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ORIGINAL RESEARCH

THE VALIDITY AND RELIABILITY OF A NEW INSTRUMENTED DEVICE FOR MEASURING ANKLE DORSIFLEXION RANGE OF MOTION

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ABSTRACT

Purpose/Background: A restriction in ankle dorsiflexion range of motion (ROM) has been linked to several clinical manifestations such as metatarsalgia, heel pain, nerve entrapment, ankle joint equinus, patellar and ankle injuries. The purpose of the present study was to examine the validity and reliability of the Leg Motion system for measuring ankle dorsiflexion ROM.

Study Design: Descriptive repeated-measures study.

Methods: Twenty-six healthy male university students were recruited to test the reliability of the Leg Motion system, which is a portable tool used for assessment of ankle dorsiflexion during the weight-bearing lunge test. The participants were tested two times separated by two weeks and measurements were performed at the same time of the day by the same single rater. To test the validity of the Leg Motion system, other maximal ankle dorsiflexion ROM assessments (goniometer, inclinometer and measuring tape) were measured in a single session (i.e., the first test session) during the weight-bearing lunge position using a standard goniometer, a digital inclinometer and a measuring tape measure with the ability to measure to the nearest 0.1 cm.

Results: Paired t-tests showed the absence of significant differences between right and left limb measurements of dorsiflexion in all tests. Mean values ± standard deviations were as follows: Leg Motion test (left 11.6cm ± 3.9; right 11.9cm ± 4.0), tape measure (left 11.6cm ± 4.0; right 11.8cm ± 4.2), goniometer (left 40.6º ± 5.2; right 40.6º ± 5.2), and digital inclinometer (left 40.0º ± 5.8; right 39.9º ± 5.6). The Leg Motion composite values (i.e., average of the two legs) showed a significant ($p < 0.05$) positive correlation with the tape measure ($r = 0.99$), with the goniometer ($r = 0.66$), and with the digital inclinometer ($r = 0.72$).

Conclusions: The results of the present study provide evidence to support the use of the Leg Motion system as a valid, portable, and easy to use alternative to the weight-bearing lunge test to assess ankle dorsiflexion ROM in healthy participants.

Level of evidence: 2b.

Key words: Ankle dorsiflexion, goniometer, inclinometer, weight-bearing lunge

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Conflict of interest
The last author declared potential conflicts of interest. He has patent pending for Leg Motion system.

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INTRODUCTION

A restriction of ankle dorsiflexion range of motion (ROM) has been linked to several clinical manifestations such as metatarsalgia, heel pain, nerve entrapment, ankle joint equinus,[1] patellar[2] and ankle injuries.[3] Restricted ankle dorsiflexion may also lead to abnormal lower extremity biomechanics during closed chain strengthening exercises.[4]For example, reduced ankle dorsiflexion during a squat results in increased knee valgus and medial knee displacement, decreased quadriceps activation, and increased soleus activation.[5] In addition, daily activities such as walking, descending stairs, and kneeling require 10º of ankle dorsiflexion ROM[6]while other actions such as sprinting and running require20° to 30°.[7]In recent years, several methods of assessment have been studied and performed in order to measure ankle dorsiflexion ROM. For instance, the weight-bearing lunge test, the goniometer, and the digital inclinometer are usually used for this purpose.[8]

Konor and colleagues[8] and Bennell and colleagues[9] found that the tape measure using the distance-to wall technique during the weight-bearing lunge test has higher intraclass correlation coefficient (ICC) values (ICC = 0.99) than the standard goniometer[8] and digital inclinometer.[8,9] However, there is no universal agreement regarding which of these methods of measurement is most preferred.[8] Weight-bearing measures are considered to be more related to daily activities[9] such as walking, running, or stair ambulation[8]than values obtained from other non-weight-bearing tests. Moreover, weight-bearing dorsiflexion ROM is associated with dynamic balance, showing a significant, fair correlation with the anterior reach distance in the star excursion balance test among healthy adults ($r = 0.53$)[10] and in individuals with chronic ankle instability ($r = 0.41$).[11]

Regardless of the higher reliability showed by the weight-bearing lunge test in comparison with other measures,[8,9] there are some potential variations that occur during testing that need to be controlled. For instance, variations in the subtalar and foot position,[12] the visual reference for the knee or the maintenance of the foot alignment during the performance of the test may change dorsiflexion results[8] and are the main limitations with regard to the standardization of this test.

