COMPARISON OF PROTOCOLS FOR DETERMINING THE SUBTALAR JOINT ANGLE

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ABSTRACT

Introduction: Many studies have analyzed the maximum subtalar pronation without any concern over the choice of model for determining this variable. Objective: To compare the maximum subtalar pronation and its moment of occurrence during the stance phase, determined based on two mathematical models consisting of two and four reference points, respectively. Method: Sixteen runners participated in two running economy tests on a treadmill at speeds of 16 and 17 km.h^{-1}. Result: The study showed significant differences in oxygen consumption between the speeds adopted, contrary to the values of maximum subtalar pronation and their moments of occurrence, which did not show any significant differences between the speeds, regardless of the mathematical model adopted. Comparing the two mathematical models, the values of maximum subtalar pronation showed significant differences, regardless of speed. However, the moments of occurrence of maximum subtalar pronation showed no significant differences. Conclusion: The measure of maximum subtalar pronation is influenced by the mathematical model adopted. However, the moment of occurrence of maximum subtalar pronation during the stance phase is independent of the model.

Keywords: Pronation. Subtalar joint. Running.

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INTRODUCTION

During recent decades, the study of human gait has been widely spread among the various sports research centers.[1] Many surveys were developed aiming to study the relationship between physical activity and injuries, particularly those related to running.[2]

Studies associating the behavior of the subtalar joint angle (subtalar pronation) and the type of shoe used for running activities, have achieved significant importance in the pursuit of a better understanding of lesions involving the hip, knee, ankle and foot.[2]

It is widely known in literature that excessive pronation of the subtalar joint of the foot (Figure 1), understood as foot eversion, dorsiflexion and abduction, which occur respectively in the frontal, sagittal and transversal planes, is closely related to joint injuries, particularly of the lower limbs.[3]

The maximum subtalar pronation value, generally reached between 20 and 40% of the stance phase (Figure 2), is mainly influenced by the running linear speed, by muscular unbalance and/or hypermobility joint, and by the running technique imposed by the runner.[3,4]

There are basically two mathematical models used by literature for the determination of subtalar pronation. The first model consists of the use of two reference points, both located in the subject's shoe: marker 1 (M1), located on the lower edge of the shoe, above the sole, and marker 2 (M2), located at the center of the upper edge of the shoe, above the Achilles tendon. In this model, subtalar pronation can be determined through the angle formed between segment M1-M2 (S1) and the vertical axis *y* or between S1 and the axis parallel to the sole of the shoe. (Figure 3a) We can cite as an example of the use of this mathematical model the study of Ferrandis *et al.*[5]

Now the second model consists of the use of four reference points, distributed as follows: markers M1 and M2, the same as the previous model, marker 3 (M3), located at the origin of the Achilles tendon (calcaneal tendon), and marker 4 (M4), located at the origin of the gastrocnemius muscle. Subtalar pronation is determined by the angle formed between segments S1 and S2 (M3-M4) (Figure 3b). We can cite as an example of use of this mathematical model the study of Wit *et al.*[6]

All the authors declare that there is no potential conflict of interest referring to this article.

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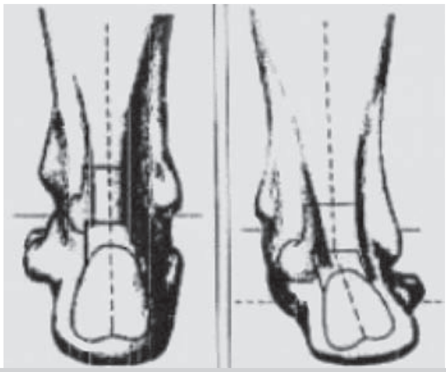


