

Original Research

Intra-rater and Inter-rater Reliability of the KangaTech (KT360) Fixed Frame Dynamometry System During Maximal Isometric Strength Measurements of the Knee Flexors.

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Background

Fixed-frame dynamometry systems are used worldwide to assess isometric strength in both general and athletic populations. There is currently a paucity of published work where reliability estimates for fixed-frame dynamometry systems have been estimated. The aim of this study was to determine the inter-and intra-rater reliability of the KangaTech (KT360) fixed frame dynamometry system when measuring maximal isometric strength of the knee flexor muscles.

Study Design

Inter and intra-rater reliability single cohort study.

Methods

Twenty healthy university-level athletes (age= 21.65 ± 3 years, weight= 74.465 ± 30kg, height= 170.1 ± 7.0cm) took part in two testing sessions where two raters collected data during a 90° hip and knee flexion protocol. Participants performed each test twice, building to a maximal isometric contraction holding over a 5 second period with 30 second rest between sets. Data were checked for normality using a Shapiro-Wilk test. Intraclass correlation coefficient (ICC), standard error of measurement (SEM) and minimal detectable change (MDC) were calculated. Finally, a Bland-Altman analysis was used to determine the levels of agreement for intra-and inter-rater measurements.

Results

High levels of agreement were demonstrated between left and right knee flexion as 95% of the differences were less than two standard deviations away from the mean. 'Almost perfect' intraclass correlation coefficient (ICC) values were demonstrated (Knee flexion: Inter-rater: Left, 0.99; Right, 0.99; Intra-rater: Left, 0.99; Right:0.99). Standard error of measurement (SEM) for inter-and intra-rater strength ranged from 0.26-0.69 kg, SEM% ranged from 1.34-2.71% and minimal detectable change (MDC) ranged from 1.14-2.31kg.

Conclusion

Overall, high level of inter-and intra-rater reliability were demonstrated when testing maximal isometric knee flexion. Therefore, the KT360 fixed frame dynamometry system may be considered a viable tool for measuring maximal isometric contraction of the knee flexors when repeat measures are required in clinical settings.

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Level of Evidence

3b

INTRODUCTION

Isometric strength testing is used extensively in sport and healthcare settings to test a participant's physical capabilities during clinical decision-making processes.^{1,2} As hamstring strain injuries are one of the most prevalent injuries in sports that require high-speed running^{3,4} measurements of maximal isometric knee flexion are important to assess for hamstring dysfunction. This measure can be used to highlight muscle imbalances between limbs,⁵ as well as monitor for risk of re-injury.⁶ Having highly reliable and repeatable measures to work with is important to justify return to play decisions that practitioners are required to make, as well as guide progression through rehabilitation protocols.

A plethora of different dynamometry devices are available on the market which are often selected according to ease of use, cost, and portability.^{7,8} Isokinetic dynamometry (IKD) is currently suggested to be the "gold standard" measurement of strength in research and clinical practice,⁹ however, this equipment is not portable, which may limit its use in certain field-based settings. To address this potential issue, portable fixed-framed dynamometry systems have recently come to market. Kangatech (KT360) (KangaTech Ltd, Melbourne, Victoria, Australia) is a portable fixed-frame dynamometry system that utilizes a stainless-steel frame with detachable dynamometers and can be positioned to assess varied muscle groups across different planes of motion.¹⁰ The system has a multitude of standardized protocols to measure the isometric strength in different fixed positions. Because the KT360 system is a novel device, there is a paucity of evidence surrounding its reliability as has been established for other portable or fixed frame dynamometry measurement tools.¹¹ A recent study evaluated the test-retest reliability of the KT360 system prior to the addition of a 360° rotational frame.¹⁰ This study found that Interclass correlation coefficient (ICC) for left knee flexion was 0.927 and 0.923 for right knee flexion. More recently, high test-retest reliability (ICC 0.895-0.974) was found in hip adductor strength with standard error of measure (SEM) and minimal detectable change (MDC) % ranging from 0.59-2.25 and 1.63-6.26, respectively.¹⁰ While this provides some initial reliability estimates for the portable fixed frame system, there are currently no studies available estimating the reliability since the 360° rotational frame was released into the market, and none that have considered the testing protocol of 90° hip and knee flexion. Furthermore, there are currently no studies that have estimated the inter-rater reliability of the equipment. As the pressure of keeping athletes in play and delivering results continues to increase within sporting environments, sports teams have a strong economic incentive to invest in injury prevention and rehabilitation.¹² Having reliability estimates will help develop practitioners to make an informed decision on whether to integrate such equipment into multidisciplinary sports science and medical departments.

It was hypothesised that the KT360 system would demonstrate a high threshold of reliability when measuring maximal strength produced during the isometric knee flexion protocol based on the results of previous literature.^{10, 11} The aim of this study was to determine the inter-and intra-rater reliability of the KT360 fixed frame dynamometry system when measuring maximal isometric strength of the knee flexor muscles.

MATERIALS AND METHODS

A cross-sectional study design was used. Ethical approval was granted by the School of Health Ethics committee at Leeds Beckett University (ethics number: 98113) and complied with the Declaration of Helsinki on Human Research international standards.

