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The Way We Stand: A Sequential Case Study on Foot Angle

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Abstract

This study quantifies the significance of foot angle as it relates to common biometric data to assess its use in the clinical realm. There are two objectives to this study; first to determine the relationship foot angle has with ten surveyed biometric data points (age, weight, height, biological makeup, shoe size, orthotic use, physical activity level, competitive sports history, lower extremity injury history, and reason for visiting doctor), and second to determine the average left and right foot angles of the population studied. The duration of this sequential case study with a sample size of 73 was December 9, 2021, to April 7, 2022. Participants were fully informed of the measurement steps, the purpose of the survey, and the goal of the project. Participants were asked to walk down the hallway as a distraction to collect the most accurate data on the participants' stance. This study was performed at the Arizona Institute of Motion, a clinical office and private practice. Participants had the option to decline participation in the study. Correlational calculations and linear regressions were performed to support or reject the existence of a relationship between foot angle and the biometric data. It was found that the average left foot angle was 26.35 degrees, and the average right foot angle was 26.54 degrees. It was found that there was a strong positive correlation between left and right foot angles, and a weak positive relationship with both foot angles and weight, height, and shoe size. The optimized linear regression model had an adjusted r^2 value of 0.549 for left foot angle against right foot angle, shoe size, and height, and an adjusted r^2 value of 0.522 for right foot angle against left foot angle, shoe size, and height. Foot angle had no other relationships with the other biometric data and had limited quantitative significance. Additional study is required to confirm its numerical importance, but foot angle may continue to be used in clinical settings in conjunction with gait analysis and qualitative assessments for musculoskeletal function. Foot angle has limited quantitative significance but may maintain a high potential for clinical utility when used in conjunction with gait analysis and qualitative assessments.

Keywords

Foot Angle, Biometric, Posture, Linear Regression, Orthopedic

1. Introduction

The purpose of this study was to determine both the average foot angle in a population of both injured and uninjured individuals and if there exists a relationship between foot angle and ten surveyed biometric data points. It is important to note that foot angle is often associated with gait analysis, which is not measured in this study, but due to its close association with foot angle, is necessary to mention. At the clinical level, gait analysis encompasses a broad spectrum of biomechanical metrics. Due to its variable nature, gait analysis is not considered a standardized practice across physicians and is thus only intended to inform the physician of potential maladies and gait abnormalities that may exist due to an issue in the lower extremity or another issue in the kinetic chain involving the hips or spine, for example. Generally, gait assessments detect biomechanical issues that could cause future musculoskeletal problems for patients as a prevention mechanism and inform physicians on the nature of their patients' musculoskeletal injuries. Abnormal gait mechanics are incredibly important in recognizing musculoskeletal pathologies specifically involving the lower extremities ([1] [2]).

With an abnormal gait, an abnormal foot angle is also present. Gait consists of three phases: the stance phase, swing phase, and float phase. The stance phase is the primary concern of this research project, as it is when the foot contacts the ground, which provides information on the foot angle. The heel then strikes the ground and transitions to the next phase, the swing phase, when the foot pushes off the ground. Walking only entails the first two phases while running gait includes the float phase when the foot is off the ground mid-stride ([1] [2]). The float phase is not of concern in this research, as the subjects of the study will not be asked to run.

Though gait analysis is not a standardized practice among physicians, there are general observations that should be made when completing a gait assessment. Walking gait assessments require multiple observations of various aspects of the body, specifically the upper body (head and torso), the pelvis, the hips, the knee and leg, and the foot and ankle [3]. A proper gait entails slight, sinusoidal vertical head movement, symmetric shoulder height and arm swing, unpronounced pelvic movement, hip adduction such that the knee does not go over the toes, slightly flexed knees when the foot initially contacts the ground, and neither ankle pronation nor supination with no toe-in or toe-out stance ([1] [2]). Foot angle is an extremely important metric of gait analysis, yet there is limited specificity available to determine the relationship between foot angle and gait pattern. One important angle related to gait is known as the Fick Angle, which is a measurement between the midline of the body and the degree of external rotation of the foot. A normal Fick Angle is between 5 and 18 degrees of external rotation from the midline, but if the angle exceeds this range, there may be a variety of contributory factors occurring higher up in the kinetic chain ([1] [2]). Another term for foot angle is known as Foot Progression Angle (FPA), which in, in essence, measures the angular axis of the foot in regard to internal or external rotation [4]. FPA is similar to the foot angle that was measured in this research; however, FPA is generally only used to determine if patients have a toe-in or toe-out gait. The foot angle measurements of this study aim to be more informative. As such, measurements in this study were accompanied by a categorical survey from which correlations were drawn. The foot angle of this study was measured similarly to Foot Progression Angle, and static standing foot angle was taken. A study involving both standing foot angle and gait analysis revealed that standing footprint analysis (essentially standing foot angle) was predictive of dynamic foot angle and gait analysis [5]. Calculating standing foot angle is more accessible and efficient in terms of data collection for this research project than attempting to calculate dynamic foot angle.