Figure 1 – *Excessive pronation of the subtalar joint*

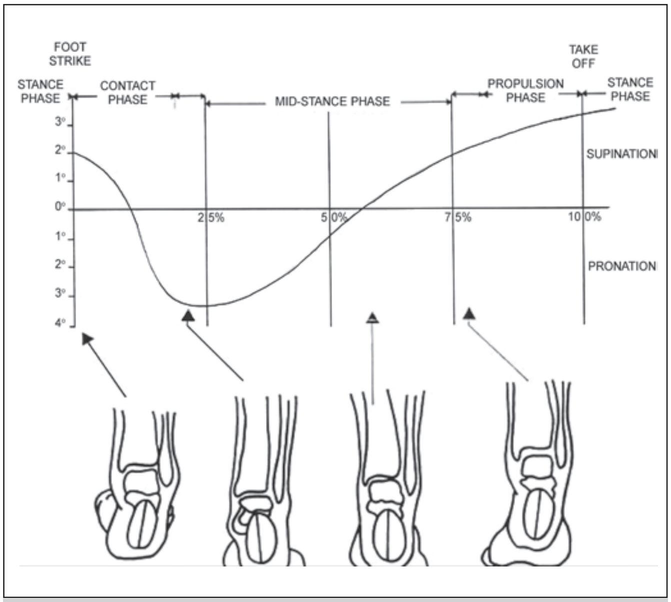


Figure 2 – *Movement of the posterior part of the foot during stance phase.*

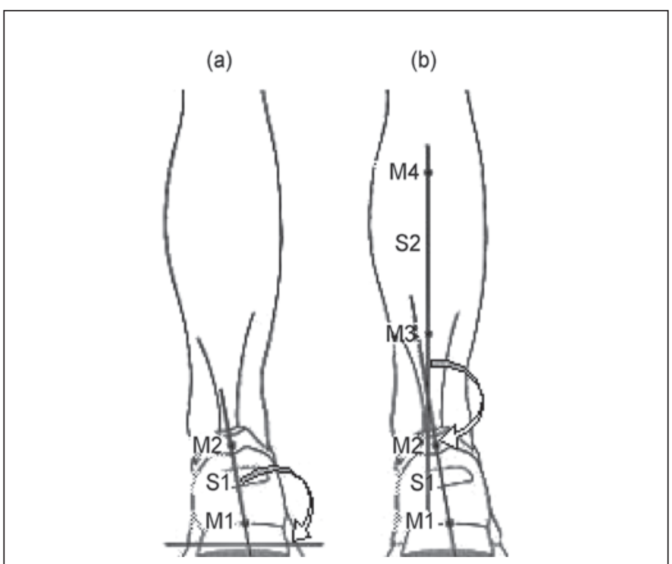


Figure 3 – *Mathematical models of two (a) and four (b) points for calculation of subtalar pronation*

Although both models are used extensively in the calculation of the subtalar joint angle, no study was developed comparing absolute values of maximum subtalar pronation and its moments of occurrence during the stance phase, determined by both methods. Accordingly, the goal was to compare the absolute values of maximum subtalar pronation and its occurrence moments during stance phase, determined by both methods, at two submaximal running speeds.

METHODOLOGY

The sample was composed of 16 active individuals, long-distance runners (10,000 m), selected in a non-random manner, as volunteers, registered with Federação de Atletismo do Estado do Rio Grande do Sul - FAERGS, exempt from physical problems and from pharmacological treatment.

The sample number (*n*) was calculated for this study based on the studies of Tartaruga *et al.*[7] and Williams and Cavanagh[8], through Computer Programs is Epidemiologic Analyses - PEPI, adopting a significance level of 0.05, a power of 80% and a correlation coefficient (*r*) of 0.7. This study was approved by the Ethics Committee of Universidade Federal do Rio Grande do Sul (No. 2007716).

The data gathering activities were developed at Instituto Brasileiro de Tecnologia do Couro, Calçado e Artefato - IBTeC, using a *Muvement* (RT250) treadmill, an *Aerosport* (KB1-C) portable gas analyzer connected to a Pentium *II* 200 MHz microcomputer, a *Punix Progressive Scan* digital camera with sampling frequency of 120 frames per second, a pair of scales and a *Filizola* stadiometer, a *Starrett* tape measure and a *Caliper* skin fold compass.

