International Journal of Strength and Conditioning

Concurrent Validity and Reliability of the My Jump Lab Smartphone Application for Break Point Angle Assessment in the Nordic Hamstring Exercise

Amândio Dias[1,2,3]*, André Gomes[1], Diogo Nogueira[1], Leonel Correia[1] and Rodrigo Trindade[1]

[1]Egas Moniz Center for Interdisciplinary Research (CiiEM); Egas Moniz School of Health & Science, 2829-511 Caparica, Almada, Portugal; [2]Integrative Movement and Networking Systems Laboratory (INMOV-NET LAB) - Egas Moniz Center for Interdisciplinary Research (CiiEM), Egas Moniz School of Health & Science, 2829-511, Caparica, Almada, Portugal; [3]Sport Physical Activity and Health Research & Innovation Center (SPRINT), 2040-413 Rio Maior, Portugal

*Corresponding Author: adias@egasmoniz.edu.pt

ABSTRACT

The Nordic Hamstring Exercise is widely used to prevent muscle strain injuries. Although isokinetic dynamometry is considered a gold standard for assessment, it is often impractical in many settings, due to several reasons. A cost-effective alternative for physical evaluations of the same muscle could be Smartphone-based, which have greatly increased in recent years due to technological advancements. This study aims to assess the concurrent validity and inter-rater reliability of the My Jump Lab smartphone application in measuring the break point angle (BPA) during the Nordic Hamstring Exercise.

Twenty-four healthy participants were recruited for this study and performed five repetitions of the nordic hamstring exercise, while being recorded via smartphone for BPA estimation. The same exercise was compared with kinematic analysis, as reference method. Concurrent validity was assessed by Pearson's product-moment correlation coefficient and Bland-Altman Plots, while inter-rater reliability was analysed by intraclass correlation coefficient (ICC), coefficient of variation (CV) and standard error of measurement (SEM).

Results revealed a very high and significant level of correlation ($r > 0.9$, $p < 0.001$) for break point angle measurements, with small proportional bias. The app showed excellent inter-rater reliability (ICC >0.9), with very small variations (CV ≈ 1%) and SEM lower that 1.3 degrees.

These outcomes suggest that My Jump Lab is a valid and reliable tool for BPA assessment, that can be used confidently to assess hamstring muscle strain in a simple, portable and practical manner.

Keywords: Break point angle; nordic; mobile applications

INTRODUCTION

Hamstring muscles are essential muscles for running, jumping and walking. Hence, they are used for almost every movement in a sports setting, but also are amongst the more common in number of injuries. The incidence of these injuries has risen in twenty years, from 12% to 24% of all injuries is soccer (Ekstrand et al., 2023), with a recurrence rate that can be as high as 64% (Diemer et al., 2021). Literature suggests that there are two non-contact injury mechanisms responsible for injuries to these muscles, which are, running at high speeds (Woods et al., 2004) and stretching with extreme ranges of movement (Askling et al., 2003). These type of strain injuries appear to occur due to an excessive muscle strain, caused by eccentric muscle contraction (Askling et al., 2003; Danielsson et al., n.d.).

The most used method to assess muscle strength and the risk of strain injuries has been isokinetic dynamometry, which has been used in multiple studies (Arnason et al., 2008; Lehance et al., 2008; Van Dyk et al., 2016), but its use and application in this type of assessment should be reassessed, due to costs, specialized training required (Green et al., 2018) and lack of portability (Whiteley et al., 2012). Alternative field-based testing methods have been suggested (Lee et al., 2018), one of which is the Nordic hamstrings curl exercise (Linklater et al., 2010). This exercise, easy to apply, is widely used to assess the strength of the hamstring muscles and is characterized by a downward movement of the body until the moment of muscle failure, known as break point angle (BPA). This breaking moment, represented by the angle that the trunk makes with the ground, has a significant relationship with peak torque, when evaluated in an isokinetic movement (Sconce et al., 2015) and also presents a significant correlation between eccentric knee flexion strength and knee flexion angle (Lee et al., 2018). Therefore, the moment of muscle failure becomes fundamental for estimating hamstrings strength. Additionally, the inclusion of exercises such as the Nordic has been shown to increase hamstring strength (Mjølsnes et al., 2004) as well as decrease the risk of injuries (Al Attar et al., 2017). However, measuring BPA can be a difficult task, with computer-based analysis (Sconce et al., 2015) or infrared markers (Delahunt et al., 2016) used in previous studies. In spite of this, there is a requirement for simple, reliable and accurate field-based assessment procedures for the Nordic exercise (Vercelli et al., 2020a). These procedures require minimal equipment and training, as well as being able to be used when there are time, space or facilities constraints (Peart et al., 2019).