PARTICIPANTS

Healthy, university level athletes were recruited to take part in the study using a convenience sampling method. All participants had to be over the age of 18, have membership with University Athletic Union, train >2 times a week, and regularly take part in sporting competitions. Participants were excluded from the study if they had any current or recent lower limb injury (within the prior six months), had induced caffeine sixty minutes prior to any measurements being taken, had completed strenuous exercise forty-eight hours prior to the day of testing, or did not score a pass on the health screening questionnaire as recommended in previous research.¹³ Prior to the commencement of the study, participants were provided with a participant information sheet which fully explained the study process. All participants were required to complete a study consent form.

PROCEDURE

Both raters were present for all testing days. Prior to the commencement of the study, both raters had undertaken two days of familiarization and training with the KT360 equipment from an experienced user who had undergone training from the manufacturer. To prevent bias, a method of simple randomization by flipping a coin was implemented to select which rater began the testing process. A computerized random number generator (using Microsoft random number generator software) picked the order in which measurements were taken for each participant.

Prior to strength measurements, demographic and anthropometric data was collected. Body mass was measured using an electronic scale (SECAAlpha770, Birmingham, UK) to the nearest 0.1kg, pre-calibrated with a 5Kg dumbbell. Height was measured using a stadiometer (SECA Alpha, Birmingham, UK) to the nearest 0.1 cm. Limb length measurements were then collected and inputted into the KT360 system. Left and right leg length was measured laying in a supine position, by measuring from the anterior -superior

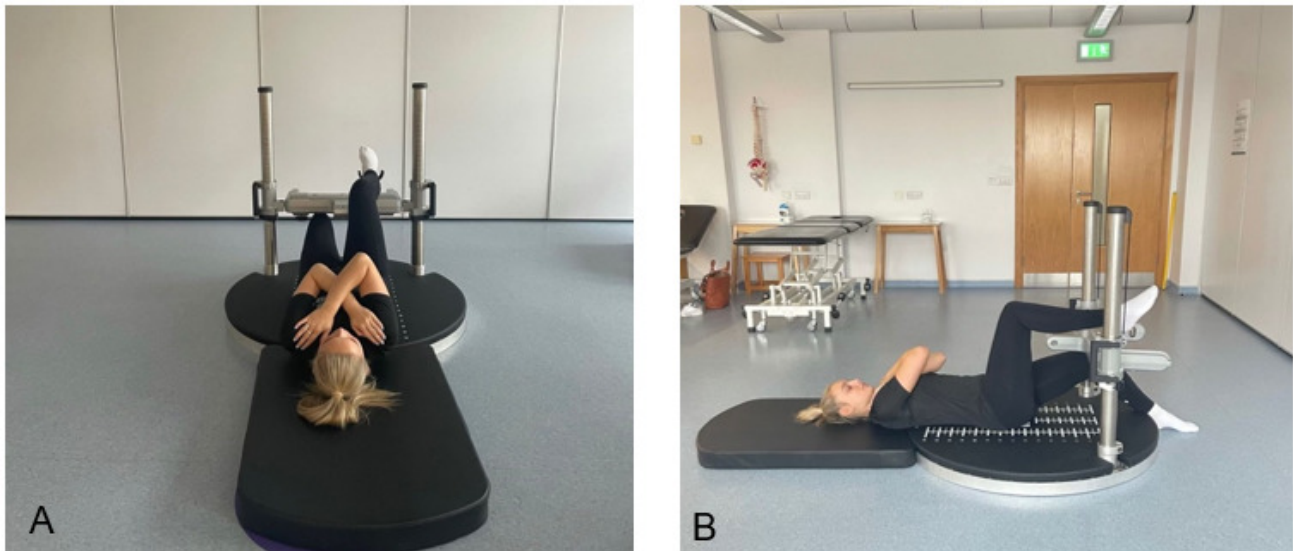


Figure 1. Knee flexion protocol set-up and 90° hip and knee flexion positioning. A: front view, B: Side view.

rior-iliac spine (ASIS) to the medial malleolus.¹⁴ Fibular length was measured from the apex of the head of the fibula to the apex of the lateral malleolus while laying supine.¹⁵ Participants were identified by a numerical value to ensure anonymity.

A standardized warm-up was then completed. This consisted of a 15-minute stationary cycle (40% VO₂ max), followed by 3 sets of 10 reps bodyweight squats and 2 sets of 8 reps of isometric hamstring curls (90° hip, 90° knee; 50% 1RM load), holding the contraction in mid-range for 5 seconds using the KT360 pads to meet the participants resistance.¹⁶ The participants knee flexion was then tested in both the right and left limbs. This was measured in supine with arms across the chest, aligned pelvis, and neutral knee position, with knees over toes. The leg being tested was placed at 90° of hip and knee flexion measured with a goniometer and positioned so the ankle of the cuff was aligned with the lateral malleolus, the housing was rotated so the cuff was flush with the achilles tendon, this angle was noted for the re-test. The resting foot was flat with the heel pressed against the base of the platform. Images of the testing position is shown in [Figure 1](#). The test was performed at 90° knee flexion as previous studies including Electromyography (EMG) measurements indicate that maximum hamstrings EMG amplitude is achieved in the mid-range knee flexion angle.¹⁷ The 90° hip flexion angle is associated with producing optimal range for force production through the knee joint.¹⁸ In this position, the knee flexors are not fully elongated or contracted, enabling the muscles to produce peak torque.¹⁸