First of all the body mass, stature, leg length and body fat percentage (%F) data were measured with the use of the scales, the stadiometer, the tape measure and the skin fold caliper. For these measurements, the individuals were barefoot, dressed in a pair of shorts or swimming trunks. The measurement of the leg length was taken on both legs, calculating the distance between the greater trochanter of the femur and the ground. The shoes were weighed separately. The percentage of body fat was calculated by means of the Siri formula.[9]

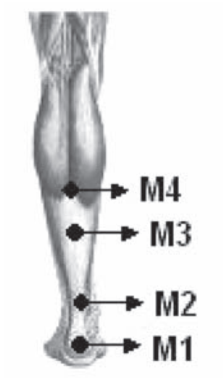
The equation developed by Jackson and Pollock[10], and validated by Petroski[11] for men aged between 18 and 61 years was used to calculate the body density.

Skinfold and perimeter measurements were evaluated by a Physical Education professional with experience in anthropometric evaluations.

Afterwards the participants fixed the anatomical points. The choice of the anatomical points was based on the studies conducted by Ferrandis *et al.*[5] and Wit *et al.*[6] The nomenclature of the anatomical markers used in this study (4 in the posterior frontal plane of the left leg) was taken, among others, from the recommendations made by Wu *et al.*[12] The anatomical markers were distributed according to Figure 4.

The accessories corresponding to ergospirometry were added at the end. A pneumotacograph with variation from 10 to 120 $l.min^{-1}$ was used for mean flow, coupled to a neoprene mask and to the gas analyzer.

Prior to the start of the tests the equipment was calibrated through gases with known concentrations and a calibration of volume was



M4) Ascending gastrocnemius: ascending point of the calcaneal tendon
M3) Descending gastrocnemius: ¼ of the ascending point of the calcaneal tendon
M2) Posterior ankle: ¾ of the ascending point of the calcaneal tendon
M1) Posterior heel: calcaneal tuberosity

Figure 4 – *Posterior view of the left leg*

performed for each range of volume measured. Automatic calibration was performed between each test during the collection session with a basis on the values of ambient gases. The individual values and the barometric pressure value were included after the calibration, according to the solicitation of the equipment.

After the preparation phase, the individuals rested for a while stationary on the walking belt until they reached a respiratory exchange ratio (RER) below 0.95. After this period, the treadmill was turned on and the speed progressively increased up to 10 $km.h^{-1}$, where it was maintained for 2 minutes for warm-up and adaptation. After this the individuals started to run at 16 $km.h^{-1}$ during the first 6 minutes than at 17 $km.h^{-1}$ for a further 6 minutes, totalizing 12 minutes of running. These speeds corresponded to 10% and 5% of average speed at the anaerobic threshold of the group analyzed.

The values referring to ergospirometry were stored from rest up to the end of the ergometric test, in an instantaneous manner, in a microcomputer by means of the use of the *Aerograph* software.

The magnitude of the subtalar joint angle was recorded in the last two minutes of running at each speed through the use of the *Spica* kinematic system. The subjects were filmed for 15 s in the posterior frontal plane using a digital camera. The video camera was placed at an approximate distance of three meters from the study subject and one meter from the ground.

During the data gathering activity, the temperature and the environmental humidity were controlled by an HVAC system. The room temperature was kept at 25 °C and the humidity at 53%, according to the ISO-8573-1 international standards.

All the runners were instructed to use their own training shoes, with rubber soles and without cleats.

The data handling phase started once the data gathering phase had finished. Three pace cycles were analyzed as of the third pace, starting at the fourth and tenth minutes of running.

The submaximal oxygen consumption ($Vo_{2submax}$) values were exported to a Microsoft Excel worksheet, XP version, in which the running economy value (ECO) of each runner was determined with a basis on the mean oxygen consumption values recorded in the last two minutes of test for each speed. ECO means the $Vo_{2submax}$ at a certain submaximal running speed.

