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Validity and reliability of clinical tests for assessing passive ankle stiffness

Validade e confiabilidade de medidas clínicas para avaliação da rigidez passiva da articulação do tornozelo

Vanessa L. Araújo, Viviane O. C. Carvalhais, Thales R. Souza, Juliana M. Ocarino, Gabriela G. P. Gonçalves, Sérgio T. Fonseca

Abstract

Background: The presence of inadequate levels of passive ankle stiffness have been associated with the occurrence of movement disorders, the development of pathological conditions and the reduction in the performance of functional activities such as walking, running and jumping. Therefore, clinical tests to evaluate ankle stiffness may be useful for the physical therapy assessment. **Objectives:** To investigate the concurrent validity and the intra- and inter-examiner reliability of clinical measures developed to assess passive stiffness of the ankle joint during dorsiflexion movement. **Methods:** Fifteen healthy participants underwent to test-retest evaluations of their ankles by two examiners. Two clinical measures were performed: 'position of first detectable resistance' and 'change in passive resistance torque'. The results of these tests were compared to the passive stiffness measured with an isokinetic dynamometer, in which the electromyography activity of specific muscles was monitored to ensure that the test was performed passively (gold standard measure). **Results:** Pearson correlation coefficients ranged from $r=-0.81$ to -0.88 ($p<0.001$) for the correlation between the passive ankle stiffness measured with the isokinetic dynamometer and the results of the clinical measure 'position of the first detectable resistance'. For the measure of 'change in passive resistance torque', these coefficients ranged from $r=0.72$ to 0.83 ($p<0.004$). The Intraclass Correlation Coefficients (ICCs) for the intra- and inter-examiner reliability ranged from 0.75 to 0.98. **Conclusion:** The clinical measures presented satisfactory validity and reliability to be used in clinical practice.

Keywords: passive stiffness; clinical test; ankle; validity of tests; reproducibility of results.

Resumo

Contextualização: Níveis inadequados de rigidez passiva do tornozelo têm sido associados à ocorrência de disfunções de movimento, ao desenvolvimento de patologias e à redução no desempenho em atividades como marcha, corrida e salto. Testes clínicos para investigar a rigidez dessa articulação podem ser úteis no processo de avaliação fisioterápica. **Objetivos:** Investigar a validade concorrente e as confiabilidades intra e interexaminadores de medidas clínicas para avaliação da rigidez passiva do tornozelo durante o movimento de dorsiflexão. **Métodos:** Quinze voluntários saudáveis foram submetidos a avaliações teste-reteste do tornozelo por dois examinadores. Duas medidas clínicas foram realizadas: "posição de primeira resistência detectável" e "mudança do torque passivo de resistência". Os resultados desses testes foram comparados à medida da rigidez passiva realizada com um dinamômetro isocinético, no qual a atividade eletromiográfica dos músculos foi monitorada para garantir que o teste fosse realizado passivamente (medida padrão-ouro). **Resultados:** Os Coeficientes de Pearson variaram de $r=-0,81$ a $-0,88$ ($p<0,001$) para a correlação entre a medida da rigidez com o dinamômetro isocinético e os resultados da medida "posição de primeira resistência detectável". Para a medida "mudança do torque passivo de resistência", esses coeficientes variaram de $r=0,72$ a $0,83$ ($p<0,004$). Os Coeficientes de Correlação Intraclass (CCIs) obtidos para as confiabilidades intra e interexaminadores variaram de 0,75 a 0,98. **Conclusão:** Os testes propostos apresentaram validade e confiabilidades satisfatórias para serem utilizados na prática clínica.

Palavras-chave: rigidez passiva; teste clínico; tornozelo; validade dos testes; reprodutibilidade dos resultados.

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Introduction ::::

Joint stiffness is a mechanical property related to the resistance that a joint provides to the movement, being graphically represented by the slope of the torque-angle curve¹. This resistance is due to the stiffness of the tissue surrounding the joints^{1,2}. Faced with an external perturbation, the greater the stiffness presented by these tissues, the faster the joint reaches a resistance torque sufficient to avoid the prolongation of joint displacement^{1,3}. Stiffness regulation can be determined either by muscle contraction and passive mechanisms^{1,2}. The passive components may act to allow that the resistance to joint movement occurs with the lowest possible muscle activity and therefore, with a lower energy expenditure^{4,5}. Depending on the magnitude of resistance torque that a joint needs to generate, the passive mechanisms may be sufficient to resist undesirable movements or they may act as a complementary mechanism of muscle activation⁵⁻⁹. Therefore, the contribution of the passive components in stiffness is necessary to allow the occurrence of appropriate movement patterns with a lower energy expenditure^{4,5}.

