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Reliability and Concurrent Validity of a Clinometer+ Bubble Smartphone Application to Assess Hamstring Muscle Length

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Abstract

Purpose: Muscle flexibility is a component of physical fitness. Using traditional tools in muscle length evaluation tests creates challenges. Therefore, the use of smartphones and health-related software as an alternative method has become widespread. This study aimed to investigate smartphones' intra- and inter-rater reliability and validity for measuring hamstring muscle length. **Method:** In a blinded study design, two researchers measured hamstring flexibility through four types of tests on each of the 22 asymptomatic participants with a total of 44 lower limbs. The measurements were compared between the traditional goniometer method and the practical smartphone application method. The intraclass correlation coefficient (ICC) was used to evaluate the reliability of each smartphone measurement, and Bland-Altman analysis was used to check the measurement errors. The validity of the two methods was also investigated. **Results:** Intra- and inter-rater reliability (ICC≥0.8) were good to almost perfect. In intra-rater reliability, PSLR angle showed consistent imprecision; other tests were free of systematic error and measurement error. The inter-rater reliability revealed a constant error in the right leg's PKE angle. A good to excellent correlation ($r = 0.817–0.699$) was observed in all the measured values, indicating the two methods' validity. **Conclusion:** These findings support from intra- and inter-rater reliability and validity of both instruments when measuring hamstring muscle length.

Keywords: flexibility, reliability, validity, smartphone, measurement.

Introduction

One of the factors that is required for physical fitness and engaging in various activities is flexibility (Khan et al., 2023; Pawar et al., 2021). Both a decrease and an excessive gain in flexibility have an impact on an individual's performance level and make them more susceptible to many injuries (Albeshri & Youssef, 2023; Pawar et al., 2021). Therefore, using the muscle length test to assess flexibility, understanding the structure and function of muscles, and preventing possible injuries will be helpful (Pawar et al., 2021). One of the muscles discussed in the field of flexibility is the hamstring (Allam et al., 2023). Because it is a biarticular muscle, the hamstring is vulnerable to tightness, which can lead to compensatory adaptations in the motions of the adjacent segments and overall body posture (Salemi et al., 2021). Previous studies showed that improper flexibility of the hamstrings can affect the body posture and walking style (Gulrandhe et al., 2023; Liu et al., 2022) and lead to an increase in compressive stresses on the patellofemoral joint (Sherazi et al., 2022). Also, knee arthritis (Sherazi et al., 2022) and back pain (Krishna et al., 2021) may be the consequences of hamstring stiffness. Other complications of hamstring stiffness may include muscle tears, loss of lumbar spine curvature, sacroiliac joint conditions, or plantar fascia conditions (Osailan et al., 2021). As a result, assessing the flexibility of the hamstring muscle, which is one of the most effective muscles in the position of the pelvis, has clinical importance (Allam et al., 2023; Reurink et al., 2013).

Two commonly used methods for assessing hamstring flexibility are the knee extension (KE) test (Reurink et al., 2013) and the straight leg raise (SLR) test (Neto et al., 2015). The KE test is performed in the supine position while the hip and knee joints are maintained at a 90˚ angle flexion, and then the knee joint is slowly extended. The goniometer is positioned with its center on the lateral femoral condyle; One arm is positioned parallel to the thigh, extending towards the greater trochanter, while the other one is positioned parallel to the lower leg, extending towards the lateral malleolus. SLR test is measured while lying on the back; the knee is fully extended, and the hip joint is flexed to the maximum angle. On the greater trochanter, the center of the goniometer is placed with one arm parallel to the thigh, extending towards the lateral femoral condyle, and the other one on the side of the trunk and parallel to the table. If the tests are passive, then the assessor performs the movements. Otherwise, the participant will perform the test in an active mode. Excellent intra-rater reliability was reported for active knee extension (ICC=0.91) and passive straight leg raise (ICC=0.95) using a universal goniometer (UG) (Neto et al., 2015). The tools utilized in this domain possess certain limitations. For instance, the goniometer presents challenges in touching anatomical landmarks, correctly aligning the arms, and stabilizing other areas during the measurement process. Similarly, the inclinometer is not able to measure in the transverse plane. However, clinical examinations extensively employ these tools (Keogh et al., 2019; Miyachi et al., 2022; Norris et al., 2016). As a result, testers' knowledge, technique, and experience are required to ensure measurement accuracy (Miyachi et al., 2022).