Cejudo and colleagues[13] described a new simplified version of the weight-bearing lunge test to assess ankle dorsiflexion ROM and reported high relative reliability scores (ICC > 0.9). However, no study provides an alternative, validated weight-bearing test associated with the most common ankle dorsiflexion ROM tests. An alternative option to perform a weight-bearing evaluation that provides a standardized assessment is the Leg Motion system, a new portable device designed to assess ankle dorsiflexion ROM, in a similar manner to the weight-bearing lunge test assessment. For instance, during the weight-bearing lunge test subjects have adjust their foot toward or away from the wall, whereas during the assessment with the Leg Motion system, the metal stick is progressed away from knee, allowing for improved standardization during testing, since the foot is always in the same position and any possible movement that may influence in the outcome is reduced. Moreover, the Leg Motion system is a more efficient method for testing compared to the traditional wall lunge test as each measurement can be noted by simply moving the stick away from the knee as ankle dorsiflexion increases rather that measuring multiple attempts where participants have to stop and modify foot and body posture each time. The Leg Motion system also provides greater standardization due to the measurement scale where the foot is placed in comparison with the measuring tape that is used during the typical weight-bearing lunge test. Additionally, the Leg Motion system is a portable device that allows for easier completion of the test in virtually any location, without the need for walls or a particular floor where a measuring tape needs to be placed or where the normal weight-bearing lunge test has limitations (e.g., a grass surface). To the authors' knowledge, this is the first device that enables the performance of a weight-bearing test in such standardized conditions and no study has been conducted to evaluate the comparison of the measurements achieved via this novel device with other typical ankle dorsiflexion ROM measures. The purpose of the present study was to examine the validity and the reliability of the Leg Motion system for measuring ankle dorsiflexion ROM. The authors' hypothesized that Leg Motion system would provide both valid and reliable measurements of ankle dorsiflexion ROM.

METHODS

Subjects

Twenty-six healthy male university students (age 22.5 ± 2.1 years, height 165.9 ± 48.7 cm, weight 77.2 ± 8.4 kg, body mass index 14.54 ± 2.87 kg/m^2) volunteered to take part in this study. Participants were required to be free from lower extremity injury for at least six months prior to testing, and have no prior history of hip, knee, or ankle surgery.

All participants signed an institutional informed consent form before starting the protocol and the study was approved by the institutions' review boards. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its 2008 amendment.

Protocol

Height (IP0955, Invicta Plastics Limited, Leicester, England), body mass, and body fat (Tanita model BF-350, Tokyo, Japan) were obtained according to the protocol used in the study conducted by Garcia-Masso and colleagues.[14]

In order to test the reliability of the Leg Motion system, the participants were tested in two different sessions at the same time of day, with a separation of two weeks between sessions. Both assessments were conductedby the same researcheraccording to the reliability protocol established by Ortega and colleagues.[15] The researcher was a third year physiotherapy student with basic experience in the use of the goniometer and the inclinometer.

To test the validity of the Leg Motion system, the other maximal ankle dorsiflexion ROM was measured in a single session (i.e., the first test session) during the weight-bearing lunge position using a standard goniometer with 1° increments (Baseline, USA), a digital inclinometer with 1° increments (Baseline, USA) and a measuring tape with the ability to measure to the nearest 0.1 centimeter. The weight-bearing lunge test was performed with both limbs following the recommendations by Konor and colleagues.[8] When the participant reached the maximal dorsiflexion ROM during the weight-bearing lunge test (defined as the maximum distance of the toe from the wall while maintaining contact between the wall and knee without lifting the heel),[9] a digital inclinometer was placed at the tibial tuberosity and was used to measure the angle of the tibia relative to the ground.[8] Likewise, a standard goniometer was aligned with the floor, and through the shaft of the fibula by visually bisecting the lateral malleolus and the fibular head.[8,16] The Leg Motion system test was performed in accordance with the procedures for the performance of the weight-bearing lunge test. Subjects were in a standing position on Leg Motion system (Check your MOtion, Albacete, Spain) with the test foot on the measurement scale (Figure 1). While maintaining this position, subjects were instructed to perform a lunge in which the knee was flexed with the goal of making contact between the anterior knee and the metal stick. When subject were able to maintain heel and knee contact, the metal stick was progressed away from knee. Maximal dorsiflexion ROM during the Leg Motion system test was defined as the maximum distance of the toe from the metal stick while maintaining contact between the stick and knee for three seconds, without lifting the heel.