The high level of current technology and connectivity, combined with their easy transportation and handling, emphasizes the use of mobile devices as a means of evaluating physical exercise in real time, as well as storing the information collected (Intille et al., 2012). There are currently several validated mobile phone applications that perform different type of physical assessment, such as range of motion of shoulder (Karatekin, Bilinç; Çiçel, Sinem; Içagasioglu, 2022), ankle joint (Alawna et al., 2019), knee (Tozawa et al., 2023) or hip range (Takeda & Furukawa, 2022), as well as strength assessment (Balsalobre-Férnandez et al., 2023; Sá et al., 2019) or lower limb jump performance (Vieira et al., 2023). Regarding hamstring muscle and specifically BPA estimation, it can be facilitated through video analysis, which is capable of verifying the angular amplitude by indicating BPA, which is perceived by increase in the user's fall speed and reflexes (Sconce et al., 2015). Naturally, technological developments in recent years have also led to the creation of some mobile phone applications that evaluate Nordic hamstring curl exercise. However, not all smartphone applications (apps) have been analysed for their validity. To the best of our knowledge, only three studies validated apps that assess BPA, but with different assessment procedures (Lee et al., 2018; Soga et al., 2023; Vercelli et al., 2020a). Therefore, it becomes pertinent to increase and improve the existing evidence on this topic, in order to provide practitioners with more valid and reliable alternatives. Thus, the objective of the present study is to assess the concurrent validity and inter-rater reliability of the My Jump Lab smartphone application for evaluating BPA in the Nordic hamstring curl exercise.

MATERIALS AND METHODS

Experimental approach to the problem

The study was designed as an observational experiment in a laboratory context, intended to collect experimental data from a single session from a representative sample of a population of healthy participants.

Participants were asked to perform the Nordic hamstring curl exercise five times with one-minute rest between exercises. The objective was to measure BPA using My jump Lab app and subsequently comparing it with data from Kinovea.

Subjects

Sample size estimation was calculated using a Pearson correlation coefficient analysis (G*Power version 3.1.9.6, Universität Kiel, Germany). To this end, a correlation level (ρ1) of 0.6 was set, based on the scale of Hopkins et al (Hopkins et al., 2009), with an alpha (α) of 0.05 and power (1- β) of 0.8.

This setting revealed that a sample size of nineteen participants was necessary. For the present study, a convenience sample of twenty-four (age = 21.75 ± 1,62 years; weight = 68,6 ± 10,8 kg; height= 172,6 ± 9 cm) college healthy students were recruited and agreed to participate. Of these twenty were male and five were female. The inclusion criteria were participants that can perform exercises without musculoskeletal pain, as well as no hamstring injury for a minimum of 6 months. The exclusion criteria were individuals with cardiac pathologies, individuals with hypertension, individuals with respiratory failure, individuals with spinal cord or vertebral injuries that affect the lower limb, individuals with injuries that affect proprioception (Gallardo-Fuentes et al., 2016). Written informed consent was obtained from all participants prior to data collection, explaining the aims and risks of participating in the study. The study was approved by the Ethics Committee of Egas Moniz School of Health and Science with the number 1268 and considered the procedures mentioned in the Helsinki Declaration.

Instruments and data collection

All exercises were filmed using a smartphone (iPhone 14 Plus) which was positioned in the sagittal plane of the participants, at a distance of 3m and 30cm high from the ground, supported on a tripod (Vercelli et al., 2020a). Videos were recorded at a frame rate of 240 Hz. A whiteboard was placed in the back of the frame (Figure 1), with a specific coding, so that in the analysis posteriorly performed, observers could proper identify the subject and repetition, since they were blind to subjects' identification. After data collection, an iPad mini-6 was used was used by two independent observers (App1 and App2) in two different moments, to determine BPA using the My Jump Lab app. The app is an updated version, that compiles in one application several applications that previously existed. The previous version that assessed Nordic hamstring curl was called Nordics, and remains with the same name on the updated My Jump Lab. The same videos were also analysed with Kinovea independently by two observers (Kin1 and Kin2), which was considered the reference method in our study, since it has been previously deemed valid and reliable for and angle measurement (Puig-Diví et al., 2019).

Procedures

Data collection started with the signing of the informed consent and any doubts that may exist was clarified. Participants performed a warm-up consisting of ten squats, low, medium and high skipping for twenty seconds at each intensity, with an estimated duration of five minutes, followed by