The level of passive ankle stiffness may influence the kinetic and kinematic characteristics of gait, running and jumping^{6,10,11}. Salsich and Mueller⁶ have shown that the total torque of plantar flexion (PF) generated during the stance phase of the gait is influenced from both the contraction of the plantar flexion and the passive stiffness of these muscles⁶. In addition, during the preparation phase for the jump, an appropriate stiffness of the ankle can promote the absorption and the storage of elastic potential energy and the reuse of this energy in the following muscle contraction¹⁰⁻¹². Thus, low passive ankle stiffness may demand an excessive activity of the muscles of this joint, predisposing them to fatigue and possible injuries^{5,13}. In contrast, an excessive increase of the passive resistance to dorsiflexion (DF) movement during the mid stance phase of gait could hamper the progression of the tibia on the talus, which favors the occurrence of an excessive compensatory pronation of the subtalar joint^{14,15}. This movement dysfunction has been associated to the occurrence of injuries, such as patellofemoral syndrome^{16,17}, plantar fasciitis¹⁴ and medial tibial stress syndrome¹⁸⁻²⁰. Therefore, reduced or excessive levels of passive ankle stiffness may be associated to biomechanical changes during gait, running and jumping; to a reduction in the performance of these activities and to the development of pathologies.

The ankle joint stability, i.e., the ability of this joint to resist to external disturbances is also influenced by the passive stiffness of the tissues around the joint^{5,8}. Loram, Maganaris and

Lakie⁵ concluded that nearly 70% of the ankle stiffness required for maintaining the stability during orthostatic posture is provided by the passive components, being some subjects produce 100% of this stiffness passively⁵. Moreover, ankle stiffness during running on unstable surfaces seems to be influenced by the passive tension of the gastrocnemius muscle⁸. Therefore, reduced levels of passive ankle stiffness can compromise the joint stability, facilitating the occurrence of ankle sprains and ligament injuries.

The investigation of passive ankle stiffness during DF movement may be useful in clinical practice, since this property is related to the development of pathologies^{6,14,15} and may be modified through physical therapy interventions²¹⁻²³. However, isokinetic dynamometer, the gold standard instrument for the assessment of stiffness²⁴, is not accessible for the majority of therapists. Clinical measures for evaluating the passive stiffness of the glenohumeral joint²⁵ and of the lumbar spine²⁶ were developed in previous studies, but still there are no clinical methods that allow the investigation of this property in the ankle joint.

One possible way to infer about the magnitude of the passive ankle stiffness based on the definition of this property¹, would be to determine if the angle in which the torque of passive resistance generated by the ankle plantar flexors equals a certain external torque that tends to displace the joint in DF direction. This angle could be called "position of the first detectable resistance" and, the greater the stiffness presented by the joint, the smaller would be this angle. Another approach to measure the passive stiffness would be to calculate the difference between the resistance torques recorded in two specific positions of the ankle joint in order to determine the increase of this torque after joint displacement. This measure could be called "change in passive resistance torque". For this measures being used consistently, it is crucial to determine their validity and reliability^{27,28}. Therefore, the objectives of this study were: (a) to investigate the concurrent validity between the clinical measurements ("position of the first detectable resistance" and "change in passive resistance torque") and the measurement of passive stiffness performed with the isokinetic dynamometer; (b) to determine the intra- and inter-examiner reliability of these clinical measures.

Methods ::::

Sample

Fifteen healthy subjects participated in this study (seven men and eight women), with a mean age of 24.06 ± 3.35 years, a

mean body mass of 62.10 ± 9.70 kg, a mean height of 1.68 ± 0.08 m and a mean body mass index (BMI) of 21.83 ± 2.31 kg/m². The mean foot length was of 0.16 ± 0.01 m and 93% of the participants were right-handed. The inclusion criteria of this study were age between 18 and 35 years-old, absence of symptoms in the lower limbs and a minimal DF range of motion of 10°. The subjects unable to maintain the ankle muscles relaxed during testing procedures were excluded. This study has been approved by the Ethics Committee of Research of the Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, MG, Brazil, under the protocol ETIC 136/08, and the participants signed a informed consent form.

Procedures

A scale with altimeter was used to measure body mass and height of the participants. The foot length was recorded according to the references proposed by Winter²⁹. The dominant limb was chosen for assessment.

Measurement of passive stiffness with the isokinetic dynamometer

The measurement of the passive resistance torque (PRT) produced by the ankle was performed using an isokinetic dynamometer (Biodex System 3 Pro, Shirley, USA) in the passive operation mode (speed: 5°/s). The participant remained in supine, with the knee in extended position, the foot fixed in a base and the lateral malleolus aligned with the rotation axis of the device (Figure 1). An inclinometer was used for positioning the leg horizontally. Dynamometer lever performed the DF movement from 5° of PF to 10° of DF, being the neutral position (0°) defined as an angle of