Foot angle is a non-invasive method with the potential to characterize lower extremity issues. In a study assessing the reliability of gait analysis and foot angle to inform a diagnosis, it was found that foot angle had potential to predict the amount of loading that the knee bears in a healthy individual [6]. Because of its ability to predict stress on the knee, there are clinical implications: foot angle can help detect surgical and nonsurgical knee abnormalities. It is also a predictor for a number of other conditions, such as plantar fasciitis and incidence of diabetic ulcerations on the foot due to its ability to determine plantar pressure distribution of the foot [7]. The data collected in this study aim to strengthen the suggestion that foot angle analysis is an incredibly useful, informative, and non-invasive tool used to inform diagnoses.

Because foot angle analysis is not standardized across clinical practices, this study proposes a standardizable method to approach this metric in the hopes that foot angle analysis will gain more clinical prominence. One suggestion for a standardizable method for foot angle analysis that already exists is the "Foot Posture Index." This method provides rubric-like guidelines and analyzes multiple aspects of the foot, including palpating the Talar Head and assessing arch congruence and ankle flexibility ([8] [9]). However, because of the rubric-like nature of this assessment, the results of the assessment are more abstract and less informative than measuring the actual angle of a patient's foot. Additionally, this is an extensive analysis method that would take time away from direct patient care. The method for foot angle analysis that is proposed in the methodology section of this study is time-conscious and accessible.

Furthermore, what studies exist on foot angle analysis are limited to either specific groups or specific pathologies. There is a growing volume of studies that use foot angle with patients with knee osteoarthritis, a debilitating condition common in elderly populations [10]. One study involving subjects with knee osteoarthritis found that foot angle and changes in gait pattern altered the neuromuscular demands on lower extremities of both the healthy control subjects and the subjects with knee osteoarthritis [11]. Another similar study using foot angle to measure people with knee osteoarthritis found that those who assumed a toe-out stance experienced less progression of knee osteoarthritis [12]. Foot angle was an important metric involved in patients with knee osteoarthritis in both studies, which reveals its high potential for clinical utility. Both studies were limited in both sample size and population, as these studies used sample sizes of less than 60 subjects, and the subjects (excluding the control) all had knee osteoarthritis. This study assesses 73 orthopedic patients that are not characterized by a specific demographic or pathology.

The other limitations of foot angle studies involve the population of subjects studied. Many studies focus on the foot angle and gait pattern of specific demographics. For example, several studies have analyzed the gait pattern and foot angle of morbidly obese patients to examine the effect of excess body weight on the way people walk ([13] [14] [15]). It was found that the subjects studied had musculoskeletal impairment and abnormal gaits due, in part, to their excessive weight. The study noted that more in-depth, longer-term research was needed to examine the gait patterns and foot angle of obese individuals more fully. Although the scope of this study does not include a focus on the gait of obese individuals, the data of this study are more extensive in the diversity of subjects studied and the length of time for which they were studied. Other demographics that frequently have their gaits and foot angles studied are the elderly, as they usually have the poorest musculoskeletal performance and thus are more likely to have abnormal gaits and foot angles. One study found that mid-stride foot movement increases with increasing age, which may be due to ankle joint stiffness [14]. This study admitted that the trends observed needed more research to be valid assertions. Another study that analyzed the gait and foot angle differences between younger and older people provided comparable results, claiming that older people have more musculoskeletal instability, which means that they require a larger support base [16]. Both studies indicated that more research was needed to further support their conclusions. Because this study involves subjects from age 18 to 75 years, there may be more evidence to characterize the foot angles of the elderly. Because this study is not limited to a single demographic or condition, it may provide a better picture of foot angles in general.