Each participant had a familiarization repetition where they sustained a five second contraction at 50% effort, followed by 30 second rest. The knee flexors were tested twice with the participant accelerating into a maximal isometric contraction as quickly as possible and then maintaining for a five second period with a 30 second rest between tests.¹¹ The rater not collecting the data was blinded to the results by waiting outside the testing room. The resting period be-

tween the second test for Rater 1 and the single test for Rater 2 was five minutes as previous studies have suggested that this is sufficient time to facilitate recovery between tests.¹⁹

Motivational cues given by both raters during testing included 'push' to maximal effort as soon as possible straight after the '3, 2, 1 Go' visual display on the KT360 tablet. This verbal encouragement has been suggested in previous research to increase motivation to encourage subjects to exert maximal strength.²⁰ A standardized script of instructions to explain the protocol was used to ensure consistency within and between raters. A schematic of the study testing procedure can be found in [Figure 2](#).

DATA ANALYSIS

Data were transferred to Microsoft Excel, (Microsoft Corp, Redmond, WA, USA) and statistical analysis was conducted using SPSS version 27. The distribution of data was assessed for normality using the Shapiro-Wilk test. The intraclass correlation coefficient (ICC) was used for the analysis of relative reliability.²¹ The type of ICC model used for this was the two-way design as multiple raters obtained measures of each participant.²² Interpretations of the results were as follows: a <0.1= trivial; >0.1 to 0.3= small; >0.3 to 0.5= moderate; >0.5 to 0.7= large; >0.7 to 0.9= very large; and >0.9 to 1.0= almost perfect.²³ Standard error of measurement (SEM) was calculated using the following equation: standard deviation (sd)*(√1-ICC), the SEM% was: (SEM/mean)*100.¹¹ The minimal detectable change (MDC) was calculated using the formula: 1.96*√2*SEM.¹¹ Finally, Bland-Altman analyses were used to determine the levels of agreement for intra-and inter-rater measurements.²³ The difference of the two paired measurements was plotted against the mean of the two measurements. The limits of agreement were calculated as follows: Lower Limit, mean difference - (1.96 x standard deviation of difference); Upper Limit, mean of difference + (1.96 x standard deviation of