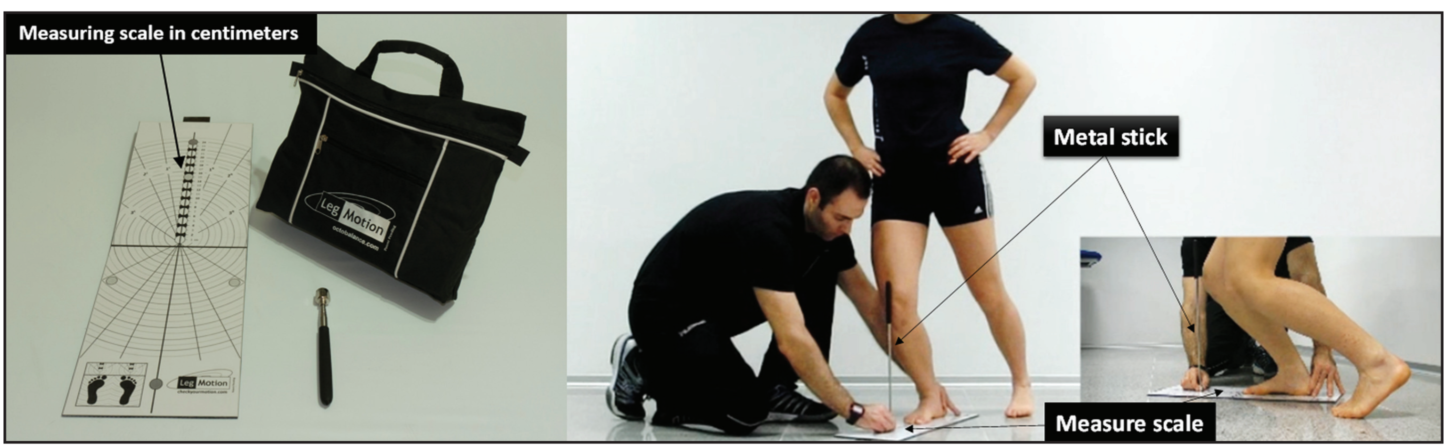

Figure 1. *The Leg Motion System*

All the measurements were completed with the participant barefoot; first performing all tests with one leg and then with the contralateral leg in a counterbalanced order. Three trials were allowed for each side, and the average value of the three trials was used for data analysis. A trial was discarded and repeated if a participantlifted their heel off the ground or did not follow the standards for performing the test.

Data analysis

Statistical analysis was carried out using SPSS version 17 (SPSS inc., Chicago, IL, USA). The level of significance was set at $p < 0.05$ for all statistical tests. Means and standard deviations were calculated for both limbs. Additionally, composite scores (i.e., average of the two legs) were calculated. Paired t-tests on the differences of scores obtained at test and retest sessions were used to ensure the absence of systematic bias.[17]

The $ICC_{(3,1)}$ was calculated to assess the relative between-session reliability, normalizing measurement error relative to the heterogeneity of the subjects.[18]Criteria ranges for ICC reliability were as follows: <0.50, poor; 0.50 to 0.75, moderate; and >0.75, good.[19]Standard error of measurement(SEM) [pooled standard deviation of all scores multiplied by the square root of 1-ICC] and 95% confidence intervals (CI) were computed to estimate the amount of error associated with the measurement. [18]Moreover, minimal detectable difference (MDD) was analyzed ($SEM*1.96*\sqrt{2}$) in order to determine the minimum threshold of measurement to ensure that differences between measurements were real and outside the error range.[18] A Pearson correlation analysis was carried out in order to evaluate the relationship between the Leg Motion system test and the other ankle dorsiflexion ROM measures.

RESULTS

Mean values ± standard deviations were as follows: Leg Motion system (left 11.6cm ± 3.9; right 11.9cm ± 4.0), tape measure (left 11.6 cm ± 4.0; right 11.8 cm ± 4.2), goniometer (left 40.6º ± 5.2; right 40.6º ± 5.2), and digital inclinometer (left 40.0º ± 5.8; right 39.9º ± 5.6) (Table 1). The Leg Motion composite values (i.e., average of the two legs) showed a significant ($p < 0.01$) positive Pearson correlation with the tape measure, the goniometer and with the digital inclinometer. Correlation results are presented in Table 2. Paired t-test showed the absence of significant differences between limbs and between test and re-test values. Test re-test reliability results for the Leg Motion system was as follows: SEM ranged from 0.58cm to 0.80cm, MDD ranged from 1.60 cm to 2.23 cm and ICC values ranged from 0.96 to 0.98. Complete reliability results are represented in Table 3.

Table 1. *Results of Ankle Dorsiflexion Range of Motion Measurements*

		Mean ± SD
Leg Motion System	Left side	11.6cm±3.9
	Right Side	11.9cm±4.0
Tape measure	Left side	11.6cm±4.0
	Right Side	11.8cm±4.2
Goniometer	Left side	40.6º ±5.2
	Right Side	40.9º ±5.3
Inclinometer	Left side	40.0º ±5.8
	Right Side	39.9º ±5.6

DISCUSSION

This is the first study to examine the validity of the Leg Motion system and report its test re-test reliability. The high correlation values obtained during the Leg Motion system test shows the validity of this device as an alternative to the weight-bearing lunge test, goniometer, and digital inclinometer for the measurement of the ankle dorsiflexion ROM. Specially, very high values were achieved when comparing the Leg Motion system test with the weight-bearing lunge test since both tests are very similar.

