor.

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Table 1
Geometric measurement definitions.

Measurement	Definition
Foot length	Defined by placing a rectangle around the maximum pressure picture whose long side is parallel to the bisection of the long plantar angle. The length of the rectangle defines the foot length.
Forefoot width	Distance between the widest points of the ball of the foot (1st and 5th metatarsophalangeal joints)
Heel width	Distance between the widest points across the flash portion of the heel
Foot progression angle	The angle between the axis (OO′) and the vertical line parallel to the platform *Y*-axis. The vertical represents the direction of travel during data collection and this angle can therefore by use to describe the angle at which the foot contacts the ground
Forefoot angle (γ4)	The angle between the medial tangent (AA′) and the line defining the forefoot width (A′B′)
Hallux angle (γ7)	The angle between the medial tangent (AA′) and the tangent to the big toe (A′C)
Heel angle (γ5)	The angle between the medial tangent (AA′) and the tangent to the heel (AP)
Lateral plantar angle (γ2)	Angle between the lateral tangent (BB′) and the bisection of the long plantar angle
Long plantar angle (γ1)	Angle is formed by the tangents for the medial (AA′) and lateral (BB′) sides of the maximum pressure picture
Medial plantar angle (γ3)	The angle between the medial tangent (AA′) and the bisection of the long plantar angle
Subarch angle (γ6)	The angle between the tangents to the forefoot (LN) and heel (LR) drawn from the most lateral displacement of the medial midfoot border
Arch index	The index is defined by the midfoot area divided by the total foot area (foot area minus toes area)
Coefficient of spreading	The forefoot width divided by the foot length
Forefoot and heel coefficient	Heel width divided by the forefoot width
Forefoot coefficient	Medial forefoot width divided by the lateral forefoot width

Table 2
Reliability analysis and descriptive statistics of geometric measurements during gait from a healthy population ($n = 10$). ICCs were calculated using data from both feet and sessions, and descriptive statistics were calculated using right foot data from the first session.

Geometric variable	ICC	Mean	(SEM)	Median	(IQR)	Min	Max
Foot length [cm]	0.992	27.41	(1.75)	27.93	(1.46)	23.08	29.18
Forefoot width [cm]	0.980	9.83	(0.80)	9.88	(0.68)	8.44	11.36
Heel width [cm]	0.992	5.61	(0.49)	5.65	(0.31)	4.76	6.50
Foot progression angle [°]	0.990	10.03	(6.17)	10.03	(9.99)	-0.54	17.46
Forefoot angle [°]	0.869	114.25	(2.93)	112.76	(3.80)	110.70	119.70
Hallux angle [°]	0.984	4.45	(5.57)	3.57	(6.38)	-3.44	14.36
Heel angle [°]	0.818	10.66	(3.28)	10.82	(5.18)	6.14	16.05
Lateral plantar angle [°]	0.985	7.50	(0.89)	7.63	(1.10)	5.96	8.84
Long plantar angle (g) [°]	0.986	15.01	(1.79)	15.24	(2.22)	11.90	17.68
Medial plantar angle [°]	0.985	7.50	(0.89)	7.63	(1.10)	5.96	8.84
Subarch angle [°]	0.975	107.28	(12.58)	106.64	(14.68)	91.70	135.16
Arch index	0.975	0.24	(0.06)	0.24	(0.06)	0.15	0.34
Coefficient of spreading	0.927	0.36	(0.02)	0.36	(0.02)	0.33	0.39
Forefoot and heel coefficient	0.972	0.57	(0.05)	0.58	(0.05)	0.47	0.65
Forefoot coefficient	0.878	1.08	(0.02)	1.08	(0.02)	1.06	1.12

Conflict of interest statement

All authors have no financial or personal relationships with other people or organizations that could inappropriately influence (bias) their work.

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