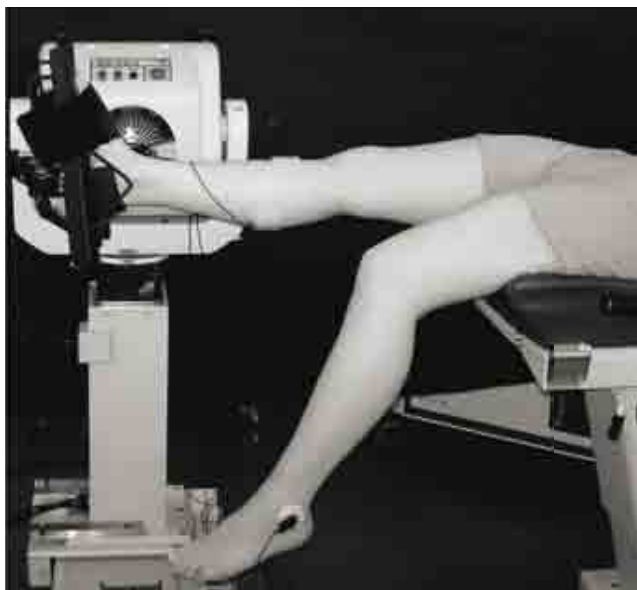


Figure 1. Measure of passive ankle stiffness with an isokinetic dynamometer.

90° formed between the base of support for the foot and the subject's leg. The participants were instructed not to resist or to voluntarily assist handler displacement. A total of five repetitions were performed for viscoelastic accommodation of the tissues and then, three valid repetitions of the test were carried out. One repetition of the lever movement was performed without the participant in order to record the torque generated only by the lever weight.

During the assessment of the PRT, the electromyographic activity of the medial gastrocnemius, soleus and tibialis anterior muscles was monitored with the purpose to ensure that the test was performed passively. Pairs of active surface electrodes were placed over the area of greater muscle belly, after of the procedures of trichotomy and skin cleansing³⁰. Muscle activity monitoring was performed using a program developed in the Matlab software (The Mathworks Inc.), which considered as muscle activity those in which the electromyographic signal was equal to or greater than the mean plus two standard deviations of the signal obtained during the muscle rest³¹. When the muscle activity was detected, the test was replaced by a new trial. Electromyographic data were collected with an electromyograph MP100 (Biopac System, Goleta, EUA), at a frequency of 1000Hz and processed with a 4th order Butterworth Bandpass filter and cutoff frequencies of 10Hz and 500Hz.

Data provided by the isokinetic dynamometer was processed using a program for calculating the passive ankle stiffness developed in the Matlab software. These data were filtered with a 4th order Butterworth low-pass filter, with cut-off frequency of 1.25Hz. The torques produced by the weight of the participant's foot were calculated based on joint displacement and on the anthropometric table from Winter²⁹. Subsequently, the torques generated by foot and dynamometer lever weights were subtracted from the total torque provided by the isokinetic dynamometer. The stiffness was calculated as the average slope of the torque-angle curve³² in the interval between 5° of PF and 10° of DF, since in this amplitude the plantar flexors muscles are tensioned and the stiffness of these muscles would have a considerable influence on ankle function during functional activities. The mean stiffness values from the three trials were calculated (Nm/rad). The measurement of passive stiffness with the isokinetic dynamometer was previously performed with seven subjects and presented an excellent test-retest reliability estimate (0.98)²⁷.

Clinical measures for the assessment of passive stiffness

The clinical measures for the assessment of passive ankle stiffness were performed in a random sequence, by two trained examiners. During the training period, the

examiners performed the clinical tests in fifteen subjects over two weeks, and in five subjects the tests were performed in the presence of both examiners with the purpose of discussing the difficulties presented. In the study, the measurements were repeated by the same examiners after a period of one week. Initially, five repetitions of the DF movement were performed to allow viscoelastic accommodation. During the tests, the ankle muscles should remain relaxed and if any signs of contraction were observed (visually or by palpation) the test was repeated.

Position of the first detectable resistance of the ankle joint

The “position of the first detectable resistance” was defined as the angle in which the resistance torque produced by the joint was equal to a standardized external torque. During the test, the subject was positioned in prone, with the knee at 90° of flexion and the ankle in the resting position, i.e., the position in which the ankle muscles were relaxed (Figure 2). A ankle weight (2 kg) was positioned on the plantar surface of the foot at a distance of 8 cm from the lateral malleolus, measured in the lateral border of the foot. This procedure was necessary because during the pilot study the torque generated by the foot weight (without the ankle weight) was not sufficient for tensioning the plantar flexors, and the position assumed by the ankle was almost the same regardless of the gravity favoring or not the DF movement. Therefore, the mean torques generated by the weight of the feet of the participants from the pilot study was calculated²⁹, and it was decided to add a weight capable to triplicate this mean torque. After the addition of the ankle weight, the position assumed by the ankle was measured using a goniometer. The stationary arm of the goniometer was positioned over a line that connected the head of the fibula to the center of the malleolus, while the movable arm was aligned parallel to the lateral border of the foot. The goniometer axis was positioned 1 cm below the lateral border of the foot according to the fibula line direction. Thus, the “position of the first detectable resistance” corresponded to the position in which the torque generated by the weight of the complex ankle weight-foot was equal to the DF resistance torque produced by the ankle. This measure was determined in degrees using the mean of the three test trials.