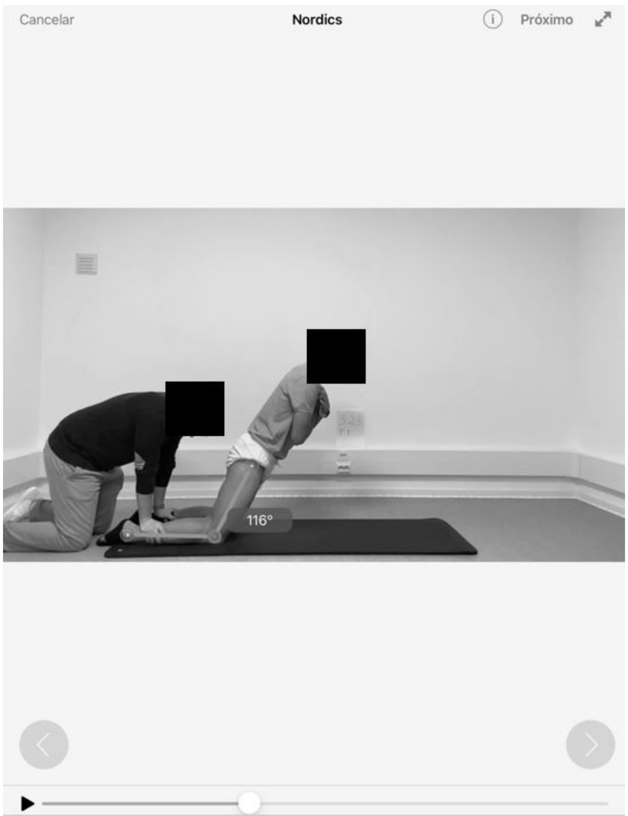

Figure 1. Break point angle (BPA) assessment in My Jump Lab

dynamic stretching of the lower limbs (Ditroilo et al., 2013). After the warm-up, three white markers were placed on the participants, which served as anatomical references for subsequent data analysis. Markers were placed on the external malleolus, lateral epicondyle of the knee and greater trochanter of the femur. The markers were round, approximately 1.5cm in diameter. All the anatomical references were placed by a 4th year physical therapy student to assure proper identification and placement. After this procedure, participants were asked to become familiarized with the exercise by performing some trials. Several attempts were allowed if participants did not perform the exercise in a correct manner (Ditroilo et al., 2013). After this period, participants were asked to perform the Nordics hamstring curl exercise five times. The inclusion of several repetitions per participant was made in order to increase the amount of data points for comparison. After placing their knees on a mattress, a physical therapy student would stand behind the participant and hold their feet. From this position, participants were asked to lean their body forward, extending their knees, until they can no longer perform the exercise. Additionally, participants were asked to perform the exercise with their hands crossed on their chest and, when it is not possible to continue extending their knees, they should remove their hands and place them next to their chest to support the fall (Sconce et al., 2015). The moment were participants removed their hand from their chest was deemed the criteria for BPA estimation. Between each exercise there was a one-minute rest period (Lee et al., 2018).

All video data was uploaded to an iPad mini-6, for analysis with My Jump Lab. Each observer (App1 and App2) selected the participant and corresponding video of each repetition to perform BPA estimation, according to the coding provided. To achieve that, observers selected the first frame were the criteria of BPA was visible (hands removed from chest). After frame selection, observers placed three markers provided by the app, that were analogous to the anatomical references previously mentioned, and BPA was automatically determined (figure 1). The other two observers that used Kinovea had similar assessment procedures. They determined the first frame where BPA criteria was present and used the software tools to estimate the angle between the three markers.

Statistical analyses

All data was entered into a database in an Excel file. The Shapiro-Wilk test was used to determine data normality. Pearson's correlation coefficient (r) was used to determine concurrent validity of the app and interpreted with the following scale (Hopkins et al., 2009): trivial <0.10; small = 0.10– 0.30; moderate >0.3-0,5; high >0.50–0.70, very high >0.70–0.90, or practically perfect >0.90. Bland-Altman plots were also used to analyse data agreement and possibility of data bias. The intraclass correlation coefficient (ICC) with a two-way agreement model was used, with a 95% confidence interval, for inter-rater reliability determination. Values under 0.5 were considered of poor reliability, 0.5-0.75 were indicative of moderate reliability, 0.75-0.90 were indicative of good reliability, and values > 0.90 suggested excellent reliability (Koo & Li, 2016). Furthermore, the coefficient of variation (CV), measured in percentage and the absolute and relative standard error of measurement (SEM) were also used to better understand reliability. For CV, excellent thresholds were set at ≤5% and acceptable were set at ≤10% (James et al., 2017). Additionally absolute and relative minimal detectable change (MDC) was also estimated. All tests were performed using the Jamovi (version 2.4) statistical software.

RESULTS

A total of 120 repetitions was used for data analysis. The descriptive data for all observers are presented on table 1.

Table 1. Descriptive data obtained by observers

	App1	App2	Kin1	Kin2
Break point angle (mean ± standard deviation)	116 ± 9.96°	118 ± 10°	119 ± 10.3°	118 ± 10.3°

App1 and App2; Observers that used My Jump Lab; Kin1 and Kin2: Observers that used Kinovea

Table 2. Concurrent validity between My Jump Lab and Kinovea

	APP1 vs KIN 1	APP1 vs KIN2	APP2 vs KIN 1	APP2 vs KIN2
Pearson's *r*	0.985***	0.989***	0.986***	0.990***