2. Methodology

2.1. Participants

The participants of this research comprised of every consenting adult at the Arizona Institute of Motion. Patients of Dr. Cory, the orthopedic surgeon that leads the Arizona Institute of Motion, were offered a consent form along with the 10-question biometric survey. All patients offered the consent form and survey were informed of the goal of the study, participation requirements, and potential risks and benefits of the study. This study has been reviewed and approved by the BASIS Phoenix IRB (IORG0010447). This study was conducted in accordance with the Declaration of Helsinki.

The sample population comprised of people from all age categories listed on the survey (18 to 75 years of age) and included both injured and uninjured individuals. It is important to note that the population excluded from this study were those unable to ambulate down a hallway without pain or further injury. Thus, given that all participants in the study could walk down a hallway with ease, this study put participants at minimized risk. The study examined 42 females and 31 males. No other demographics were necessary to note. Biometric data such as age, sex, weight, and height were also collected.

2.2. Purpose

This study was designed with the intent of maximizing accessibility and efficiency of data collection. As a sequential case study, opportunities exist to collect both qualitative and quantitative data, which are both necessary in characterizing foot angle. As a sequential case study, no control was possible, and by the design of the study, random sampling was also impossible. The main objective of this study was to quantify the significance of foot angle as it relates to common biometric data and to assess its clinical utility. There were two objectives; first to determine the relationship foot angle has with ten surveyed biometric data points (age, weight, height, biological makeup, shoe size, orthotic use, physical activity level, competitive sports history, lower extremity injury history, and reason for visiting doctor), and second to determine the average left and right foot angles of the population studied.

2.3. Procedures

Subjects were asked to complete a 10-question survey to the best of their ability (survey available upon request). This survey provided data from which correlations were drawn between foot angle and biometrics. Subjects were asked to walk 10 steps down the hallway, turn around, and walk back to the starting point. The number of steps taken and distance walked were irrelevant; the walking exercise served as a distraction for the participants to take attention away from the way they stood. After walking, subjects were asked to stand in a comfortable position, assumably their natural stance. Pictures were taken of the anterior and posterior view of both feet with a digital camera, and the image was uploaded to a computer file for foot angle measurement. All pictures were kept confidential, with each subject being assigned a number that corresponded with their foot image and survey. After the picture was taken, subjects were repeatedly informed of the study's purpose. Subjects were not given specific details about the study beforehand to ensure that they stand as they naturally do and not how they think they should be standing. The survey was designed to take less than 60 seconds for subjects to complete. The survey and walking exercises are low-risk and take minimal time from the physician's practice. The angle measurements for the pictures were conducted through a computerized program (link: https://www.ursupplier.com/tools/angle_measurement/). The foot angle was measured similarly to the Fick Angle. The angle was taken from the midline and the second toe. The second toe specifically follows the angle of the tibia for the general population. There exist cases in which a subject may present with a planar valgus foot posture, and the second toe would not necessarily follow the tibial/leg angle. However, a planar valgus foot posture means that there will be external rotation of the foot, which would affect foot angle.

The raw subject data was collected via a survey that entailed both qualitative and quantitative metrics. Data from the survey was assigned a value from 1 to 5 based on the response position on the survey page (*i.e.*, the first check box of the first question of the survey was assigned a 1, the bottom/last check box was assigned a 5) for instances in which there was not a Yes/No answer or open numerical answer (*i.e.*, shoe size). Data was collected on an Excel Spreadsheet, with subjects numbered to correspond with their survey and foot angle measurement. Foot angle measurement data was collected using an online protractor that measured the angle between the midline of the feet and the second toe of each foot. The raw data, including the foot angle measurements and survey responses, was interpreted using Python 3 Systems. Linear regressions and correlational calculations were performed. Graphs were also produced as visual representations of the data, including correlational heat maps, linear regression maps, scatter plots, pie charts, bar graphs, histograms, and box-and-whisker plots. The raw data collected from the survey and foot angle measurement provides a baseline of a diverse population of people and the precise measurement of the way they stand along with the potential context behind it given by the survey data.