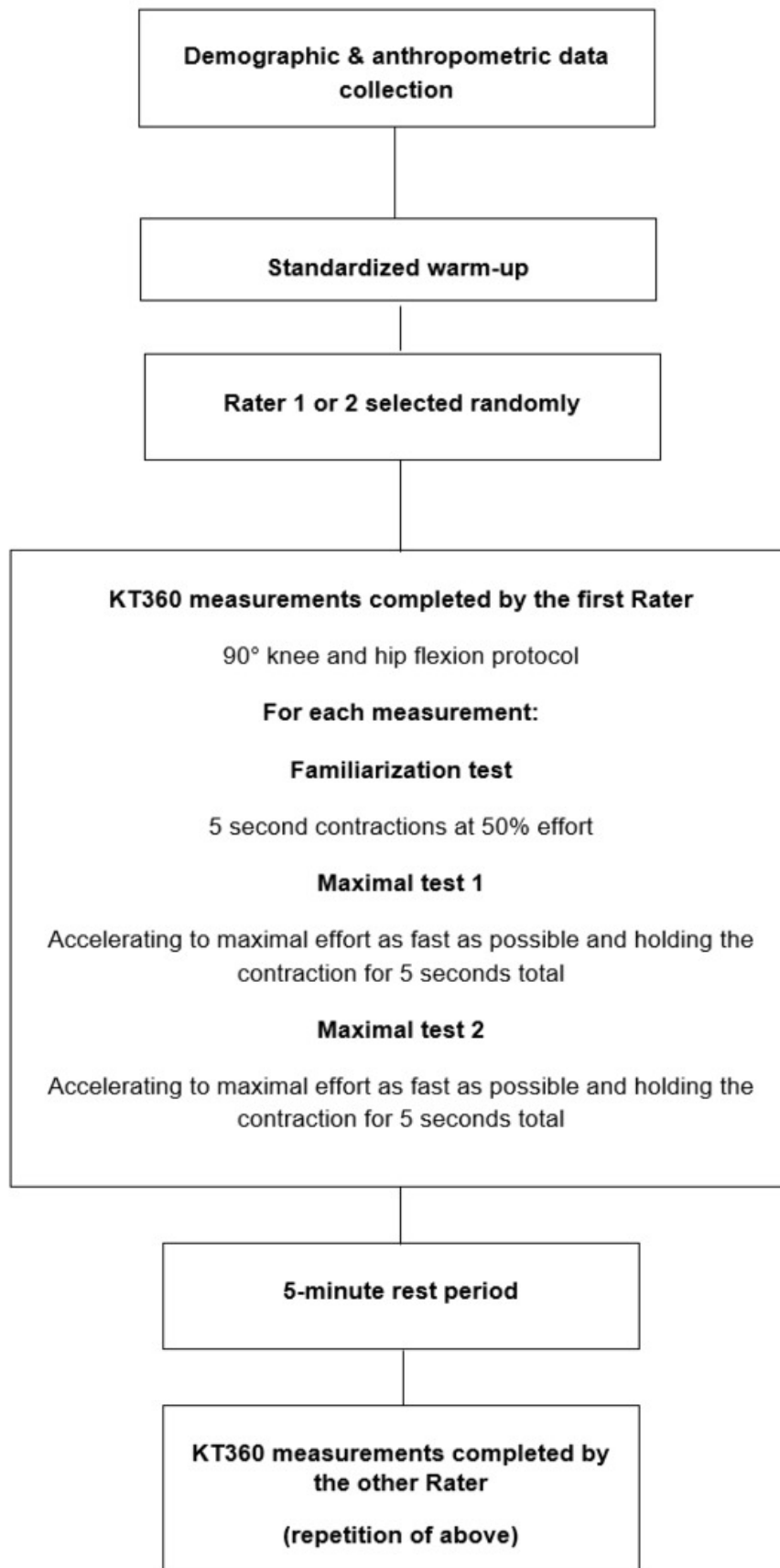


Figure 2. An illustration of the study procedure.

Table 1. Intra-rater and inter-rater reliability analysis for isometric strength measures of the knee flexors. Values are presented as the mean $\pm$ standard deviation.

Test	Mean Test $\pm$ SD (kg)	Mean Retest $\pm$ SD (kg)	ICC (95% CI)	SEM (kg)	SEM (%)	MDC (kg)
Intra-rater						
L Knee Flexion	25.69 $\pm$ 8.17	25.78 $\pm$ 8.24	0.995 (0.987, 0.998)	0.57	2.3	2.1
R Knee Flexion	26.43 $\pm$ 8.24	26.63 $\pm$ 8.63	0.997 (0.993, 0.999)	0.45	1.72	1.87
Inter-rater						
L Knee Flexion	25.75 $\pm$ 8.45	25.78 $\pm$ 8.24	0.99 (0.98, 0.99)	0.69	2.71	2.31
R Knee Flexion	26.63 $\pm$ 8.24	26.74 $\pm$ 8.69	0.99 (0.98, 0.99)	0.59	2.23	2.13

L, left; R, right; KF, knee flexion (90°); kg, kilogram; SD, standard deviation; ICC, interclass correlation coefficient; CI, confidence interval; SEM, standard error of measurement; MDC, minimal detectable change

difference). Data was interpreted as recommended by previous research¹⁹ whereby 95% of the data points should lie within ± 2 SD (2 standard deviations) of the mean difference.

RESULTS

A total of twenty (n=20) participants completed the study (age= 21.65 $\pm$ 3 years, weight= 74.465 $\pm$ 30kg, height= 170.1 $\pm$ 7.0cm).

INTRA-RATER RELIABILITY

The ICC for the data was ‘almost perfect’ between all measurements. Table 1 presents the ICC, SEM, SEM%, and MDC values. Figure 3 displays a Bland-Altman analysis. Bilateral levels of agreement were found to be $\pm$ 2 standard deviations (SD) of the interval of agreement bilaterally for knee flexion. Levels of agreement (LOA) and bias are as follows, left knee flexion: upper 2.596, lower -1.136, bias: 0.73; right knee flexion: upper 1.881, lower: -0.471, bias: 0.705.

INTER-RATER RELIABILITY

The ICC values were all ‘almost perfect’ between Rater 1 and Rater 2. The results are shown in table 1. Figures 3-6 show the results of the Bland Altman analyses. Bilateral levels of agreement were found to be $\pm$ 2 standard deviations (SD) of the interval of agreement bilaterally for knee flexion. Levels of agreement (LOA) and bias are as follows left knee flexion: upper 2.080, lower -0.780, bias: 0.65; right knee flexion: upper 1.410, lower: -0.325, bias: 0.542.

DISCUSSION

The aim of the study was to evaluate the intra-rater and inter-rater reliability of the KT360 dynamometry system when measuring the maximal isometric strength of the knee flexors. The ICC analysis shows principal findings that data collected on two occasions by the same rater and by two different raters had values between 0.98-0.99 on inter-

class correlational analysis. The SEM, SEM%, and MDC values ranged from 0.45-0.69 kg, 1.72-2.71%, and 1.87-2.31kg, respectively. High levels of agreement for inter-rater and intra-rater reliability were demonstrated in all measurements, with 95% of the differences shown to be less than two standard deviations away from the mean.

Prior to the commencement of this study, it was hypothesised that reliability would be high, as previous studies using the KangaTech system prior to the addition of a 360° had yielded excellent test-retest reliability when measuring isometric hip and knee flexor strength.^{10,11} Prior researchers have suggested that the original KangaTech model had very high reliability for left and right knee flexion (ICC 0.92),¹¹ which is in line with the present study where ICC values of 0.99 were recorded in both left and right limbs. Further research comparing the reliability of the KT360 when testing in different positions such as those used in these previous studies^{10,11} (prone with 30° and 45° hip and knee flexion with a foam roller under the pelvis and 90° hip and knee flexion) would also be a welcome addition to the KT360 literature.