**** p< 0.001*

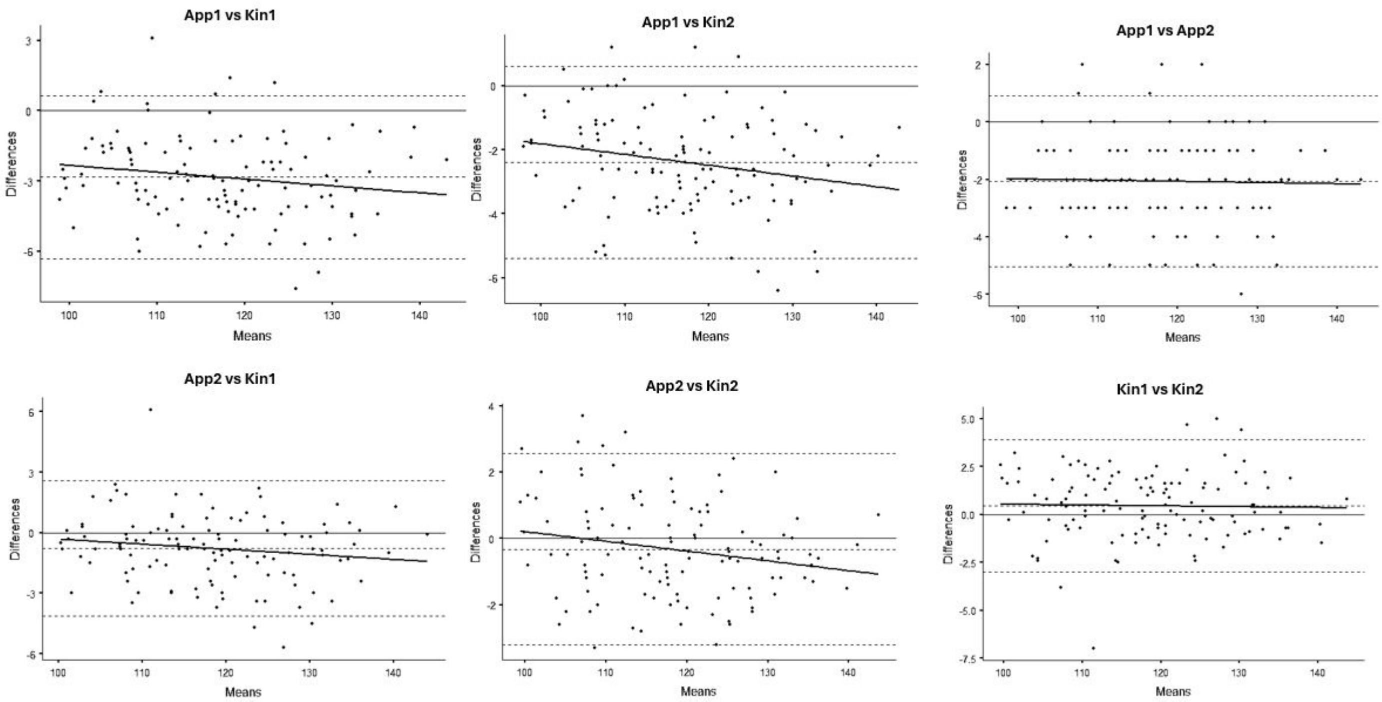

Figure 2. Bland Altman plots between all observers for My Jump Lab (App1 and App2) and Kinovea (Kin1 and Kin2), with limits of agreement (± 1.96 SD) in the upper and lower dashed lines and proportional bias in continuous line

Table 3. Inter-rater reliability

	APP1 vs KIN1	APP1 vs KIN2	APP2 vs KIN1	APP2 vs KIN2	APP1 vs APP2	KIN 1 vs KIN2
ICC (95% CI)	0.973	0.981	0.991	0.995	0.984	0.992
CV (%)	1.07	0.92	1.03	0.88	0.92	1.05
SEM (º)	1.26	1.08	1.22	1.04	1.07	1.25
SEM (%)	1.07	0.92	1.04	0.88	0.91	1.05
MDC (º)	3.49	2.99	3.38	2.88	2.96	3.46
MDC (%)	2.97	2.56	2.89	2.43	2.51	2.92

ICC: Intraclass correlation coefficient; CV: Coefficient of variation; SEM(º): Absolute values of Standard error of measurement; SEM (%): Relative values of Standard error of measurement; MDC (º): Absolute values of Minimal detectable change; MDC (%): Relative values of Minimal detectable change