The data were acquired via a survey and direct measurement using a camera and online protractor (https://www.ursupplier.com/tools/angle_measurement/). Samples that were excluded were participants that did not answer the "biological makeup" question in the survey and those that did not sign the consent form or were unable to have a foot angle measurement be collected. Data was not normalized, as no outliers were identified. Raw Data can be accessed using the Mendeley Data Repository (Data identification number: 10.17632/f9gs9rr2ng.2; Direct URL to data: https://data.mendeley.com/datasets/f9gs9rr2ng).

These data are useful in that there is a lack of data surrounding foot angle measurements. They may serve as a baseline or reference frame for future experiments or comparative studies on foot angle or standing posture. These data will yield benefits to the orthopedic foot and ankle community as well as the realm of physical therapy, as the data describes an average measurement of the standing posture or foot angle of a population of people. The foot and ankle community in orthopedics would benefit from the data collected in that there is a large absence of foot angle data, to begin with, and the physical therapy community could benefit from having these data as measurements of the standing posture of a population. These data may serve as a reference frame or baseline in other studies and could also be used in a comparative study or systematic review that looks at numerous publications with similar data. There is a lack of data on foot angle available for Open Access and in general, and this data seeks to help add to the small body of data that already exists, making foot angle data easier to find and simply contributing to the pool of data relating to foot angle measurement. Statistics are available upon request. Nine linear regression models were created, and models found in the Results section were optimized. Average foot angles and correlations were calculated via the NumPy library.

3. Results

To fulfill the first objective of the study, it was found that a strong positive correlation exists between left and right foot angle (0.738120). A weak positive correlation exists between both foot angles and shoe size (left foot angle, 0.319753; right foot angle, 0.308488), height (left foot angle, 0.383997; right foot angle, 0.325227), and weight (left foot angle, 0.261869; right foot angle, 0.264853). See Table 1 and Figure 1.

Table 1. A correlational coefficient matrix table calculated with the NumPy Library in the Python 3 system. Note that some of the biometric data is absent because the answers to those questions on the survey (for example, orthotic use) were Yes/No.

	Age	Height	Weight	Shoe Size	Physical Activity	Highest Level of Sports	Reason for visit	LFA	RFA
Age	1.000000	−0.169999	0.087631	−0.057526	−0.127895	−0.331936	−0.031546	−0.004108	0.074074
Height	−0.169999	1.000000	0.672558	0.875002	0.327420	0.230546	−0.010484	0.383997	0.325227
Weight	0.087631	0.672558	1.000000	0.703036	0.051007	0.126842	−0.055556	0.261869	0.264853
Shoe Size	−0.057526	0.875002	0.70306	1.000000	0.188768	0.244735	0.027781	0.319753	0.308488
Physical Activity	−0.127895	0.327420	0.051007	0.188768	1.000000	0.294578	0.150729	−0.018329	−0.032035
Highest Level of Sports	−0.331936	0.230546	0.126842	0.244735	0.291578	1.000000	0.060472	0.011567	0.044285
Reason for Visit	−0.031546	−0.010484	−0.055566	0.027781	0.150729	0.060472	1.000000	−0.096921	−0.002009
LFA	−0.004108	0.383997	0.261869	0.319753	−0.018329	0.011567	−0.096921	1.000000	0.739120
RFA	0.074074	0.325227	0.264853	0.308488	−0.032035	0.044285	−0.002009	0.738120	1.000000

	Age	Height	Weight	Shoe Size	Physical Activity	Highest Level of Sports	Reason for visit	LFA	RFA
Age	1	-0.169999	0.087631	-0.057526	-0.127895	-0.331936	-0.031546	-0.004108	0.074074
Height	-0.169999	1	0.672558	0.875002	0.32742	0.230546	-0.010484	0.383997	0.325227
Weight	0.087631	0.672558	1	0.703036	0.051007	0.126842	-0.055556	0.261869	0.264853
Shoe Size	-0.057526	0.875002	0.70306	1	0.188768	0.244735	0.027781	0.319753	0.308488
Physical Activity	-0.127895	0.32742	0.051007	0.188768	1	0.294578	0.150729	-0.018329	-0.032035
Highest Level of Sports	-0.331936	0.230546	0.126842	0.244735	0.291578	1	0.060472	0.011567	0.044285
Reason for Visit	-0.031546	-0.010484	-0.055566	0.027781	0.150729	0.060472	1	-0.096921	-0.002009
LFA	-0.004108	0.383997	0.261869	0.319753	-0.018329	0.011567	-0.096921	1	0.73912
RFA	0.074074	0.325227	0.264853	0.308488	-0.032035	0.044285	-0.002009	0.73812	1

Figure 1. A correlational heat map of the biometric data seen in Table 1 and the left and right foot angles. Cooler colors indicate a stronger positive correlation. Warmer colors indicate a stronger negative correlation.