Change of the ankle resistance passive torque

During this test, the subject remained in prone position with the knee flexed at 90°. A manual dynamometer (MICROFET 2, Draper, USA) was placed over the plantar surface of the foot, at a distance of 8 cm from the lateral malleolus, measured on the lateral border of the foot (Figure 3). The examiner should move the ankle in DF, applying a force perpendicular to the plantar surface of the foot.

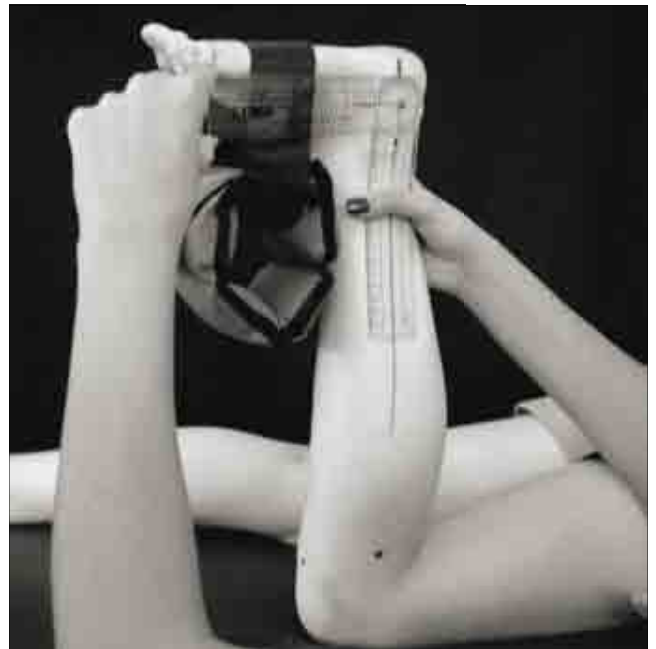


Figure 2. Clinical measure of “position of first detectable resistance” of the ankle joint.



Figure 3. Clinical measure of “change in passive resistance torque” of the ankle joint.

The manual dynamometer registered, in the low-threshold mode, the ankle passive peak resistance force generated at 5° of PF and 10° of DF. The determination of these angles was performed with the goniometer according the references described above. This measurement was performed five times, being the highest and lowest force values registered in each specific position. The mean of the three remaining values was calculated. The force values were transformed in PRTs by multiplying the force by the length of the lever arm (8 cm). Subsequently, the difference between the peak PRTs found at 10° of DF and at 5° of PF, measured in Newton-meters (Nm) was determined.

Statistical analysis

Pearson's Correlation Coefficient was used to determine the level of agreement between the results of the clinical measures and the passive stiffness values obtained with the isokinetic dynamometer. This analysis used the mean of results from the clinical tests conducted in the first and second assessment days, for each examiner. Intra and inter-examiners reliabilities were calculated using the Intraclass Correlation Coefficient (ICC). The significance level was set at 0.05. The standard error of measurement (SEM) was calculated for each clinical test.

Results

Pearson's Coefficients obtained from the data of the first examiner were $r = -0.88$ ($p < 0.001$) and $r = 0.83$ ($p < 0.001$) for the correlation between the stiffness measurement performed with the isokinetic dynamometer and the measures "position

of the first detectable resistance" and "change in passive resistance torque", respectively (Figure 4). For the second examiner, these coefficients were $r = -0.81$ ($p < 0.001$) and $r = 0.72$ ($p = 0.003$) (Figure 4). The ICCs obtained for the intra and inter-examiner reliability ranged from 0.75 to 0.98. Reliability values related to each test, the means values, standard deviations (SD) and SEM are shown in Table 1.

Discussion

The Pearson's Correlation Coefficients obtained in the present study have shown that the clinical measurements are significantly correlated with the gold-standard measure of passive ankle stiffness. Portney and Watkins²⁷ consider that the correlation coefficients above 0.75 represent a good to excellent correlation, and the values ranging between 0.50 to 0.75 suggest a moderate to good validity. Other authors considered valid clinical measurements that presented a correlation coefficient equal or greater than