The filming sessions were scanned using the *Dvideo* software. After the manual and automatic scanning in two dimensions (2D), they calculated the maximum pronation of the subtalar joint using itself two mathematical models that take into consideration the existence of two and four anatomical points (Figure 5), through two routines developed in the *Matlab* software.

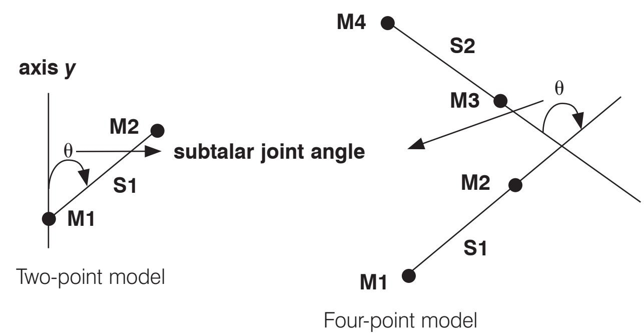


Figure 5 – *Mathematical models for calculation of the subtalar joint angle*

For the statistical treatment, the Shapiro-Wilk test was conducted first for verification of the normality of the data. As the maximum subtalar pronation and submaximal oxygen consumption data at the two submaximal running speeds, presented symmetrical behavior, parametric statistical tests were adopted. The descriptive analysis was carried out with mean and standard deviation and Student's T-test for dependent samples, with $p<0.05$. The statistical package used was the Statistical for Social Sciences Software - SPSS, version 10.0.

RESULTS

Table 1 refers to the sample characterization data.
The mean mass of the shoe used by the sample was 220.31 grams, with standard deviation of ± 87.16 grams.

Table 1 – *Characterization of the sample: mean, standard deviation (SD), minimum and maximum values of the variables age, body mass, stature, leg length, body density, percentage of body fat and performance in 10,000 meter races.*

Variables	Mean	SD	Minimum	Maximum
Age (years)	27.13	± 5.72	20.00	39.00
Body mass (kg)	64.52	± 5.88	53.10	76.30
Stature (m)	1.74	± 0.08	1.64	1.85
Leg length (m)	0.82	± 0.04	0.76	0.92
Body density (g/ml)	1.08	± 0.00	1.07	1.08
Percentage of body fat (%F)	9.11	± 1.48	6.84	11.76
Performance in 10.000m	0:32:40	±0:00:18	0:30:27	0:33:35

Table 2 contains the mean values, the standard errors and the minimum and maximum values of the variables oxygen consumption, maximum pronation angle and moment of occurrence of maximum subtalar pronation during stance phase, both calculated with the use of two and four points, at the speeds of 16 and 17 $km.h^{-1}$.

Table 2 – *Mean, standard deviation (SD), minimum and maximum values of the variables oxygen consumption, maximum pronation angle and moment of occurrence of maximum subtalar pronation during stance phase, both calculated with two and four points, at the speeds of 16 and 17 $km.h^{-1}$.*

Variables	Mean	SD	Minimum	Maximum
16 $km.h^{-1}$				
Oxygen consumption ($ml.kg^{-1}.min^{-1}$)	43.7*	± 3.52	36.0	49.3
Maximum subtalar pronation – 2 pts (degrees)	2.5*a*	± 4.44	-5.6	13.8
Maximum subtalar pronation – 4 pts (degrees)	11.6	± 4.48	0.53	19.6
Moment of occurrence of maximum subtalar pronation during contact phase – 2 pts (%)	48.3	± 12.36	22.7	69.2
Moment of occurrence of maximum subtalar pronation during contact phase – 4 pts (%)	43.3	±10.80	22.7	58.3
17 $km.h^{-1}$				
Oxygen consumption ($ml.kg^{-1}.min^{-1}$)	45.9	± 3.88	36.2	52.5
Maximum subtalar pronation – 2 pts (degrees)	2.6*b*	± 4.76	-5.8	14.4
Maximum subtalar pronation – 4 pts (degrees)	11.1	± 5.04	0.1	20.1
Moment of occurrence of maximum subtalar pronation during contact phase – 2 pts (%)	49.6	± 10.44	30.4	69.2
Moment of occurrence of maximum subtalar pronation during contact phase – 4 pts (%)	42.3	± 13.48	20.8	75.9

Note: Asterisks represent statistically significant differences between the speeds; letters represent statistically significant differences between the two mathematical models for the same speed (*a* for 16 $km.h^{-1}$ *b* for 17 $km.h^{-1}$) Negative values subtalar supination. Rate of significance adopted of 0.05.