Smartphones (SP) have supplanted measuring tools due to their widespread accessibility and convenience in transmitting, receiving, and organizing data (Cox et al., 2018; Miyachi et al., 2022; Norris et al., 2016). Furthermore, the adoption of software about the domains of health and fitness (Dos Santos et al., 2017), such as a clinometer for measuring in the frontal and sagittal planes and a compass for measuring in the horizontal plane, became prevalent (Ganokroj et al., 2021). Recent studies have examined the reliability and validity of SP software in assessing the extent of movement in several joints of the body, such as the neck (Monreal et al., 2020), shoulder (Werner et al., 2014), wrist (Pourahmadi et al., 2017), hip (Miley et al., 2019; St-Pierre et al., 2020; Whyte et al., 2021), ankle (Cox et al., 2018; Zunko & Vauhnik, 2021), and trunk (Furness et al., 2018).

Nevertheless, previous research has solely focused on assessing the range of motion in joints. To this day, no study has provided data on the reliability and validity of four different hamstring muscle length tests conducted simultaneously using both a SP application and a UG. Therefore, the purpose of this study was to examine the reliability and validity of assessing the length of the hamstring muscles using an SP, as opposed to the conventional method, including a UG, in order to fill the gap in current knowledge.

Methods

Participation

In this cross-sectional methodological study, a total of 22 participants (44 lower limbs) were included. Of these participants, four were men. The demographic characteristics of all subjects are presented in Table 1. The study's inclusion criteria being healthy and being in age range of 18-25 years. The exclusion criteria encompassed acute pain in the lower limbs, an inability to tolerate test positions (Olivencia et al., 2020), and a prior history of knee or hip joint surgery (Neto et al., 2015). Before signing the informed permission form for the research, all participants were provided with spoken information regarding the study’s protocol (Liu et al., 2022). The participants received prior notice regarding the date and time of the evaluation (Medeiros et al., 2019). The beginning and continuation of the subject's participation in the research was voluntarily. All the necessary precautions were taken to protect the privacy of the subjects and the confidentiality of their information. Because warm-up may affect the biomechanical property of collagen, as well as the viscoelastic property of muscles (Mutungi & Ranatunga, 1998), the participants refrained from performing any warm-up or stretching movements prior to the test (Medeiros et al., 2019). In this study, a goniometer, Samsung Galaxy A53, and Clinometer+ bubble level application were used. The user obtained this application at no cost from the Google Play store.

Procedure

Two assessors collected the data in this study. When one of the assessors measured the muscle length test, the second assessor, as an observer, recorded the measurement data for the blindness of the first assessor (Vohralik et al., 2015). During the active testing, the subjects were unable to see the measurements being taken. Similarly, during the passive tests, the assessor who moved the lower limb could not see the measurement recorded by the instrument (Neto et al., 2015). At first, tester A performed 2 trials with an interval of 30 seconds (Ayala et al., 2012) for the right leg and immediately for the left leg using a smartphone. No time was spent between measuring the two legs. In order to assess intra-rater reliability, after 5 minutes of rest (Vohralik et al., 2015), the same protocol was repeated by tester A. In general, tester A performed 4 trials for each leg using a smartphone. Then, after resting for 5 minutes, to assess inter-rater reliability, tester B performed 2 trials with an interval of 30 seconds for the right leg and immediately for the left leg using a smartphone. Next, tester B performed 2 trials with an interval of 30 seconds for the right leg and immediately for the left leg using a goniometer without wasting time to assess the validity of the tool. In general, tester B performed 2 trials for each leg using a smartphone and 2 trials for each leg using a goniometer. The time interval between the tests was 10 minutes (Neto et al., 2015). During all experiments, the smartphone was fixed adjacent to the leg and aligned with the fibula (the outside edge of the leg) (Hopper et al., 2005).

The Active Straight Leg Raise Test (ASLR)

The test was performed with the subject lying on the back, with the hip flexed slightly while the knee was fully extended to reach the maximum angle of leg elevation. The angle of the long axis of the SP with respect to the ground was assessed (Miyachi et al., 2022).