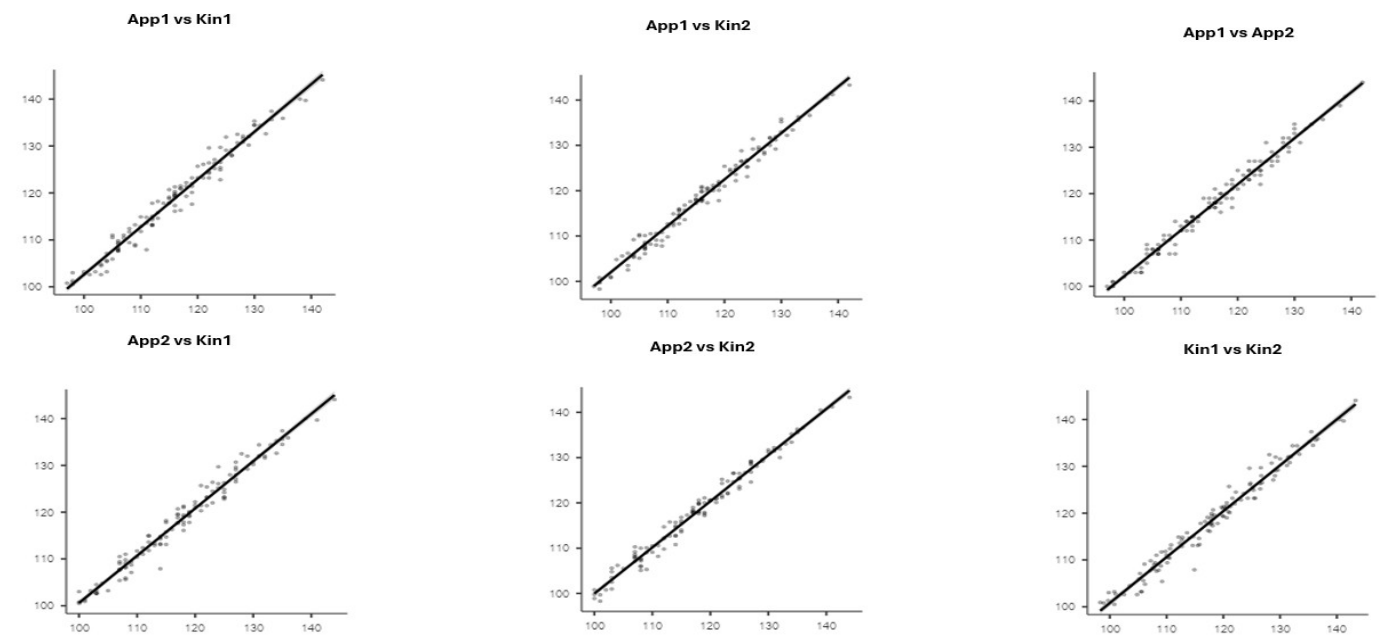

Figure 3. Correlation plots between all observers for My Jump Lab (App1 and App2) and Kinovea (Kin1 and Kin2).

In the Bland-Altman plots (figure 2) we can see that in all graphs most of the differences between the measurement methods are within the limits of agreement, suggesting that the methods are in fact in agreement.

There is a small negative systematic bias between the measurement methods, excluding the graph comparing App1 with App2 and Kin1 with Kin2 where this bias is zero. In terms of bias, the downward slope of the trend line suggests that the difference between the two measurements decreases as the magnitude of the measurements increases. Inter-rater reliability was also very high. As can be seen in table 3, all combinations between observers obtained ICC values greater than 0.9. Additional reliability analysis that was performed also showed very good reliability, with CV reporting variations of less than or close to 1% between evaluators, which is deemed excellent (CV≤5%) and SEM variation between 1.04º and 1.26º, which shows that the measurement error was always low.

In Figure 3 the correlation plots between all observers for both My Jump Lab and Kinovea are represented. Most of the data points align with the equality line, demonstrating a high level of correlation between observers.

DISCUSSION

The objective of this study was to analyse the concurrent validity and inter-rater reliability of the My Jump Lab application, by evaluating BPA in the Nordic hamstring curl exercise. Given that determining the degree of validity of the same with video analysis is still a minor explored topic, it becomes a pertinent issue in scientific evidence. The results of this study show that the agreement between the My Jump Lab and Kinovea applications is excellent for all comparisons. Pearson's correlation coefficients indicate extremely high correlations between all pairs of measurements ($r \geq 0.9$, $p < 0.001$), suggesting a practically perfect correlation between assessments. The correlations plot (figure 3) supports this idea, since they demonstrate high correlation between all observers. Bland-Altman plots (figure 2) showed that variation in measurement errors between methods are within the 95% limits of agreement, suggesting high levels of agreement, and thus further demonstrating the concurrent validity between assessment methods. However, a small systematic negative bias was observed between measurement methods, excluding comparisons between observers of the same instrument. Heteroskedasticity was minimal, with differences decreasing as the means increased, as evidenced by the downward slope of the trend line.

Inter-rater reliability was excellent, as demonstrated by the ICC values which were all >0.9, indicating high consistency in measurements between different observers. With regards to CV values, they were all very small (CV < 5%) which suggests minimal variation between observers and measurements. The SEM absolute values ranged from 1.08º to 1.26º, indicating a low measurement error, which reinforces the high reliability of the evaluated methods.

Moreover, the low relative values for SEM and MDC (SEM < 5%; MDC < 10%) denotes high precision for both sports and rehabilitation (Lexell & Downham, 2005), further supporting the elevated inter-rater reliability.

From the reviewed literature and to the best of our knowledge, this is the first study that reports on the concurrent validity and inter-rater reliability of the My Jump Lab for Nordic exercise assessment. Few studies have tested a video analysis method for Nordic exercise evaluation. Vercelli et al (Vercelli et al., 2020b) tested the agreement and reproducibility of a smartphone app, which used a similar method for BPA estimation (angle between the lower limb segments) and compared it to the same reference method as our study. Results presented mixed values regarding reliability, with ICC values varying from 0.41 to 0.8. Validity was only established using Bland-Altman plots and homoscedasticity tests and did not present any data regarding correlation between methods. Another study also tested BPA evaluation with an app and compared it with a two-dimensional motion analysis software that can calculate angles (Soga et al., 2023). Results revealed a high correlation ($r = 0.75$), but with no statistical significance and very high ICC values for reliability. These outcomes reported by Soga et al (Soga et al., 2023) were a bit smaller than the results of the present study regarding concurrent validity, with similar values for reliability. However, the low number of participants in the study (n=7) limits the conclusions of the study and raises issues regarding the agreement of the smartphone app that was used.

Video analysis was also used in other study, but it was recorded with a video camera and posteriorly analysed on a computer (Lee et al., 2017). The estimation of BPA was different than our study, since the angle between the trunk and vertical (initial position) was used for assessment. Likewise, angular velocity was used as criteria for the moment of BPA and not visual clues, as in our study. Values for reliability reported by the authors were lower than those presented in our study (ICC = 0.815). Moreover, data outputs were not instantly obtainable, which could damper the usefulness of this method.

A study used another type of Nordic exercise assessment, by utilizing the smartphone's inertial sensors, when secure to the side of the thigh, to detect BPA (Teixeira, 2023). This study also used Kinovea as a reference method, and the results showed a significant correlation (*r* =0.82) but the small number of subjects (n=2) calls into question the study's conclusions and the validity of the application used.