Previously, researchers have considered handheld dynamometry (HHD) as a portable and low-cost alternative to estimate maximal isometric strength.^{24,25} The efficacy of using HHD at joints such as the knee where larger forces can be produced has been questioned,²⁶ although implementing best-practice techniques such as external stabilization when using HHD has been shown demonstrate acceptable reliability.²⁴ Researchers measured the inter-rater and intra-rater reliability of maximal isometric knee flexion at a 90° hip and knee position in both seated and prone positions with clinician stabilization, using the Hoggan MicroFET2 HHD.²⁶ The authors reported ICC values of 0.92 (0.75-0.97) and 0.89 (0.69-0.96) for the seated protocol and 0.90 (0.76-0.96) and 0.94 (0.82-0.98) for the prone protocol.²⁶ The MDC values were for the seated protocol were 27.3N (2.78kg) and 29.4N (2.99kg) and for the prone protocol were 24.3N (2.47kg) and 22.7N (2.31kg). In the present study, ICC values of 0.99 (0.98-0.99) were reported for both inter- and intra-rater data, showing that when comparing both studies, the KT360 produces higher relative reliability

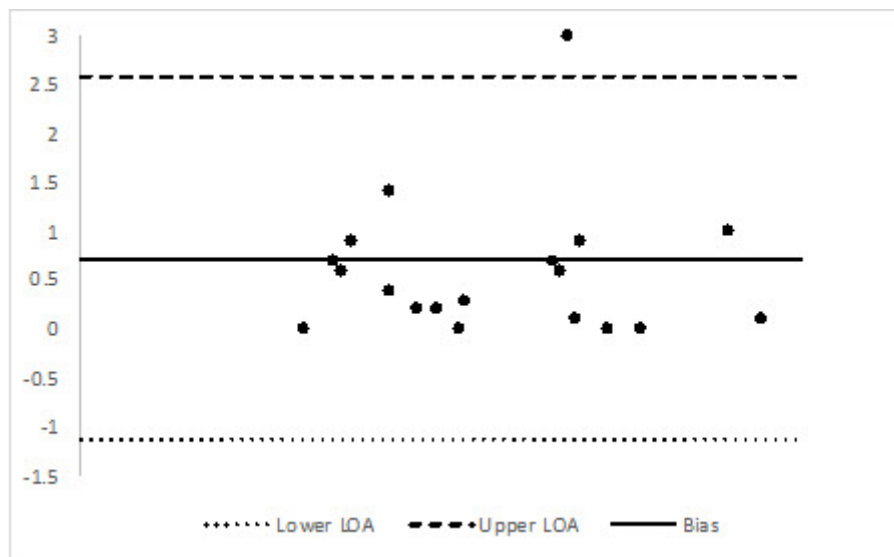


Figure 3. Bland-Altman analysis for intra-rater measures of left knee flexion. Displaying the mean difference between test-retest and 95% confidence limits for the measures.

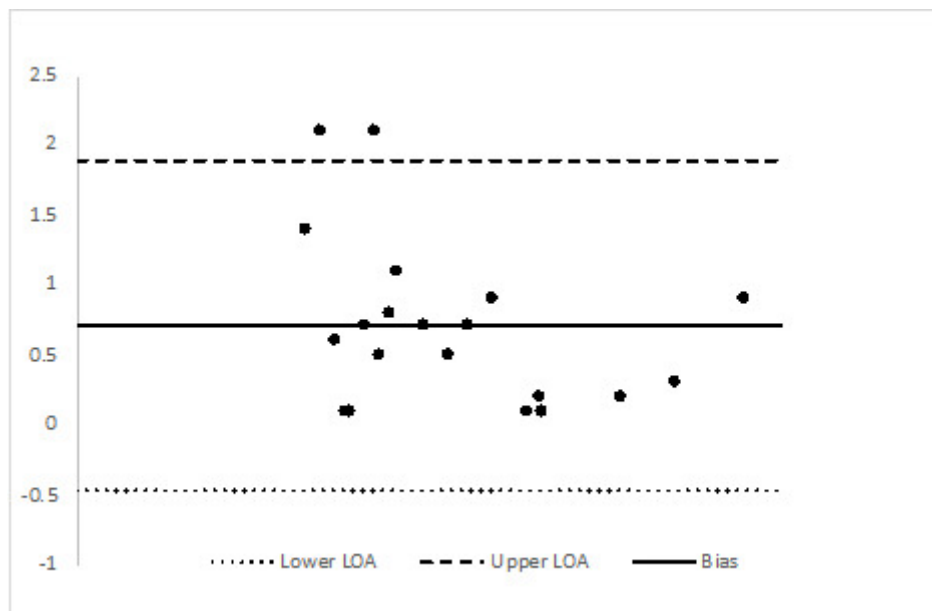


Figure 4. Bland-Altman analysis for intra-rater measures of right knee flexion. Displaying the mean difference between test-retest and 95% confidence limits for the measures.

for both inter-rater and intra-rater reliability. Furthermore, the present study reported MDC values of 2.13-2.31kg and 1.87-2.10kg, indicating that the fixed-frame device produces a smaller amount of measurement error compared to a HHD system. Future studies are needed to directly compare the level of agreement between KT360 and HHD in a range of muscle groups and testing positions.