The Passive Straight Leg Raise Test (PSLR)

During the test, the assessor grasped the subject's ankle with one hand and positioned the other one above the knee of the same leg to control the movement (Ayala et al., 2012; Reese & Bandy, 2016). Afterward, the assessor flexed the hip joint without any voluntary movement from the subject while ensuring that the knee remained completely straight (Medeiros et al., 2019).

The endpoint for both modalities of SLR testing was determined based on one or both of the following criteria: (a) The examiner's observation of strong opposition and (b) the noticeable beginning of pelvic tilt (Ayala et al., 2012).

The Active Knee Extension Test (AKE)

The participant was lying on the back, and both hip and knee joints of the tested leg were maintained at flexion 90˚. They were then asked to maintain plantar flexion of the tested ankle (Olivencia et al., 2020). Additionally, the assessor maintained the thigh on the same side at a 90˚ angle during the test (Reurink et al., 2013). Next, the participant was directed to straighten her/his knee until he/she reached the maximum tolerated excursion of the hamstring muscle.

The Passive Knee Extension Test (PKE)

The individual was positioned in a supine posture with the hip and knee flexed at a 90˚ angle. The leg being evaluated was in a relaxed state, whereas the other leg was fully extended. The assessor gradually extended the knee joint until the participant indicated the beginning of tightness in the hamstring muscles (Dos Santos et al., 2017).

To avoid imprecise measurements caused by pelvic tilt, it is important to maintain the lower limb of the opposite side on the support surface during all tests and ensure that the knee is fully extended (Reese & Bandy, 2016).

Statistic

The data analysis was conducted using SPSS version 27 software. According to existing literature, the meaning of each intraclass correlation coefficient is as follows: if ICC ≤ 0.5, it indicates poor reliability; if $0.5 \leq$ ICC ≤ 0.75, it indicates moderate reliability; if $0.75 \leq$ ICC ≤ 0.9, it indicates good reliability and values greater than 0.90 indicate excellent reliability (Chenani & Madadizadeh, 2021).

Bland-Altman analysis was performed to identify systematic errors and determine the limit of agreement (LOA). If the difference between two measurements is zero, it can be concluded that there is no fixed error. When there is no significant relationship between the difference in two measurements and the mean of the two measurements, proportional bias does not exist. The standard error of measurement (SEm) and the minimum detectable change (MDC) were calculated to check the measurement error (Miyachi et al., 2022) using the following mathematical equation: $SEM = S_x\sqrt{(1 - r_{xx})}$ in which S_x is the standard deviation and r_{xx} is the reliability coefficient. ($MDC = SEM \times 1.96 \times \sqrt{2}$) (Liu et al., 2022).

Pearson's rank correlation coefficient was calculated to assess the validity of the two measurement methods, using the measurements taken by examiner B. 0.00 to .25 indicated little or no relationship; .25 to .50 indicated fair relationship; .50 to .75 indicated moderate to a good relationship and above .75 indicated good to excellent relationship (Portney & Watkins, 2009)

Results

Demographic characteristics and descriptive statistics are presented in Table 1.

Table 1: Participants' characteristics

	participants (n=22)
Gender, male:female	4:18
Age (years), mean ± SD	20.27±1.85
Height (cm)	1.66±0.07
Weight (kg)	58.27±8.04
Dominant leg, right:left	20:2

Good to excellent intra-rater reliability was found for all tests and for both legs. Mean values, standard deviation, and intra-rater reliability information are presented in Table 2.

Table 2: Intra-rater reliability (ICC 3) for muscle length measurement

	Mean±SD		ICC(95% CI)		SEm		MDC	
	Right	Left	Right	Left	Right	Left	Right	Left
PSLR	67.1 ±6.0	63.9 ±6.0	0.972 (0.946,0.987)	0.950 (0.904,0.977)	1.01	1.34	2.82	3.73
ASLR	65.3 ±7.1	64.1 ±7.0	0.938 (0.881,0.971)	0.954 (0.912,0.979)	1.78	1.52	4.93	4.21
PKE	28.1 ±9.3	27.9 ±8.4	0.987 (0.976,0.994)	0.972 (0.947,0.987)	1.06	1.41	2.95	3.90
AKE	30.4 ±9.0	29.1 ±9.8	0.975 (0.952,0.988)	0.983 (0.967,0.992)	1.42	1.28	3.95	3.57

SD: standard deviation; ICC: intraclass correlation coefficient; 95% CI: 95% confidence interval; SEm: standard error of measurement; MDC: minimal detectable change; PSLR: passive straight leg raise; ASLR: active straight leg raise; PKE: passive knee extension; AKE: active knee extension

Good to excellent interrater reliability was found for all tests and for both legs. The mean values, standard deviation, and inter-rater reliability information are presented in Table 3.