Based on the obtained results, My Jump Lab app appears to demonstrate slightly higher concurrent validity and reliability values compared to studies investigating other apps (Soga et al., 2023; Teixeira, 2023; Vercelli et al., 2020b), signalling greater accuracy and consistency in measurements. It adds to the existing literature, by demonstrating that video analysis can be used as a valid and reliable method, thus overcoming the necessity for isokinetic dynamometry evaluation. Consequently, it appears that My Jump Lab application could be recommended for use in research and clinical settings with confidence, providing a valid and effective alternative to the traditional methods available. It makes the assessment of hamstring muscles more practical, allowing it to be carried out in different locations and contexts, without the need of specialized equipment. According to the literature, there are no doubts on the use of the Nordic hamstring exercise to improve hamstring strength (Llurda-Almuzara et al, 2021). The exercise provides high eccentric loading and produces greater hypertrophy compared to other knee-based exercises (Sahinis et al, 2025) for both semitendinosus and biceps femoris muscles (Llurda-Almuzara et al, 2021; Sahinis et al, 2025). The validation of this smartphone application could help practitioners to assess hamstring muscle forces. Additionally, since rater experience does not seem to affect BPA results (Vercelli et al., 2020b), it can be used as a tool for health promotion and injury prevention.

There were some limitations of the present study that are worth noting, such as: a) accessibility to the application as it is a paid, which naturally affects general access to the public; b) Although each subject performed five repetitions for evaluation, the total sample size is not large, thus limiting the strength of this study; c) The results of the present study are restricted to the population that was enrolled in the study and extrapolation to other type of populations is not warranted.

Future studies on this app and topic should consider larger sample sizes and/or test-retest designs, to further examine the validity and reliability of the app. Also, studies with athletes should be conducted, since their increased strength training could impact data reliability. Finally, studies with subjects with previous hamstring injuries should be conducted, to further determine the usefulness of this app.

Considering these results, My Jump Lab application was proven to be a valid and reliable tool, recommended for use in research and clinical setting, providing an effective instrument for BPA estimation.

CONCLUSION

The validation of this app allows both coaches, practitioners as well as healthcare professionals to be confident on carrying assessments of hamstring muscles in an easier and more accessible way, thus promoting injury prevention procedures. The findings in our study could be of interest to sports scientists as well as physical therapists, since it provides them with an instrument that can help increase athletes' safety and also assess training programs, without the need of expensive equipment.

ACKNOWLEDGEMENTS

The authors would like to thank to all the participants for the participation in their study.

CONFLICTS OF INTEREST

The first author of the present manuscript was involved in the translation of the mentioned app. In order to assure independency from all data collection and analyses, data was collected and examined by the other authors of this manuscript, which have no type of relationship with the app development and translation.

FUNDING

This study received no specific funding in order to be completed.

ETHICAL APPROVAL

The study was approved by the Ethics Committee of Egas Moniz School of Health and Science with the number 1268 and considered the procedures mentioned in the Helsinki Declaration.