Nine linear regression models were developed: model 1 testing right foot angle against left foot angle and all 10 biometrics, model 2 testing right foot angle against left foot angle and shoe size, model 3 testing right foot angle against shoe size and age, model 4 testing right foot angle against left foot angle, physical activity level, sports history, and reason for visiting doctor, model 5 testing left foot angle against right foot angle and shoe size, model 6 testing right foot angle against all other biometrics, model 7 testing right foot angle against biometric data with the lowest p values, model 8 testing right foot angle against shoe size, left foot angle, and height, and model 9 testing left foot angle against right foot angle, shoe size, and height. See Table 2 for relevant statistical values.

It was determined that models 8 and 9 were the most statistically relevant to this study and from which conclusions were drawn. Using these three models, it was found that for both foot angles, shoe size, height, and the opposing foot angle were the only relevant factors in predicting the data trend. Using model 9, the adjusted r^2 value for left foot angle against right foot angle, shoe size, and height is 0.549. Using model 8, the adjusted r^2 value for right foot angle against left foot angle, shoe size, and height is 0.522. Note that the p value for the variables included in the optimized linear regressions were as such: shoe size ($p = 0.007$), left foot angle ($p = 0.000$), right foot angle ($p = 0.000$), height ($p = 0.015$, 0.039). There are two different p values for height, as only two height categories in the survey (height 1, 5'11 to 6'1, $p = 0.015$, and height 2, 5'2 to 5'5, $p = 0.039$) had a low enough p value to be considered relevant.

To fulfill the second objective of the study, the average left foot angle was 26.35 degrees, and the average right foot angle was 26.54 degrees.

Additional Data: (Figure 2)

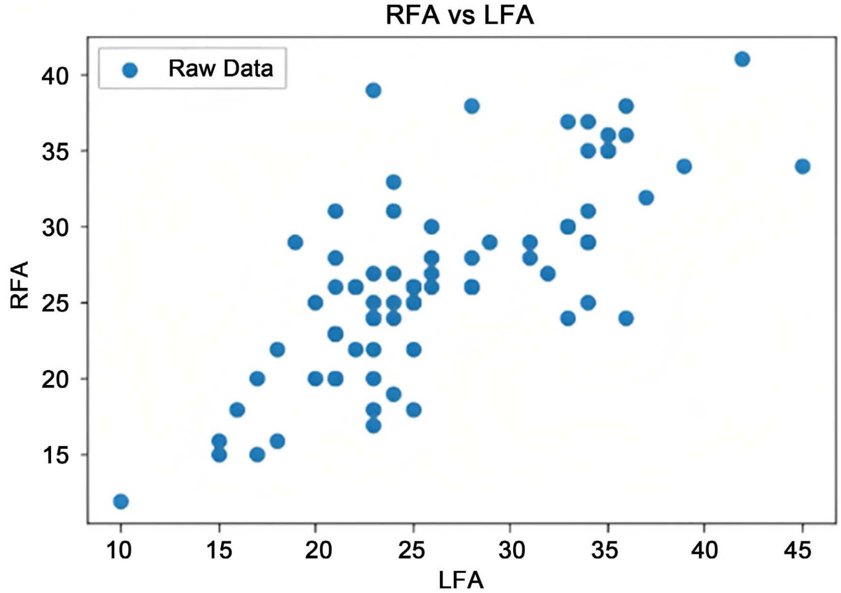

Figure 2. This graph shows the strong positive correlation between Left Foot Angle (LFA) and Right Foot Angle (RFA). Note that this is raw data. Foot angles are measured in degrees.