Table 3: Inter-rater reliability (ICC 3) for muscle length measurement

		Examiner A Mean ±SD	Examiner B Mean ±SD	ICC (95% CI)	SEm	MDC	LOA	Fixed error		Proportional bias	
								95%CI	Re-sult	p-value	Re-sult
Right	PSLR	68.3 ±6.7	66.9 ±6.5	0.927 (0.813,0.970)	1.74	4.83	-5.00 ~ 7.87	-0.02 ~ 2.88	No	0.711	No
	ASLR	64.9 ±7.0	65.7 ±8.6	0.842 (0.621,0.934)	2.90	8.05	-12.32 ~ 10.68	-3.42 ~ 1.78	No	0.177	No
	PKE	28.2 ±8.9	24.9 ±9.1	0.909 (0.645,0.968)	2.65	7.34	-5.38 ~ 11.88	1.29 ~ 5.20	Yes	0.819	No
	AKE	30.6 ±8.7	28.9 ±10.1	0.928 (0.826,0.970)	2.45	6.80	-7.69 ~ 10.96	-0.47 ~ 3.74	No	0.185	No
Left	PSLR	65.0 ±6.8	64.0 ±6.8	0.882 (0.719,0.951)	2.22	6.16	-7.83 ~ 9.65	-1.06 ~ 2.88	No	0.943	No
	ASLR	63.7 ±7.4	64.8 ±7.8	0.883 (0.723,0.951)	2.48	6.89	-10.82 ~ 8.60	-3.31 ~ 1.08	No	0.705	No
	PKE	27.6 ±8.6	27.9 ±7.8	0.947 (0.874,0.978)	1.85	5.14	-7.74 ~ 7.01	-2.03 ~ 1.30	No	0.331	No
	AKE	29.1 ±9.4	29.9 ±10.5	0.954 (0.891,0.981)	2.09	5.80	-9.08 ~ 7.35	-2.72 ~ 0.995	No	0.229	No

SD: standard deviation; ICC: intraclass correlation coefficient; 95% CI: 95% confidence interval; SEm: standard error of measurement; MDC: minimal detectable change; LOA: limit of agreement; PSLR: passive straight leg raise; ASLR: active straight leg raise; PKE: passive knee extension; AKE: active knee extension

Moderate to excellent validity was found between the two measurement methods. Information about Pearson's rank correlation coefficients is presented in Table 4.

Table 4: Validity for muscle length measurement

		Goniometer method Mean±SD	Smartphone measurement method Mean±SD	Correlation coefficient	p-value
Right	PSLR	64.2±4.7	66.9±6.5	0.736	.001
	ASLR	64.3±7.5	65.7±8.6	0.734	.001
	PKE	37.0±9.1	24.9±9.1	0.814	.001
	AKE	38.5±8.5	28.9±10.1	0.715	.001
Left	PSLR	62.0±5.6	64.0±6.8	0.699	.001
	ASLR	62.9±7.2	64.8±7.8	0.733	.001
	PKE	38.4±8.5	27.9±7.8	0.809	.001
	AKE	40.4±7.1	29.9±10.5	0.817	.001

Discussion

The study indicated that each of the four tests had a high level of intra-rater reliability, with an ICC value of 0.9 or above. The 95% confidence intervals for PSLR, ASLR, PKE, and AKE tests had lower limits over 0.88, showing strong and consistent reliability within the same rater. We found no previous study that measured PSLR using a smartphone. Liu's study showed excellent intra-rater reliability (ICC = 0.94) for the PSLR test using a digital clinometer (Liu et al., 2022). Muyor et al reported excellent intra-rater reliability (ICC > 0.98) for the PSLR test using the clinometer and WIMU system (Muyor, 2017). Aalto et al found that the PSLR test, using a goniometer to measure the hip's passive range of motion, had excellent intra-rater and intra-day reliability (ICC ≥ 0.94) (Aalto et al., 2005). Miyachi et al reported high