DATES OF REFERENCE

Submission - 07/11/2024
Acceptance - 21/06/2025
Publication - 24/10/2025

REFERENCES

1. Al Attar, W. S. A., Soomro, N., Sinclair, P. J., Pappas, E., & Sanders, R. H. (2017). Effect of Injury Prevention Programs that Include the Nordic Hamstring Exercise on Hamstring Injury Rates in Soccer Players: A Systematic Review and Meta-Analysis. Sports Medicine (Auckland, N.Z.), 47(5), 907–916. https://doi.org/10.1007/S40279-016-0638-2
2. Alawna, M. A., Unver, B. H., & Yuksel, E. O. (2019). The Reliability of a Smartphone Goniometer Application Compared With a Traditional Goniometer for Measuring Ankle Joint Range of Motion. Journal of the American Podiatric Medical Association, 109(1), 22–29. https://doi.org/10.7547/16-128
3. Arnason, A., Andersen, T. E., Holme, I., Engebretsen, L., & Bahr, R. (2008). Prevention of hamstring strains in elite soccer: an intervention study. Scandinavian Journal of Medicine & Science in Sports, 18(1), 40–48. https://doi.org/10.1111/J.1600-0838.2006.00634.X
4. Askling, C., Karlsson, J., & Thorstensson, A. (2003). Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. Scandinavian Journal of Medicine & Science in Sports, 13(4), 244–250. https://doi.org/10.1034/j.1600-0838.2003.00312.x
5. Balsalobre-Férnandez, C., Xu, J., Jarvis, P., Thompson, S., Tannion, K., & Bishop, C. (2023). The validity of a smartphone app using artificial intelligence for the real time measurement of barbell velocity in the bench press exercise. The Journal of Strength and Conditioning Research, 37(12), e640–e645. https://doi.org/10.1519/JSC.0000000000004593
6. Danielsson, A., Horvath, A., Senorski, C., Alentorn-Geli, E., Garrett, W. E., Cugat, R., Samuelsson, K., & Senorski, E. H. (n.d.). The mechanism of hamstring injuries-a systematic review. https://doi.org/10.1186/s12891-020-03658-8
7. Delahunt, E., McGroarty, M., De Vito, G., & Ditroilo, M. (2016). Nordic hamstring exercise training alters knee joint kinematics and hamstring activation patterns in young men. European Journal of Applied Physiology, 116(4), 663–672. https://doi.org/10.1007/s00421-015-3325-3
8. Diemer, W. M., Winters, M., Tol, J. L., Pas, H. I. M. F. L., & Moen, M. H. (2021). Incidence of Acute Hamstring Injuries in Soccer: A Systematic Review of 13 Studies Involving More Than 3800 Athletes With 2 Million Sport Exposure Hours. The Journal of Orthopaedic and Sports Physical Therapy, 51(1), 27–36. https://doi.org/10.2519/JOSPT.2021.9305
9. Ditroilo, M., De Vito, G., & Delahunt, E. (2013). Kinematic and electromyographic analysis of the Nordic Hamstring Exercise. Journal of Electromyography and Kinesiology, 23(5), 1111–1118. https://doi.org/10.1016/j.jelekin.2013.05.008
10. Ekstrand, J., Bengtsson, H., Waldén, M., Davison, M., Khan, K. M., & Hägglund, M. (2023). Hamstring injury rates have increased during recent seasons and now constitute 24% of all injuries in men's professional football: the UEFA Elite Club Injury. Br J Sports Med, 57, 292–298. https://doi.org/10.1136/bjsports-2021-105407
11. Gallardo-Fuentes, F., Gallardo-Fuentes, J., Ramírez-Campillo, R., Balsalobre-Fernández, C., Martínez, C., Caniuqueo, A., Cañas, R., Banzer, W., Loturco, I., Nakamura, F. Y., & Izquierdo, M. (2016). Intersession and intrasession reliability and validity of the my jump app for measuring different jump actions in trained male and female athletes. Journal of Strength and Conditioning Research, 30(7), 2049–2056. https://doi.org/10.1519/JSC.0000000000001304
12. Green, B., Bourne, M. N., & Pizzari, T. (2018). Isokinetic strength assessment offers limited predictive validity for detecting risk of future hamstring strain in sport: a systematic review and meta-analysis. British Journal of Sports Medicine, 52(5), 329–336. https://doi.org/10.1136/BJSPORTS-2017-098101
13. Hopkins, W. G., Marshall, S. W., Batterham, A. M., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. Medicine and Science in Sports and Exercise, 41(1), 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278
14. Intille, S. S., Lester, J., Sallis, J. F., & Duncan, G. (2012). New Horizons in sensor development. Medicine and Science in Sports and Exercise, 44(SUPPL. 1), 1–13. https://doi.org/10.1249/MSS.0b013e3182399c7d
15. James, L. P., Roberts, L. A., Haff, G. G., Kelly, V. G., & Beckman, E. M. (2017). Validity and Reliability of a Portable Isometric Mid-Thigh Clean Pull. Journal of Strength and Conditioning Research, 31(5), 1378–1386. https://doi.org/10.1519/JSC.0000000000001201
16. Karatekin, Bilinç; Çiçel, Sinem; Içagasioglu, A. (2022). Validity and Reliability of iPhone Application in Active Internal Rotation Measurement of Shoulder in Patients with Shoulder Pain. Bosphorus Medical Journal, 9(1), 54–59. https://doi.org/10.14744/bmj.2022.86547
17. Koo, T. K., & Li, M. Y. (2016). A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. Journal of Chiropractic Medicine, 15(2), 155–163. https://doi.org/10.1016/J.JCM.2016.02.012
18. Lee, J. W. Y., Cai, M.-J., Yung, P. S. H., & Chan, K.-M. (2018). Reliability, Validity, and Sensitivity of a Novel Smartphone-Based Eccentric Hamstring Strength Test in Professional Football Players. International Journal of Sports Physiology and Performance, 13(5), 620–624. https://doi.org/10.1123/ijspp.2017-0336
19. Lee, J. W. Y., Li, C., Yung, P. S. H., & Chan, K.-M. (2017). The reliability and validity of a video-based method for assessing hamstring strength in football players. Journal of Exercise Science & Fitness, 15(1), 18–21. https://doi.