Table 2. Linear regression calculations for each linear regression model were developed for this data. RMSE is Root Mean Square Error. MSE is Mean Square Error. Models 2, 8 and 9 have the highest adjusted r^2 value. Model 2 only addresses foot angle and shoe size, which makes it less relevant. Note large MSE and RMSE on models 8 and 9.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8	Model 9
r^2	0.630	0.545	0.099	0.529	0.537	0.274	0.697	0.561	0.586
adjusted r^2	0.325	0.533	0.018	0.374	0.524	−0.472	0.386	0.522	0.549
RMSE	4.855	3.810	4.920	6.230	5.091	8.790	10.010	8.430	9.480
MSE	23.572	14.500	24.230	38.818	25.923	77.290	100.260	71.010	89.970

4. Discussion

Foot angle appears to have limited quantitative and statistical significance. These optimized models are only slightly better than using the mean to predict the data, suggesting that on a larger scale, performing statistics on foot angle is not clinically useful, but it is directional. The correlational calculations yielded one strong positive correlation between left and right foot angle, which suggests that in general, foot angles are symmetrical to each other. This is supported by the fact that the average left and right foot angles have a difference of a mere 0.19 degrees. The weak correlations found require further analysis in a study with a larger sample size to confirm or deny statistical significance. The biometric data, with the exception of shoe size, height, and opposing foot angle, have no relationship with foot angle. Shoe size may have overemphasized importance in relation to foot angle due to the nature of measurement. A larger size of shoe being measured in the image taken may yield a higher foot angle simply because the shoe size is larger. Given that shoe size and height are positively correlated, the same could be said for height. A study with a larger sample size may confirm or deny this suggestion. Additionally, the nature of the measurement could have been more precise at the cost of reduced efficiency and increased time spent collecting data. It was left to the subjects' discretion and comfort level to decide to take shoes and socks off for the image to measure foot angle. The most accurate foot angle measurements were with images of subjects' bare feet. However, subjects were not required to have bare feet in the interest of their comfort, time, and safety. This may have resulted in less accurate foot angle data.

Small sample size was a limitation of this study. A larger sample size could bring clarity to correlational calculations. A lack of available resources, such as a sufficient database of foot angles and funding for complex biomechanical analysis technologies, was another limitation.

5. Conclusions

Though foot angle appears to have limited statistical significance, the same cannot be said about its clinical meaningfulness. Along with the survey and images, qualitative data was taken to provide further context to subjects' foot angles. This qualitative data included lifestyle habits, injury history, and other relevant factors that more accurately characterized the data. The qualitative data suggests that foot angle is greater on the lower extremity that has a history of being injured or having muscular tightness. This means that the foot that appears to have greater external rotation may be the leg that has sustained more injuries, trauma, or degradation over time. Given this suggestion, foot angle maintains clinical value because it has the potential to be a marker for injuries and muscle tightness of the lower extremities.

It is suggested that foot angle should be examined more closely in clinical settings, but given its limited quantitative significance, exact measurements of foot angle are unnecessary; rather, foot angle should be analyzed in the context of other qualitative observations such as injury history and lifestyle as well as gait analysis. Studying foot angle alone as part of a treatment plan for a patient would be an incomplete assessment of a patient's musculoskeletal condition. However, foot angle can have high clinical utility when used in conjunction with other musculoskeletal assessments, such as gait analysis.

Conflicts of Interest

There are no conflicts of interest to declare. No funding was provided for this study.

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References

[1] Herradine, P., Gates, L. and Bowen, C. (2018) Real Time Non-Instrumented Clinical Gait Analysis as Part of A Clinical Musculoskeletal Assessment in the Treatment of Lower Limb Symptoms in Adults: A Systematic Review. *Gait & Posture*, **62**, 135-139. https://doi.org/10.1016/j.gaitpost.2018.03.012

[2] Higginson, B.K. (2009) Methods of Running Gait Analysis. *Current Sports Medicine Reports*, **8**, 136-141. https://doi.org/10.1249/JSR.0b013e3181a6187a

[3] Hudson, D. (2016) The Rotational Profile: A Study of Lower Limb Axial Torsion, Hip Rotation, and the Foot Progression Angle in Healthy Adults. *Gait & Posture*, **49**, 426-430. https://doi.org/10.1016/j.gaitpost.2016.08.004

[4] Uhlrich, S.D., Kolesar, J.A., Kidziński, Ł., Boswell, M.A., Silder, A., Gold, G.E., Delp, S.L. and Beaupre, G.S. (2022) Personalization Improves the Biomechanical Efficacy of Foot Progression Angle Modifications in Individuals with Medial Knee Osteoarthritis. *Journal of Biomechanics*, **144**, Article 111312. https://doi.org/10.1016/j.jbiomech.2022.111312