Isokinetic dynamometry (IKD) is suggested to be the gold standard measurement of strength within sports science and clinical practice.⁹ When comparing results from the present study and previous studies that have measured isometric knee flexion strength with other dynamometry devices, the KT360 device shows higher values. ICC values for intra-rater reliability of isometric knee flexor strength

using the Cybex II IKD was 0.93 compared to 0.92 when measured with the 'BTE technologies', a portable fixed frame dynamometer.²⁷ This highlights that the ICC values were 0.06 and 0.1 higher when using the KT360 compared to the IKD and 0.07 and 0.03 compared to 'BTE technologies' dynamometer used in the study.²⁷ This shows that the KT360 is a reliable tool for measuring the strength of knee flexors and is comparable to IKD devices. Further research evaluating the level of agreement between the KT360 to IKD at a fixed angle on the same subjects would provide further evidence regarding validity regarding whether the different types of equipment could be used interchangeably in sporting and healthcare settings.

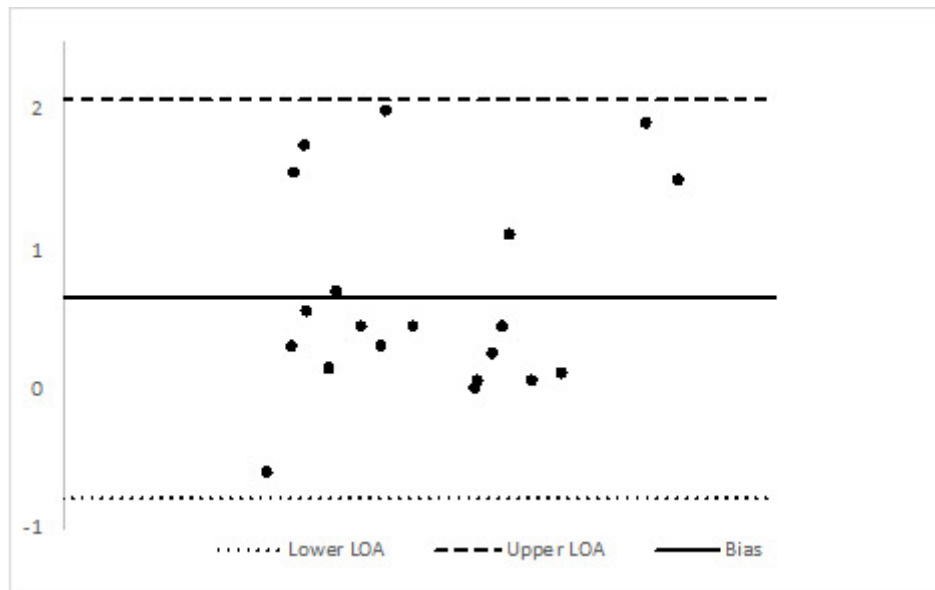


Figure 5. Bland-Altman analysis for inter-rater measures of left knee flexion. Displaying the mean difference between test-retest and 95% confidence limits for the measures.

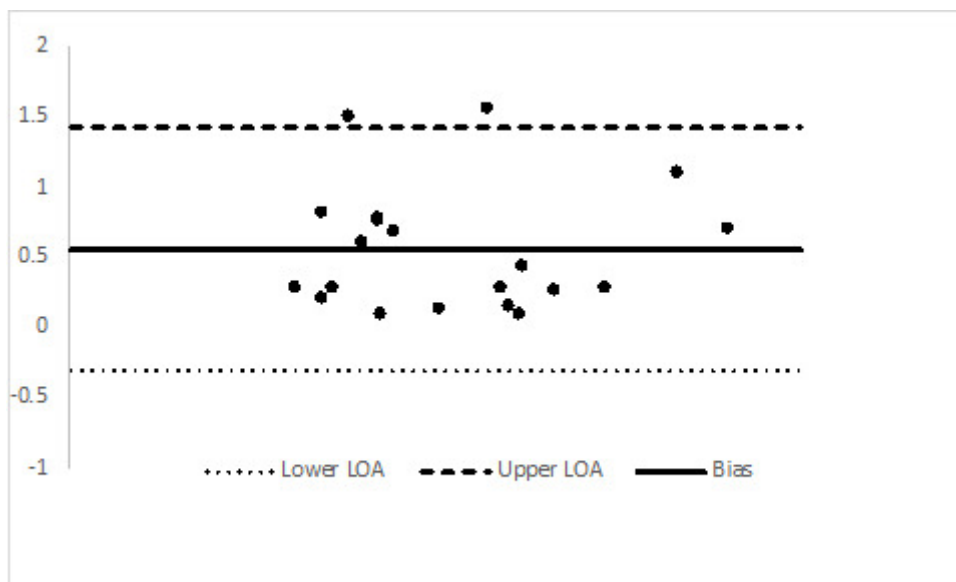


Figure 6. Bland-Altman analysis for inter-rater measures of right knee flexion. Displaying the mean difference between test-retest and 95% confidence limits for the measures.