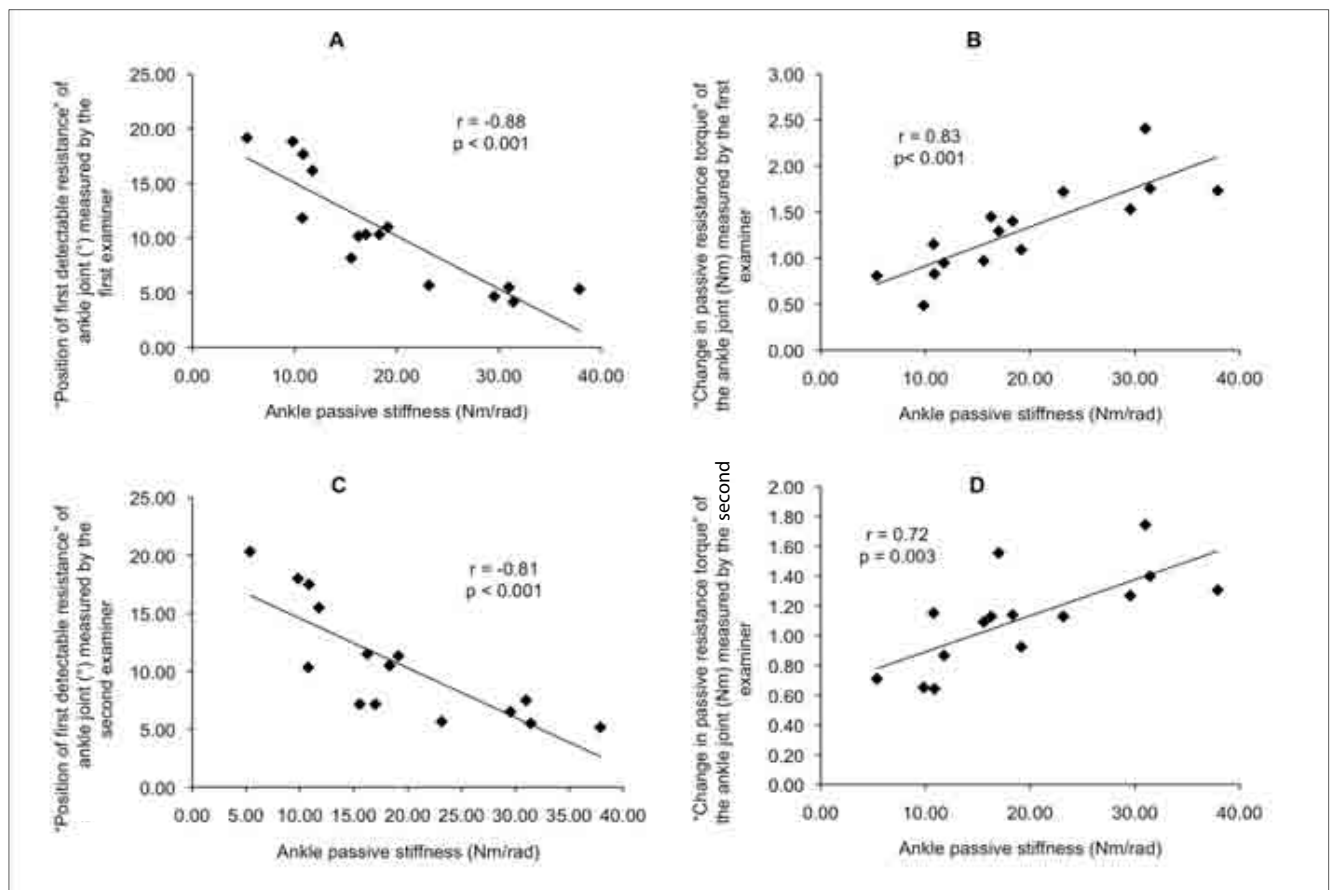


Figure 4. Scatter plots of the association between the passive stiffness measured with an isokinetic dynamometer and: A) "position of first detectable resistance" measured by the first examiner; B) "change in passive resistance torque" measured by the first examiner; C) "position of first detectable resistance" measured by the second examiner; D) "change in passive resistance torque" measured by the second examiner.

Table 1. Means, standard deviations (SD), Intra-class Correlation Coefficients (ICC) and Standard Errors of Measurement (SEM) for the clinical measures of “position of the first detectable resistance” and “change in passive resistance torque” of the ankle joint.

	“Position of first detectable resistance” of the ankle joint		“Change in passive resistance torque” of the ankle joint	
	Mean (°)	SD (°)	Mean (Nm)	SD (Nm)
E1(1)	10.89	4.90	1.37	0.52
E1(2)	10.31	5.69	1.24	0.52
E2(1)	10.18	4.89	1.15	0.39
E2(2)	11.11	5.50	1.08	0.31
	ICC	SEM	ICC	SEM
E1(1) X E1(2)	0.97	0.86	0.87	0.18
E2(1) X E2(2)	0.93	1.42	0.80	0.16
E1(1) X E2(1)	0.98	0.74	0.87	0.17
E1(2) X E2(2)	0.97	1.03	0.75	0.21

Positive angles values indicate positions of ankle dorsiflexion. Positive torque values indicate resistance to dorsiflexion of the ankle joint. E1=examiner one; E2=examiner two. (1)=test; (2)=re-test.

0.57³³⁻³⁵. Considering that the Pearson's Correlation Coefficients found in the present study were higher than 0.72, the clinical measures presented a satisfactory correlation with the measurement of stiffness performed with the isokinetic dynamometer. In addition, the ICC values of the measure “position of the first detectable resistance” indicates an excellent reliability, while the ICC values of the measure “change in passive resistance torque” represents good reliability²⁷. Other studies that investigated the reliability of clinical measures for assessing the glenohumeral joint and lumbar spine stiffness had also found reliability ranging from good to excellent^{25,26,36}. These studies highlighted the relevance of the existence of reliable clinical measures for the assessment of passive stiffness. Therefore, this study demonstrated that the proposed measures have shown satisfactory validity and reliability for clinical use.

