Validity and reliability of handheld dynamometry to assess isometric hamstrings and quadriceps strength at varying muscle lengths

Abstract

Context: The hamstrings are the most commonly injured muscle in sports and are especially injury prone in lengthened positions. Measuring knee muscle strength in such positions could be relevant to establish injury risk. Handheld dynamometry has been shown to be a valid, reliable and practical tool to measure isometric muscle strength clinically. The aim of this study was to assess the validity and reliability of the assessment of isometric knee muscle strength with a handheld dynamometer at various muscle lengths, by modifying the hip and knee angles during testing.

Design: Concurrent validity and test-retest reliability

Methods: Thirty young healthy participants were recruited. Hamstring and quadriceps isometric strength was measured with a handheld dynamometer (HHD) and with an isokinetic dynamometer, over two testing sessions, in a randomised order. Isometric strength was measured on the right lower limb in six different positions, with the hip at either 0° or 80° of flexion, and the knee at either 30°, 60° or 90° of flexion. Pearson and Spearman correlations were used to assess the validity and intraclass correlation coefficients were calculated to establish the test-retest reliability of the HHD.

Results: Good to excellent reliability and moderate to good validity was found in all the tested muscle length positions, except for the hamstrings in a seated position with the knee extended at 30°.

Conclusions: The use of a HHD is supported in the clinical setting to measure knee muscle strength at varying muscle lengths in healthy adults, but not for the hamstrings in a lengthened position (hip flexed and knee extended). These results will have to be confirmed in sport-specific populations.

Keywords: dynamometer, hamstrings, psychometrics, quadriceps, knee

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Lower limb injuries account for 50-95% of all injuries in sport, depending on the discipline, in women and men [1-3]. The hamstrings are the most frequent injured muscle of the lower limb [4] and tend to occur in sports that involve acceleration, deceleration, change of direction, kicking, sprinting and jumping [5,6]. It is thought that hamstring injuries are sustained either due to an eccentric overload or to overstretching of the muscle as it lengthens [4,6]. However, it has also been proposed that in sprinting, a combination of spring-, brake- and motor-driven functioning occurs across the different muscles forming the hamstrings, owing to their individual architecture and activation patterns [7]. Irrespective of the type of contraction sustained, a recent study on male rugby union professional players has confirmed that one common mechanism of hamstring strain injuries was the lengthened position of the hamstring across the hip and knee joints, or trunk flexion with an associated active knee extension [6].

Measuring muscle strength clinically can help to identify patients at higher risk for injury, or to establish their readiness to return to sport or work after an injury [8]. It may therefore be clinically relevant to assess knee muscle strength at varying muscle lengths, which may be more representative of the muscle elongations sustained during specific sporting or work-related activities. The amount of flexion at the hip and the knee joints is directly related to the elongation sustained by the thigh muscles [9,10]. Modifying hip and knee angles during muscle strength measurement could therefore allow to quantify muscle strength at varying muscle lengths (elongated, neutral and shortened). The gold standard to measure knee muscle strength, isokinetic dynamometry, conventionally assesses the patient in a seated position. Indeed, knee muscle strength is classically tested following standardized protocols, with the patient seated on the dynamometer, with the hip and knee flexed. While some studies have assessed knee muscle strength with a handheld dynamometer (HHD) with the knee at more extended angles [11], most researchers modify angles at a single joint, when it appears that the combination of alterations across several joints can impact isometric knee torque, especially that of the hamstrings, given their largely biarticular anatomy [8].

Moreover, while being the reference standard, the use of isokinetic dynamometers (IKD) is limited, partly owing to their prohibitive cost [11,12]. HHDs represent a cost-effective and portable instrument and have been shown to be valid and reliable to provide a quantified measurement of muscle strength in a clinical setting [13]. They may constitute a more pragmatic means to measure isometric hamstring muscle strength in lengthened positions. While the reliability and validity of isometric muscle strength has been measured at 30° knee flexion with a HHD on professional soccer players [11], to the best of the authors' knowledge, it has not yet been assessed on the general population, and not with both the hip and knee angles being modified.

As increased quadriceps peak torque has been shown to increase the risk for hamstring muscle strain injuries [5], it is also relevant to assess the strength of knee extensors in different muscle lengths, in addition to that of the hamstrings.

The aim of this study was therefore to determine the validity and reliability of a HHD to assess the strength of quadriceps and hamstring muscles at different muscle lengths, by changing hip and knee angles of measurement. Based on previous research, it was hypothesized that at least good reliability and validity of the HHD would be found for the knee flexors and extensors irrespective of muscle length [11,14-16]. It was hypothesized that validity would be lower at muscle lengths that facilitated higher peak torque generation, ie. In hip flexion and knee extension for the hamstrings [8] , and in hip extension and knee flexion for the quadriceps [17], as this places a higher demand in terms of stability and strength on the examiner.