Despite this study representing reliable results of high absolute agreement, inter-rater and intra-rater reliability, limitations require highlighting. The 90° hip and knee protocol was selected from the variety of standardized protocols available on the KT360 system. Although specific joint angles were chosen in relation to previous research suggesting these testing positions serve to achieve peak torque,^{13,28} some hip extension movement may have occurred during testing due to the nature of the maximal contraction of the hip flexors, which may affect the results found in the study. Attempts were made to mitigate this with verbal cues and familiarization. However, further research using this protocol with an additional fixation around the hips and trunk would be required to discover if

this did influence the data collected in the present study. Furthermore, the sample utilized was a convenience sample of healthy university level athletes between the ages of 19-23. Therefore, data may not be extrapolated to non-sporting or injured populations. Further investigations are required to determine if equivalent findings exist in different age groups or populations.

CONCLUSIONS

Almost perfect inter-and intra-rater reliability was demonstrated when testing isometric knee flexion with the KT360 as well as low SEM, SEM%, and MDC values. This suggests

that the protocol used in the study is worthy of consideration when repeat measurements of isometric knee flexion are required in non-elite sports populations.

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DATA AVAILABILITY

The data used to support the findings of this study are available from the corresponding author upon request.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

FUNDING STATEMENT

This research did not receive any specific funding. However, the research was performed as part of the authors employment and/or academic qualification at Leeds Beckett University.

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REFERENCES

1. Croisier JL, Ganteaume S, Binet J, Genty M, Ferret JM. Strength imbalances and prevention of hamstring injury in professional soccer players: a prospective study. *Am J Sports Med.* 2008;36(8):1469-1475. [doi:10.1177/0363546508316764](https://doi.org/10.1177/0363546508316764)
2. van Dyk N, Witvrouw E, Bahr R. Interseason variability in isokinetic strength and poor correlation with Nordic hamstring eccentric strength in football players. *Scand J Med Sci Sports.* 2018;28(8):1878-1887. [doi:10.1111/sms.13201](https://doi.org/10.1111/sms.13201)
3. Ekstrand J, Waldén M, Häggglund M. Hamstring injuries have increased by 4% annually in men's professional football, since 2001: A 13-year longitudinal analysis of the UEFA Elite Club injury study. *Br J Sports Med.* 2016;50(12):731-737. [doi:10.1136/bjsports-2015-095359](https://doi.org/10.1136/bjsports-2015-095359)
4. Ekstrand J, Krutsch W, Spreco A, et al. Time before return to play for the most common injuries in professional football: a 16-year follow-up of the UEFA Elite Club Injury Study. *Br J Sports Med.* 2020;54(7):421-426. [doi:10.1136/bjsports-2019-100666](https://doi.org/10.1136/bjsports-2019-100666)
5. Nara G, Samukawa M, Oba K, et al. The deficits of isometric knee flexor strength in lengthened hamstring position after hamstring strain injury. *Phys Ther Sport.* 2022;53:91-96. [doi:10.1016/j.ptsp.2021.11.011](https://doi.org/10.1016/j.ptsp.2021.11.011)
6. De Vos RJ, Reurink G, Goudswaard GJ, Moen MH, Weir A, Tol JL. Clinical findings just after return to play predict hamstring re-injury, but baseline MRI findings do not. *Br J Sports Med.* 2014;48(18):1377-1384. [doi:10.1136/bjsports-2014-093737](https://doi.org/10.1136/bjsports-2014-093737)
7. Gonosova Z, Stastny P, Belka J, Bizovska L, Lehnert M. Muscle strength variations of knee joint muscles in elite female handball players after pre-season conditioning. *J Hum Kinet.* 2018;63(1):105-115. [doi:10.2478/hukin-2018-0011](https://doi.org/10.2478/hukin-2018-0011)
8. Katoh M, Hiiragi Y, Uchida M. Validity of isometric muscle strength measurements of the lower limbs using a hand-held dynamometer and belt: a comparison with an isokinetic dynamometer. *J Phys Ther Sci.* 2011;23(4):553-557. [doi:10.1589/jpts.23.553](https://doi.org/10.1589/jpts.23.553)
9. Kambič T, Lainščak M, Hadžić V. Reproducibility of isokinetic knee testing using the novel isokinetic SMM iMoment dynamometer. *PLoS One.* 2020;15(8):e0237842. [doi:10.1371/journal.pone.0237842](https://doi.org/10.1371/journal.pone.0237842)
10. Dunne C, Callaway AJ, Thurston J, Williams JM. Validity, reliability, minimal detectable change, and methodological considerations for HHD and portable fixed frame isometric hip and groin strength testing: A comparison of unilateral and bilateral testing methods. *Phys Ther Sport.* 2022;57:46-52. [doi:10.1016/j.ptsp.2022.07.002](https://doi.org/10.1016/j.ptsp.2022.07.002)
11. Ransom M, Saunders S, Gallo T, et al. Reliability of a portable fixed frame dynamometry system used to test lower limb strength in elite Australian Football League players. *J Sci Med Sport.* 2020;23(9):826-830. [doi:10.1016/j.jsams.2020.03.006](https://doi.org/10.1016/j.jsams.2020.03.006)
12. Eckard TG, Kerr ZY, Padua DA, Djoko A, Dompier TP. Epidemiology of quadriceps strains in National Collegiate Athletic Association athletes, 2009–2010 through 2014–2015. *J Athl Train.* 2017;52(5):474-481. [doi:10.4085/1062-6050-52.2.17](https://doi.org/10.4085/1062-6050-52.2.17)
13. Price OJ, Tsakirides C, Gray M, Stavropoulos-Kalinoglou A. ACSM pre-participation health screening guidelines: a UK university cohort perspective. *Med Sci Sports Exerc.* Published online 2018. [doi:10.1249/MSS.0000000000001868](https://doi.org/10.1249/MSS.0000000000001868)
14. Vogt B, Gosheger G, Wirth T, Horn J, Rödl R. Leg length discrepancy—treatment indications and strategies. *Dtsch Arztebl Int.* 2020;117(24):405. [doi:10.3238/arztebl.2020.0405](https://doi.org/10.3238/arztebl.2020.0405)
15. Ide Y, Matsunaga S, Harris J, Connell DO, Seikaly H, Wolfaardt J. Anatomical examination of the fibula: digital imaging study for osseointegrated implant installation. *J Otolaryngol Head Neck Surg.* 2015;44(1):1. [doi:10.1186/s40463-015-0055-9](https://doi.org/10.1186/s40463-015-0055-9)
16. Barroso R, Silva-Batista C, Tricoli V, Roschel H, Ugrinowitsch C. The effects of different intensities and durations of the general warm-up on leg press 1RM. *J Strength Cond Res.* 2013;27(4):1009-1013. [doi:10.1519/JSC.0b013e3182606cd9](https://doi.org/10.1519/JSC.0b013e3182606cd9)
17. Keerasomboon T, Mineta S, Hirose N. Influence of altered knee angle and muscular contraction type on electromyographic activity of hamstring muscles during 45 hip extension exercise. *J Sports Sci Med.* 2020;19(4):630.
18. Kellis E, Blazevich AJ. Hamstrings force-length relationships and their implications for angle-specific joint torques: a narrative review. *BMC Sports Sci Med Rehabil.* 2022;14(1):166. [doi:10.1186/s13102-022-00555-6](https://doi.org/10.1186/s13102-022-00555-6)