The lowest correlation coefficient and ICC values found for the measure “change in passive resistance torque” can be explained by the difficulty to register the force resistance at 10° of ankle DF (due to the high tension of the plantar flexors). At this angle, the examiner needed to perform a large amount of force on the plantar surface of the foot, while controlling the amplitude through goniometry. Thus, the difficulty to perform this test may justify the results found. However, such results still support the use of this test.

Regarding the measure “position of the first detectable resistance”, the higher the passive resistance provided by the tissues, the lower the ankle displacement in DF and the smaller the angle registered. Thus, subjects whom obtained the highest values of stiffness measured with the dynamometer showed lower values in the measure “position of the first detectable resistance”, justifying the negative correlation between these measures.

The SEM values found in this study can be used as a reference to detect changes in the results of the clinical measures that may have occurred due to measurement error. These values can be useful in monitoring the evolution of patients, and changes in the results of the clinical tests below the SEM do not evidence a real change in stiffness.

Stiffness measurements are influenced by the torques produced by foot weight. In the assessment with isokinetic dynamometer, the results obtained were normalized by these torques, while, in clinical measurements, the results were not normalized, which could lead to challenge the validity of the clinical measurements. In order to verify the influence of this factor in the correlations obtained, an additional analysis was performed using the values of the clinical measurements normalized by the foot torque. The values of correlation coefficient were similar to those obtained without the normalization by the torques. The correlation coefficients found after correction by the foot torque, according to the results of the first examiner, were: $r=-0.82$ for the measure “position of the first detectable resistance” and $r=0.83$ for the measure “change in passive resistance torque”. The small foot weight and its small variability among the subjects seem to justify the similarity of the correlation values and, therefore, the influence of the torque produced by the foot weight on the clinical measurements could be ignored. Thus, the measurements can be used without the normalization by the foot torque in order to facilitate their use in clinical practice.

The measurement of passive stiffness with the isokinetic dynamometer was performed with the knee in extension, since during the stance phase of gait, the knee maintains ranges of motion close to the extension and, therefore, to investigate the stiffness in this condition would be functionally relevant. However, it was not possible to measure “change in passive resistance torque” with the knee in extension, because of the increase in stiffness of the ankle

in this position that offered difficulty for the examiners to register the force of resistance at 10° of DF, while they were controlling the amplitude. In addition, the execution of the measurement “position of the first detectable resistance” with the knee extended would preclude the placement of the ankle weight on plantar surface of the foot. However, the different knee positions used, although they generate different tensions in uni- and bi-articular muscles, did not compromise the usefulness of clinical measurements to inform about the values of the gold-standard measurement. This may be explained by the fact that subjects with higher levels of stiffness with the knee extended are probably those with higher levels of stiffness with the knee flexed.

The clinical measures proposed are not applicable for subjects presenting pain or muscle spasms during the test execution, since they would be unable to maintain the ankle muscles relaxed. Moreover, one of the inclusion criteria of the present study was the presence of a range of motion of at least 10° of DF, and therefore, the clinical measures cannot be applied for this group of subjects.

The participants of the present study presented BMI up to 27 Kg/m² which makes it difficult to generalize the results to the entire population. Besides that, lower values of correlation coefficient and ICC are expected if the clinical measurements are performed by examiners without previous training. Finally, this study did not have the purpose to classify the ankle stiffness values as low, normal or high, and still there is no evidence that allow such classification.

Several tests and scales are proposed for evaluating the flexibility^{37,38} and spasticity³⁹ of the ankle plantar flexors and often these tests are used in clinical practice to infer about ankle passive stiffness⁴⁰. However, in contrast to the passive stiffness, flexibility measurement is not only determined by mechanical properties, since it is influenced by individual levels of tolerance to stretching⁴¹. Some studies have shown that less than 30% of the variability found in stiffness measurement may be explained by flexibility^{40,42}. The spasticity involves reflex muscle activation during the performance of a passive movement⁴³, while the measurement of the passive stiffness requires the electromyographic silence of the muscles¹. Thus, the passive stiffness provides more

appropriate and objective information on the joint mechanics than the measures of flexibility and spasticity^{40,42,44}.

The proposed clinical tests used simple and accessible instruments for physical therapist's practice. These tests can be used during the evaluation of patients with conditions related to ankle stiffness changes and are useful in the investigation of the existence of asymmetry between limbs. In addition, these measures present applicability in prevention, since the tests may be used to identify subjects requiring interventions targeting change of the ankle levels of stiffness, with the purpose to prevent the occurrence of injuries. In the situations where ankle stiffness needs to be modified, techniques of muscle strengthening and stretching are efficient to increase or decrease stiffness levels²¹⁻²³. Despite the measures contribute for professional practicing, it is necessary that further studies investigating the relationship between the results of these measures and the presence of movement dysfunctions and pathologies. Thus, the clinical measures proposed allow the therapist to investigate a relevant joint property that may be clinically modified to rehabilitate or prevent injuries.