intra-rater reliability (ICC = 0.93) for the ASLR test using a smartphone (Miyachi et al., 2022). Liu's study showed high intra-rater reliability (ICC = 0.92) for the PKE test using a digital clinometer (Liu et al., 2022). Olivencia et al reported good intra-rater reliability (ICC = 0.88) for the AKE test using a clinometer (Olivencia et al., 2020). The calculations of SEM and MDC did not reveal any measurement errors in any of these three tests. The reliability and validity of a smartphone application for measuring ROM are regarded as satisfactory if both the SEM and the MDC are < 5° (Keogh et al., 2019). In this investigation, all SEM and MDC values for the PSLR, ASLR, PKE, and AKE angles were < 5°. Hence, the mistakes fall within the acceptable range.
The study measured ICC ≥ 0.8 for all values, indicating high inter-rater reliability. The lower limit of the 95% confidence interval for the PSLR test of the right and left legs was 0.81–0.71; the ASLR of the left leg was 0.72; the PKE of the left leg was 0.87; and the AKE of the right and left legs was 0.82–0.89, respectively, indicating high reliability as well as intra-rater reliability results. However, additional research is necessary to enhance the dependability of the results, as the bottom limit of the 95% confidence interval for the right leg ASLR was 0.62, and for the right leg, PKE was 0.64. Miyachi et al reported high interrater reliability (ICC = 0.93) for the ASLR test using a smartphone (Miyachi et al., 2022). Dos Santos et al reported high interrater reliability for the PKE (ICC ≥ 0.93) using a smartphone (Dos Santos et al., 2017). Liu's study showed high inter-rater reliability (ICC = 0.92) for PSLR and PKE tests using a digital clinometer (Liu et al., 2022). Reurink et al reported good interrater reliability (ICC = 0.76) for the AKE test in the uninjured hamstring using the inclinometer (Reurink et al., 2013). The Bland-Altman analysis revealed the absence of any systematic errors in the PSLR, ASLR, left leg PKE, and AKE tests. Nevertheless, fixed errors were observed in the PKE of the right leg. The LOA was computed to ascertain the permissible range of fixed errors in the PKE. The LOAs calculated in our study for the right leg PKE ranged from -5.3 to 11.8°. In this investigation, all SEM values were < 5°. Hence, the mistakes fall within the acceptable range. The

calculated MDC was 4.8–8.0° (right leg) and 5.1–6.8° (left leg), which was high. When there is more than one examiner, it is important to take into account both of these metrics when determining the limits of agreement.

The measured values exhibited a positive correlation, validating the accuracy of both approaches. The PSLR correlation coefficients indicate a "moderate to good" positive correlation; the ASLR indicates a "moderate to good" positive correlation; the PKE indicates a "good to excellent" positive correlation; and the AKE indicates a "good to excellent" positive correlation. A robust positive association was observed between the PKE. In summary, the smartphone approach to measuring these items is both clinically viable and a legitimate substitute for the conventional method, which is considered the most accurate way to measure muscle length.

The prevalence of smartphones, along with the affordability of health-related applications, will render this approach more favorable than existing measurement methods in this domain. Additional rationales for utilizing a smartphone as a tool for measuring muscle length include its user-friendly interface, the absence of a requirement for specialist anatomical expertise, and the provision of a comfortable experience for the evaluator. Consequently, this technique has the potential to replace assessment techniques in clinical, scientific, and sports settings.

With regard to limitations, this study samples were healthy, young individuals in good physical condition. Hence, additional research is required to assess validity and reliability in various groups with hamstring injuries. Since conducting experiments at long time intervals can lead to different results, the lack of inter-day reliability data can be seen as another limiting factor of this study.

Conclusion

The findings of the current study support the intra- and inter-rater reliability of the smartphone application when measuring hamstring muscle length. This method had a good correlation with goniometer as the gold standard. However, MDC's high values limit its practical application. Training of assessors and changes in the implementation protocol may improve reliability values if the results are substantiated.

Conflict of Interests

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea and study design.

Ethical considerations

The author has completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct and/or falsification, double publication and/or redundancy, submission, etc.

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