The statistical analysis showed significant differences in oxygen consumption between the speeds adopted, contrary to the maximum subtalar pronation values and their moments of occurrence, which did not present significant differences between the independent speeds of the mathematical model adopted. Comparing the two mathematical models, the values of maximum subtalar pronation presented significant differences, regardless of speed. On the other hand, the moments of occurrence of maximum subtalar pronation throughout the stance phase did not exhibit significant differences.

DISCUSSION

Ferrandis *et al.*[5], while analyzing the maximum subtalar pronation determined through the two-point method, did not verify significant differences between the left and right feet of the individuals, in both genders. The same result was verified by Wit *et al.*[6], who encountered similar behaviors in the maximum subtalar pronation values between the right and left feet of the individuals assessed, using the four-point method. Accordingly, the decision was made to analyze the behavior of the left leg of each individual.

Analyzing oxygen consumption, a significant increase was verified with the increase of the running speed. According to Williams and Cavanagh[8], Kyrolainen *et al.*[13], Tartaruga *et al.*[7] and Nummela *et al.*[14], oxygen consumption, directly influenced by the running speed, can significantly alter the magnitude of the biomechanical variables of human locomotion.

In our study, we did not verify a significant increase in maximum subtalar pronation with the increase of speed and of oxygen consumption, regardless of the mathematical model used. Tartaruga *et al.*[3] verified that the maximum subtalar pronation increased significantly from 11 $km.h^{-1}$ to 13 $km.h^{-1}$ (5.87 ± 4.66 degrees to 9.44 ± 5.15 degrees) in the women, and from 14 $km.h^{-1}$ to 16 $km.h^{-1}$ (6.79 + 4.01 degrees to 9.69 ± 3.14 degrees) in the men, demonstrating, contrary to our findings, that the running speed probably directly influences the behavior of the subtalar joint angle. Gheluwe and Madsen[15] demonstrated that the increase of maximum pronation, and that of maximum supination, are directly connected to intensity of effort and not to increase of running linear speed. They adopted the speeds of 13.6 and 16.2 $km.h^{-1}$.

The differences in the findings of our study in relation to the abovementioned studies are probably related to the speeds of 16 and 17 $km.h^{-1}$. Although both gave rise to statistically significant differences in oxygen consumption, the difference in speed might not have been sufficient to result in significant changes in the angular behavior of the subtalar joint, regardless of the mathematical model used. Fromme *et al.*[16] emphasize that speed alone is not capable of influencing the movement of the subtalar joint during running. Muscle fatigue has a significant influence on the angular behavior of the subtalar joint during human locomotion. In our study, the individuals remained running for 6 minutes at each speed. The running time might not have been sufficient to generate muscle fatigue, and consequently, to modify the maximum pronation angle at each one of the speeds adopted.

Likewise, the percentages of the stance phase of maximum subtalar pronation, calculated with two and four points, were not influenced by the change of speed either. The moment of occurrence of maximum subtalar pronation during the stance phase is probably also influenced by the muscle fatigue associated with the running speed.

Regardless of speed, maximum subtalar pronation presented statistically significant differences among the calculation methods adopted. The difference might be related to the movement resulting from segment S2, influenced by the rotation movements along the longitudinal axis and translation movements of the tibia. According to Mcclay and Manal[17], the internal rotation of the tibia is one of the main causes of subtalar pronation, contributing significantly to its absolute value. Likewise, the pronation action of the foot provokes internal rotation of the tibia and of the femur, followed by the rotation of the entire leg. According to the authors, a tibial rotation of 11.1° might entail dorsiflexion of the posterior part of the foot of 18.7°, which allows a higher risk of injury on the hip, knee and ankle.