Conclusion

The present study demonstrated that the tests proposed could inform about the levels of passive ankle stiffness during DF. Although both tests have shown satisfactory validity and reliability, the measure “position of the first detectable resistance” is suggested for clinical practice since it requires the use of simpler instruments and showed higher values for the Pearson's correlation coefficients and ICC.

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References

1. Latash ML, Zatsiorsky VM. Joint stiffness: Myth or reality? *Hum Mov Sci.* 1993;12(6):653-92.
2. Obusek JP, Holt KG, Rosenstein RM. The hybrid mass-spring pendulum model of human leg swinging: stiffness in the control of cycle period. *Biol cybern.* 1995;73(2):139-47.
3. Fonseca ST, Ocarino JM, Silva PLP, Aquino CF. Integration of stress and their relationship to the kinetic chain. In: Magee DJ, Zachazewski JE, Quillen WS, editors. *Scientific foundations and principles of practice in musculoskeletal rehabilitation*. St Louis: Saunders Elsevier; 2007. p. 476-86.
4. Gleim GW, Stachenfeld NS, Nicholas JA. The influence of flexibility on the economy of walking and jogging. *J Orthop Res.* 1990;8(6):814-23.
5. Loram ID, Maganaris CN, Lakie M. The passive, human calf muscles in relation to standing: the non-linear decrease from short range to long range stiffness. *J Physiol.* 2007;584(Pt 2):661-75. Epub 2007 Sep 6.
6. Salsich GB, Mueller MJ. Effect of plantar flexor muscle stiffness on selected gait characteristics. *Gait Posture.* 2000;11(3):207-16.
7. Moritz CT, Farley CT. Passive dynamics change leg mechanics for an unexpected surface during human hopping. *J Appl Physiol.* 2004;97(4):1313-22.
8. Müller R, Grimmer S, Blickhan R. Running on uneven ground: leg adjustments by muscle pre-activation control. *Hum Mov Sci.* 2010;29(2):299-310. Epub 2010 Mar 20.