With regard to the reliability analysis, the authors' found highly reliable results on test re-test measures, since SEM values ranged from 0.58 cm to 0.80 cm, MDD ranged from 1.60 cm to 2.23 cm and ICC's ranged from 0.96 to 0.98. In accordance, other ankle dorsiflexion ROM measurements during weight-bearing positions have been shown to demonstrate high intra-rater reliability results using the digital inclinometer and the distance-to-wall measurements (ICC ranging from 0.97-0.98).[9] Similarly, Konor and colleagues[8] found good intra-rater reliabil-

Table 2. *Correlation coefficients between Leg Motion system test results and other ankle dorsiflexion range of motion measurements*

		Leg Motion Left Side	Leg Motion Right Side	Leg Motion Composite
Tape measure	Left side	0.98*	0.89*	0.96*
	Right Side	0.91*	0.98*	0.97*
	Composite	0.96*	0.96*	0.99*
Goniometer	Left side	0.72*	0.52*	0.64*
	Right Side	0.65*	0.57*	0.63*
	Composite	0.71*	0.57*	0.66*
Inclinometer	Left side	0.77*	0.54*	0.67*
	Right Side	0.66*	0.73*	0.71*
	Composite	0.78*	0.62*	0.72*

Composite values= average of right and left sides

* Denotes significant Pearson's correlation coefficients ($p < 0.01$).

Table 3. *Intrarater reliability for Leg Motion results*

	Mean	SD	SEM	MDD	ICC (95% CI)
Left Side	12.37	3.82	0.58	1.60	0.98 (0.95; 0.99)
Right Side	12.73	3.83	0.80	2.23	0.96 (0.90; 0.98)
Composite	12.55	3.70	0.59	1.62	0.98 (0.95; 0.99)

Abbreviations. SD: standard deviation; SEM: standard error of measurement; MD: minimal difference; ICC: intraclass correlation coefficient values and 95% CI: confidence intervals. Composite values= average of right and left sides

ity (ICC > 0.85) results for weight-bearing ankle dorsiflexion ROM measures when the measurements were performed by a novice rater utilizing a goniometer, inclinometer, or tape measure. However, these authors found that the reliability values for the digital inclinometer and the weight-bearing lunge test were higher than those using the goniometer. Good inter-rater reliability results using a digital inclinometer (ICC ranging from 0.77 to 0.88) were found when authors compared novice and experienced raters.[16]While it is difficult to compare between reliability coefficients from different studies, the weight-bearing tests provide the same or higher ICC values when those are compared with other tests using the inclinometer or the goniometer.[8]

The low measurement error found in the current study is in accordance with the SEM values provided by Konor and colleagues[8] (intrarater SEM ranging from 0.4 cm from 0.6 cm) and Bennell and colleagues[9] (intra-rater SEM ranging from 0.5 cm from 0.6 cm) for measurements taken using the tape measure. Moreover, in the study conducted by Konor and colleagues,[8] authors found MDD values that were similar to the current results (MDD ranging from 1.1cm to 1.5 cm).

Since the Leg Motion system provides a standardized device in order to perform the weight-bearing lunge test under a controlled condition, the measurements during this test may vary slightly compared with the other distance-to-wall assessments. For example, during the Leg Motion test, participants progress their knee towards a metal stick instead of towards the wall, providing a visual target to maintain foot and knee alignment.

The results of this study are limited to the healthy participants that were studied, so the results may not be extrapolated to other injured populations. Another limitation of the study is the use of a nonrandomized order when the tests were performed. However, since the main objective was to validate the Leg Motion test, the measurement of the ROM with the inclinometer and the goniometer needed to be performed during the weight-bearing lunge test, and the lack of randomized order likely had no effect. The use of a rater with basic experience could be a limitation, especially with regard to reliability testing. However, the authors found highly reliable results that are in similar to the previous literature demonstrating that a person with basic experience may perform the test with high reliability, adding to the feasibility and the practical application of the Leg Motion system.

CONCLUSIONS

The results of the present study provide evidence to support the use of the Leg Motion system as a valid, portable, and easy to use alternative to the weight-bearing lunge test to assess ankle dorsiflexion ROM in healthy participants. Moreover, the current findings demonstrate that a single rater with basic experience demonstrates highly reliable results during the assessment of dorsiflexion ROM using the Leg Motion system.

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