CONCLUSION

This study verified that the maximum subtalar pronation value measured is influenced by the mathematical model adopted for the calculation of aforesaid variable. Using the mathematical model of two points, both located in the foot, results in lower values of maximum subtalar pronation in comparison with the mathematical model of four points, two in the leg and two in the foot. However, regardless of the mathematical model, the moment of occurrence of greatest subtalar pronation during the stance phase remains the same.

For studies aimed at determining the moment of occurrence of the highest subtalar production over the course of the stance phase, the use of both mathematical models is satisfactory. However, if the objective is to determine the magnitude of maximum subtalar pronation, a variable that significantly influences musculoarticular injuries in the ankle and knee region, the use of the four-point model is recommended due to the influence of tibial inclination.

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REFERENCES

1. Conley DL, Krahenbuhl GS. Running economy and distance running performance of highly trained athletes. Med Sci Sports Exerc. 1980;12:357-60.
2. James SL, Bates BT, Osternig LR. Injuries to runners. Am J Sports Med. 1978;6:40-50.
3. Tartaruga LAP, Tartaruga MP, Black GL, Coertjens M, Ribas LR, Kruel LFM. Comparação do ângulo da articulação subtalar durante velocidades submáximas. Acta Ortop Bras. 2005;13:57-60.
4. Santos JOLD, Nazario PF, Palhano R, Manfio EF, Nabinger E, Zaro MA et al. Análise do movimento de eversão do calcanhar e comportamento do centro de pressão plantar (COP) durante a marcha em diferentes velocidades. Tecnicouro. 2007;231:42-6.
5. Ferrandis R, García AC, Ramiro J, Hoyos JV, Vera P. Rearfoot motion and torsion in running: the effects of upper vamp stabilizers. J Appl Biomech. 1994;10:28-42.
6. Wit BD, Clercq DD, Leonoir M. The effect of varying midsole hadness on impact forces and foot motion during foot contact in running. J Appl Biomech. 1995;11:395-406.
7. Tartaruga LAP, Tartaruga MP, Ribeiro JL, Coertjens M, Ribas LR, Kruel LFM. Correlação entre economia de corrida e variáveis cinemáticas em corredores de alto nível. Rev Bras Biomec. 2004;5:51-8.
8. Williams KR, Cavanagh PR. Relationship between distance running mechanics, running economy, and performance. J Appl Physiol. 1987;63:1236-45.
9. Siri WE. Body composition from fluid spaces and density: analysis of methods. 1961. Nutrition. 1993;9:480-91.
10. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. Br J Nutr. 1978;40:497-504.
11. Petroski EL. Desenvolvimento e validação de equações generalizadas para predição da densidade corporal. [Tese]. Santa Maria: Universidade Federal de Santa Maria; 1995.
12. Wu G, Siegler S, Allard P, Kirtley C, Leardini A, Rosenbaum D et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion--part I: ankle, hip, and spine. International Society of Biomechanics. J Biomech. 2002;35:543-8.
13. Kyrolainen H, Belli A and Komi PV. Biomechanical factors affecting running economy. Med Sci Sports Exerc. 2001;33:1330-7.
14. Nummela A, Keranen T, Mikkelsson LO. Factors related to top running speed and economy. Int J Sports Med. 2007;28:655-61.
15. Gheluwe BV, Madsen G. Frontal rearfoot kinematics in running prior to volitional exhaustion. J Appl Biomech. 1997;13:66-75.
16. Fromme A, Winkelmann F, Thorwesten L, Reer R, Jerosch J. Pronation angle of the rear foot during running in relation to load . Sportverletz Sportschaden. 1997;11:52-7.
17. Mcclay I, Manal K. Coupling parameters in runners with normal and excessive pronation. J Appl Biomech. 1997;13:109-24.