9. Morasso PG, Sanguineti V. Ankle muscle stiffness alone cannot stabilize balance during quiet standing. *J Neurophysiol*. 2002;88(4):2157-62.
10. Granata KP, Padua DA, Wilson SE. Gender differences in active musculoskeletal stiffness. Part II. Quantification of leg stiffness during functional hopping tasks. *J Electromyogr Kinesiol*. 2002;12(2):127-35.
11. Stefanyshyn DJ, Nigg BM. Dynamic angular stiffness of the ankle joint during running and sprinting. *J Appl Biomech*. 1998;14(3):292-9.
12. Lindstedt SL, Reich TE, Keim P, LaStayo PC. Do muscles function as adaptable locomotor springs? *J Exp Biol*. 2002;205(Pt 15):2211-6.
13. Woods C, Hawkins R, Hulse M, Hodson A. The Football Association Medical Research Programme: an audit of injuries in professional football: an analysis of ankle sprains. *Br J Sports Med*. 2003;37(3):233-8.
14. McPoil TG, Brocato RS. The foot and ankle: biomechanical evaluation and treatment. In: Gould JA, editor. *Orthopaedic and sports physical therapy*. St. Louis: CV Mosby; 1985. p. 313-41.
15. Hintermann B, Nigg BM. Pronation in runners. Implications for injuries. *Sports Med*. 1998;26(3):169-76.
16. Barton CJ, Levinger P, Menz HB, Webster KE. Kinematic gait characteristics associated with patellofemoral pain syndrome: a systematic review. *Gait Posture*. 2009;30(4):405-16.
17. Tiberio D. The effect of excessive subtalar joint pronation on patellofemoral mechanics: a theoretical model. *J Orthop Sports Phys Ther*. 1987;9(4):160-5.
18. Bennett JE, Reinking MF, Pluemer B, Pentel A, Seaton M, Killian C. Factors contributing to the development of medial tibial stress syndrome in high school runners. *J Orthop Sports Phys Ther*. 2001;31(9):504-10.
19. Willems TM, De Clercq D, Delbaere K, Vanderstraeten G, De Cock A, Witvrouw E. A prospective study of gait related risk factors for exercise-related lower leg pain. *Gait Posture*. 2006;23(1):91-8. Epub 2005 Jan 13.
20. Willems TM, Witvrouw E, De Cock A, De Clercq D. Gait-related risk factors for exercise-related lower-leg pain during shod running. *Med Sci Sports Exerc*. 2007;39(2):330-9.
21. Ocarino JM, Fonseca ST, Silva PL, Mancini MC, Gonçalves GG. Alterations of stiffness and resting position of the elbow joint following flexors resistance training. *Man Ther*. 2008;13(5):411-8. Epub 2007 Jun 6.
22. Klinge K, Magnusson SP, Simonsen EB, Aagaard P, Klausen K, Kjaer M. The effect of strength and flexibility training on skeletal muscle electromyographic activity, stiffness, and viscoelastic stress relaxation response. *Am J Sports Med*. 1997;25(5):710-6.
23. Mahieu NN, McNair P, De Muynck M, Stevens V, Blanckaert I, Smits N, et al. Effect of static and ballistic stretching on the muscle-tendon tissue properties. *Med Sci Sports Exerc*. 2007;39(3):494-501.
24. Chesworth BM, Vandervoort AA, Koval JJ. A pilot study to compare the subjective and objective evaluation of passive ankle joint stiffness. *Physiother Can*. 1991;43:13-8.
25. Lin JJ, Yang JL. Reliability and validity of shoulder tightness measurement in patients with stiff shoulders. *Man Ther*. 2006;11(2):146-52.
26. Gombatto SP, Klaesner JW, Norton BJ, Minor SD, Van Dillen LR. Validity and reliability of a system to measure passive tissue characteristics of the lumbar region during trunk lateral bending in people with and people without low back pain. *J Rehabil Res Dev*. 2008;45(9):1415-29.
27. Portney LG, Watkins MP. *Foundations of clinical research: application to practice*. New Jersey: Prentice Hall Health; 2000.
28. Gadotti IC, Vieira ER, Magee DJ. Importance and clarification of measurement properties in rehabilitation. *Rev Bras Fisioter*. 2006;10(2):137-46.
29. Winter DA. Anthropometry. In: Winter DA, editor. *Biomechanics and motor control of human movement*. New York: Wiley and Sons Inc.; 1990. p. 59-74.
30. Cram JR, Kasman GS, Holtz J. *Electrode Placements*. In: Cram JR., Kasman GS, Holtz J, editors. *Introduction to surface eletromyography*. Gaithersburg: Aspen Publishers, Inc.; 1998. p. 45-80.
31. Lamontagne A, Malouin F, Richards CL, Dumas F. Impaired viscoelastic behaviour of spastic plantarflexors during passive stretch at different velocities. *Clin Biomech (Bristol, Avon)*. 1997;12(7-8):508-15.
32. Bressel E, Larsen BT, McNair PJ, Cronin J. Ankle joint proprioception and passive mechanical properties of the calf muscles after an Achilles tendon rupture: a comparison with matched controls. *Clin Biomech (Bristol, Avon)*. 2004;19(3):284-91.
33. Baraúna MA, Canto RST, Sanchez HM, Bustamante JCF, Ventura-Silva RA, Malusá S. Validade e confiabilidade intra-indivíduo do cifolordômetro na avaliação da convexidade torácica. *Rev Bras Fisioter*. 2005;9(3):319-25.
34. McEwan I, Herrington L, Thom J. The validity of clinical measures of patella position. *Man Ther*. 2007;12(3):226-30.
35. McKenna L, Straker L, Smith A. The validity and intra-tester reliability of a clinical measure of humeral head position. *Man Ther*. 2009;14(4):397-403.
36. Lin HT, Hsu AT, An KN, Chang Chien JR, Kuan TS, Chang GL. Reliability of stiffness measured in glenohumeral joint and its application to assess the effect of end-range mobilization in subjects with adhesive capsulitis. *Man Ther*. 2008;13(4):307-16.
37. Venturini C, Ituassú NT, Teixeira LM, Deus CVO. Confiabilidade intra e interexaminadores de dois métodos de medida da amplitude ativa de dorsiflexão do tornozelo em indivíduos saudáveis. *Rev Bras Fisioter*. 2006;10(4):407-11.
38. Bennell KL, Talbot RC, Wajswelner H, Techovanich W, Kelly DH, Hall AJ. Intra-rater and inter-rater reliability of a weight-bearing lunge measure of ankle dorsiflexion. *Aust J Physiother*. 1998;44(3):175-80.
39. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. *Phys Ther*. 1987;67(2):206-7.
40. Aquino CF, Gonçalves GGP, Fonseca ST, Mancini MC. Análise da relação entre flexibilidade e rigidez passiva dos isquiotibiais. *Rev Bras Med Esporte*. 2006;12(4):195-200.
41. Magnusson SP, Simonsen EB, Aagaard P, Sørensen H, Kjaer M. A mechanism for altered flexibility in human skeletal muscle. *J Physiol*. 1996;497 (Pt 1):291-8.
42. Wilson GJ, Wood GA, Elliott BC. The relationship between stiffness of the musculature and static flexibility: an alternative explanation for the occurrence of muscular injury. *Int J Sports Med*. 1991;12(4):403-7.
43. Vaz DV, Brício RS, Aquino CF, Vianna SO, Mancini MC, Fonseca ST. Alterações musculares em indivíduos com lesão do neurônio motor superior. *Fisioter Pesqui*. 2006;13(2):58-66.
44. Gleim GW, McHugh MP. Flexibility and its effects on sports injury and performance. *Sports Med*. 1997;24(5):289-99.