org/10.1016/j.jesf.2017.04.001
20. Lehance, C., Binet, J., Bury, T., & Croisier, J. L. (2008). Muscular strength, functional performances and injury risk in professional and junior elite soccer players. Scandinavian Journal of Medicine & Science in Sports, 19(2), 243–251. https://doi.org/10.1111/j.1600-0838.2008.00780.x
21. Lexell, J. E., & Downham, D. Y. (2005). How to Assess the Reliability of Measurements in Rehabilitation. American Journal of Physical Medicine & Rehabilitation, 84(9), 719–723. https://doi.org/10.1097/01.phm.0000176452.17771.20
22. Linklater, J., Hamilton, B., Carmichael, J., Orchard, J., & Wood, D. (2010). Hamstring Injuries: Anatomy, Imaging, and Intervention. Seminars in Musculoskeletal Radiology, 14(02), 131–161. https://doi.org/10.1055/s-0030-1253157
23. Llurda-Almuzara, L., Labata-Lezaun, N., López-de-Celis, C., Aiguadé-Aiguadé, R., Romaní-Sánchez, S., Rodríguez-Sanz, J., Fernández-de-las-Peñas, C., Pérez-Bellmunt, A. (2021). Biceps Femoris Activation during Hamstring Strength Exercises: A Systematic Review. Int. J. Environ. Res. Public Health , 18, 8733. https://doi.org/10.3390/ijerph18168733
24. Mjølsnes, R., Arnason, A., Østhagen, T., Raastad, T., & Bahr, R. (2004). A 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. Scandinavian Journal of Medicine & Science in Sports, 14(5), 311–317. https://doi.org/10.1046/J.1600-0838.2003.367.X
25. Peart, D. J., Balsalobre-Fernández, C., & Shaw, M. P. (2019). Use of Mobile Applications to Collect Data in Sport, Health, and Exercise Science: A Narrative Review. Journal of Strength and Conditioning Research, 33(4), 1167–1177. https://doi.org/10.1519/JSC.0000000000002344
26. Puig-Diví, A., Escalona-Marfil, C., Padullés-Riu, J. M., Busquets, A., Padullés-Chando, X., & Marcos-Ruiz, D. (2019). Validity and reliability of the Kinovea program in obtaining angles and distances using coordinates in 4 perspectives. PLoS ONE, 14(6), 1–14. https://doi.org/10.1371/journal.pone.0216448
27. Sá, E. C. de, Medeiros, A. R., Ferreira, A. S., Ramos, A. G., Janicijevic, D., & Boullosa, D. (2019). Validity of the iLOAD® app for resistance training monitoring. PeerJ, 2019(8), 1–14. https://doi.org/10.7717/peerj.7372
28. Sahinis, C., Amiridis, I. G., Enoka, R. M., & Kellis, E. (2025). Differences in activation amplitude between semitendinosus and biceps femoris during hamstring exercises: A systematic and critical review with meta-analysis. Journal of Sports Sciences, 43(11), 1054–1069. https://doi.org/10.1080/02640414.2025.2486879
29. Sconce, E., Jones, P., Turner, E., Comfort, P., & Graham-Smith, P. (2015). The Validity of the Nordic Hamstring Lower for a Field-Based Assessment of Eccentric Hamstring Strength. Journal of Sport Rehabilitation, 24(1), 13–20. https://doi.org/10.1123/jsr.2013-0097
30. Soga, T., Yamaguchi, S., Inami, T., Saito, H., Hakariya, N., Nakaichi, N., Shinohara, S., Akiyama, K., & Hirose, N. (2023). The Validity and Reliability of a Smartphone Application for BreakPoint Angle Measurement during Nordic Hamstring Exercise. International Journal of Sports Physical Therapy, 18(4), 917–922. https://doi.org/10.26603/001c.83936
31. Takeda, Y., & Furukawa, K. (2022). Clinical reliability and usability of smartphone goniometers for hip range of motion measurement. Journal of Physical Therapy Science, 34, 433–439. https://doi.org/10.1589/jpts.34.433
32. Teixeira, B. (2023). Análise Cinemática da Extensão Nórdica com Aplicativo Mobile. Universidade de Brasília.
33. Tozawa, R., Ishii, N., Onuma, R., & Kawasaki, T. (2023). The reliability and validity of joint range of motion measurement using zoom and a smartphone application. Journal of Physical Therapy Science, 35(7), 538–541. https://doi.org/10.1589/jpts.35.538
34. Van Dyk, N., Bahr, R., Whiteley, R., Tol, J. L., Kumar, B. D., Hamilton, B., Farooq, A., & Witvrouw, E. (2016). Hamstring and Quadriceps Isokinetic Strength Deficits Are Weak Risk Factors for Hamstring Strain Injuries: A 4-Year Cohort Study. The American Journal of Sports Medicine, 44(7), 1789–1795. https://doi.org/10.1177/0363546516632526
35. Vercelli, S., Baldaccini, A., Sartorio, F., Bravini, E., Corna, S., & Ferriero, G. (2020a). Reproducibility of the DrGoniometer app for field-based assessment of the break-point angle in Nordic Hamstring exercise. International Journal of Rehabilitation Research, 43(3), 272–275. https://doi.org/10.1097/MRR.0000000000000415
36. Vercelli, S., Baldaccini, A., Sartorio, F., Bravini, E., Corna, S., & Ferriero, G. (2020b). Reproducibility of the DrGoniometer app for field-based assessment of the break-point angle in Nordic Hamstring exercise. International Journal of Rehabilitation Research, 43(3), 272–275. https://doi.org/10.1097/MRR.0000000000000415
37. Vieira, A., Ribeiro, G. L., Macedo, V., de Araújo Rocha Junior, V., Baptista, R. de S., Gonçalves, C., Cunha, R., & Tufano, J. (2023). Evidence of validity and reliability of Jumpo 2 and MyJump 2 for estimating vertical jump variables. PeerJ, 11, 1–13. https://doi.org/10.7717/peerj.14558
38. Whiteley, R., Jacobsen, P., Prior, S., Skazalski, C., Otten, R., & Johnson, A. (2012). Correlation of isokinetic and novel hand-held dynamometry measures of knee flexion and extension strength testing. Journal of Science and Medicine in Sport, 15(5), 444–450. https://doi.org/10.1016/J.JSAMS.2012.01.003
39. Woods, C., Hawkins, R. D., Maltby, S., Hulse, M., Thomas, A., & Hodson, A. (2004). The Football Association Medical Research Programme: an audit of injuries in professional football--analysis of hamstring injuries. British Journal of Sports Medicine, 38(1), 36–41. https://doi.org/10.1136/BJSM.2002.002352