[5] Curran, S.A., Upton, D. and Learmonth, I.D. (2005) Dynamic and Static Footprints: Comparative Calculations for Angle and Base of Gait. *The Foot*, **15**, 40-46. https://doi.org/10.1016/j.foot.2004.12.004

[6] Andrews, M., Noyes, F.R., Hewett, T.E. and Andriacchi, T.P. (1996) Lower Limb

Alignment and Foot Angle Are Related to Stance Phase Knee Adduction in Normal Subjects: A Critical Analysis of the Reliability of Gait Analysis Data. *Journal of Orthopaedic Research*: *Official Publication of the Orthopaedic Research Society*, **14**, 289-295. https://doi.org/10.1002/jor.1100140218

[7] Cibulka, M.T., Winters, K., Kampwerth, T., McAfee, B., Payne, L., Roeckenhaus, T. and Ross, S.A. (2016) Predicting Foot Progression Angle during Gait Using Two Clinical Measures in Healthy Adults, A Preliminary Study. *International Journal of Sports Physical Therapy*, **11**, 400-408.

[8] Redmond, A.C., Crane, Y.Z. and Menz, H.B. (2008) Normative Values for the Foot Posture Index. *Journal of Foot and Ankle Research*, **9**, Article No. 6. https://doi.org/10.1186/1757-1146-1-6

[9] Keenan, A.M., *et al.* (2007) The Foot Posture Index: Rasch Analysis of A Novel, Foot-Specific Outcome Measure. *Archives of Physical Medicine and Rehabilitation*, **88**, 88-93. https://doi.org/10.1016/j.apmr.2006.10.005

[10] Seagers, K., Uhlrich, S.D., Kolesar, J.A., Berkson, M., Kaneda, J.M., Beaupre, G.S. and Delp, S.L. (2022) Changes in Foot Progression Angle during Gait Reduce the Knee Adduction Moment and Do Not Increase Hip Moments in Individuals with Knee Osteoarthritis. *Journal of Biomechanics*, **141**, 111204. https://doi.org/10.1016/j.jbiomech.2022.111204

[11] Rutherford, D.J., Hubley-Kozey, C.L. and Stanish, W.D. (2010) The Neuromuscular Demands of Altering Foot Progression Angle during Gait in Asymptomatic Individuals and Those with Knee Osteoarthritis. *Osteoarthritis and Cartilage*, **18**, 654-661. https://doi.org/10.1016/j.joca.2010.01.005

[12] Chang, A., Hurwitz, D., Dunlop, D., Song, J., Cahue, S., Hayes, K. and Sharma, L. (2007) The Relationship between Toe-Out Angle during Gait and Progression of Medial Tibiofemoral Osteoarthritis. *Annals of the Rheumatic Diseases*, **66**, 1271-1275. https://doi.org/10.1136/ard.2006.062927

[13] de Souza, S.A.F., Faintuch, J., Valezi, A.C., Sant' Anna, A.F., Gama-Rodrigues, J.J., de Batista Fonseca, I.C., Souza, R.B. and Senhorini, R.C. (2005) Gait Cinematic Analysis in Morbidly Obese Patients. *Obesity Surgery*, **15**, 1238-1242. https://doi.org/10.1381/096089205774512627

[14] Russell, E.M., Braun, B. and Hamill, J. (2010) Does Stride Length Influence Metabolic Cost and Biomechanical Risk Factors for Knee Osteoarthritis in Obese Women? *Clinical Biomechanics*, **25**, 438-443. https://doi.org/10.1016/j.clinbiomech.2010.01.016

[15] Ogrodzka, K., Niedźwiedzki, T. and Chwała, W. (2011) Evaluation of the Kinematic Parameters of Normal-Paced Gait in Subjects with Gonarthrosis and the Influence of Gonarthrosis on the Function of the Ankle Joint and Hip Joint. *Acta of Bioengineering and Biomechanics Biomech*, **13**, 47-54.

[16] Rigas, C. (1984) Spatial Parameters of Gait Related to the Position of the Foot on the Ground. *Prosthetics and Orthotics International*, **8**, 130-134. https://doi.org/10.3109/03093648409146073