19. Neves PP, Alves AR, Marinho DA, Neiva HP. Warming-Up for Resistance Training and Muscular Performance: A Narrative Review. *Cont Adv Sports Sci*. Published online 2021. [doi:10.5772/intechopen.96075](https://doi.org/10.5772/intechopen.96075)
20. Midgley AW, Marchant DC, Levy AR. A call to action towards an evidence-based approach to using verbal encouragement during maximal exercise testing. *Clin Physiol Funct Imaging*. 2018;38(4):547-553. [doi:10.1111/cpf.12454](https://doi.org/10.1111/cpf.12454)
21. Buczinski S. Reliability Associated with the Measurement of Continuous Variables in Veterinary Medicine: What the Different Possible Indicators Tell, and How to Use and Report Them. *Animals*. 2023;13(17):2793. [doi:10.3390/ani13172793](https://doi.org/10.3390/ani13172793)
22. Ribeiro B, Pereira A, Neves P, Marinho D, Marques M, Neiva HP. The effect of warm-up in resistance training and strength performance: a systematic review. *Motricidade*. 2021;17(1):87-94.
23. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Int J Nurs Stud*. 2010;47(8):931-936. [doi:10.1016/j.ijnurstu.2009.10.001](https://doi.org/10.1016/j.ijnurstu.2009.10.001)
24. Mentiplay BF, Perraton LG, Bower KJ, Adair B, Pua YH, Williams GP, et al. Assessment of lower limb muscle strength and power using hand-held and fixed dynamometry: a reliability and validity study. *PLoS one*. 2015;10(10):e0140822. [doi:10.1371/journal.pone.0140822](https://doi.org/10.1371/journal.pone.0140822)
25. Stark T, Walker B, Phillips JK, Fejer R, Beck R. Hand-held dynamometry correlation with the gold standard isokinetic dynamometry: a systematic review. *PM R*. 2011;3(5):472-479. [doi:10.1016/j.pmrj.2010.10.025](https://doi.org/10.1016/j.pmrj.2010.10.025)
26. Larson D, Lorenz D, Melton B. Can clinician-stabilization with hand-held dynamometry yield a reliable measure of knee flexion torque? *Int J Sports Phys Ther*. 2022;17(6):1095. [doi:10.26603/001c.37907](https://doi.org/10.26603/001c.37907)
27. Toonstra J, Mattacola CG. Test-retest reliability and validity of isometric knee-flexion and-extension measurement using 3 methods of assessing muscle strength. *J Sport Rehabil*. 2013;22(1). [doi:10.1123/jsr.2013.TR7](https://doi.org/10.1123/jsr.2013.TR7)
28. Maloney SJ. The relationship between asymmetry and athletic performance: A critical review. *J Strength Cond Res*. 2019;33(9):2579-2593. [doi:10.1519/JSC.0000000000002608](https://doi.org/10.1519/JSC.0000000000002608)