Methods

Young healthy physiotherapy students (18 to 30 years old) which had followed an initiation to strength training were invited to participate in the study. Exclusion criteria included: muscle tightness that prevented adequate positioning during the test, hip, knee or ankle injury in the last three months and pregnancy. Ethics approval was obtained from the local ethics review board (number

XXXXX). All of the participants provided written informed consent and procedures were performed according to the Declaration of Helsinki [18].

Procedure

Peak force was measured isometrically for hamstring and quadriceps muscles of the right lower limb with a HHD (Hoggan MicroFET 2, Hoggan Scientific, Salt Lake City, USA). Peak torque was measured with an IKD (Biodex Medical Systems, Shirlex, New York, USA), with the hip at 0° of flexion (participant supine) and at 80° (participant sitting) and with the knee at either 30, 60 or 90 ° of flexion. Each participant attended two testing sessions (one with the IKD test and one with two HHD tests). The order of testing (device, muscle group and hip/knee angles) was randomised using a randomisation table, in order to minimise learning bias and the effect of fatigue. Each testing session began with a five-minute warm-up on a cycle ergometer at 60rpm and 80W (CycleOps 300 Pro, Saris Cycling Group, WI, USA), as well as a series of five isometric contractions of hamstrings and quadriceps muscles against the resistance of the examiner. Participants were then given standardised verbal cues to complete two three-second maximal isometric contractions (for the twelve measurements), with 10-second breaks between both measures. The best of the two measures was recorded as the peak force/torque and used for analyses. Each testing session was separated by a week, lasted one hour, was scheduled on the same day of the week and at the same time of day, with the same examiner (two male examiners in total). All participants attended a familiarisation session one week prior to testing, allowing them to experience isometric contractions in the various knee and hip positions with both measuring devices.

Isokinetic dynamometry

Knee angles were measured using a handheld goniometer. On the IKD, hip angles were measured with the chair angle and participants were secured on the chair with a belt at the trunk, pelvis and on the right thigh. The IKD arm was attached to the tested leg 5cm above the malleoli. For the supine position, a pillow was placed under the participants' lower back to stabilise their pelvic position. Participants were asked to hold themselves on their forearms (Figure 1). Lower limb weight was calculated and accounted for directly by the IKD and automatic gravity correction was carried out by the Biodex system.

Handheld dynamometry

For the seated position, the participant was seated on a plinth and was asked to sit upright and to hold onto the plinth (Figure 2). The lying position was the same as that described for the IKD, with the participant supine on the plinth. The HHD was placed perpendicularly on the anterior (for the quadriceps) or posterior (for the hamstrings) surface of the shank, 5 cm above the malleoli. The examiner used a belt to stabilise the HHD during measures as shown on Figure 2 [19]. To apply gravity correction according to the various testing positions, the cosine of the knee angle was multiplied by the weight of the lower leg and this value was subtracted from the force value obtained during the test. To measure the weight (in N) of the lower leg, the HDD was applied on the posterior surface of the shank, 5 cm above the malleoli with the hip and knee flexed at 0°. Participants were supine with the shank hanging over the edge of the plinth and were asked to remain completely relaxed during the reading.

Statistical analysis

Gravity corrected values of the IKD and HHD were used for analyses. For the validity analysis, a power calculation revealed that to obtain a minimally acceptable correlation coefficient of 0.50 with a power of 0.80 and an $\alpha = 0.05$, 7 participants were necessary. Pearson and Spearman correlation coefficients were used to assess the correlation of the second session HHD peak force with that of the IKD of the hamstrings and quadriceps in the six positions.

Correlation coefficients were interpreted as follows: > 0.90: very high, 0.70 to 0.89: high and 0.50 to 0.69: moderate. [20]

The test-retest relative reliability of the HHD in various lengths was measured using the intra-class correlation coefficient using a single rater, 2-way mixed methods, absolute agreement[21]. ICC values were interpreted as follows: ICC ≥ 0.90: excellent, 0.75 ≤ ICC < 0.90: good, 0.50 ≤ ICC <0.75: moderate and ICC < 0.50: poor [22]. The power analysis for the reliability analysis revealed that considering a minimum acceptable ICC value of 0.75, a power of 0.80 and an α= 0.05, 10 participants were necessary.

The test-retest absolute reliability of the HHD was measured using the standard error of measurement (SEm), minimal detectable change (MDC) and coefficient of variation (CV). A CV value of <10% was considered as acceptable[23]. Bland-Altman plots with their corresponding limits of agreement (LOA) were used to assess systematic biases in the various hip and knee positions[24]. All statistical analyses were carried out with SPSS (Statistical package version 27, SPSS Inc, USA).

Results

Thirty participants (50% female, 24.7 ± 2.3 years old, 171.6 ± 9.0 cm, 69.1 ± 10.8 kg) took part in the study. Validity results are presented in Table 1. Validity of the HHD was globally better for the quadriceps compared to the hamstring muscles (average correlation coefficient of 0.77 and 0.59, respectively), irrespective of muscle length. Both muscle groups, in all positions, had at least moderate validity (>0.50) except for the hamstrings in a seated position and with the knee flexed at 30° (r=0.35, p=0.061). When considering both muscle groups, validity is higher the more flexed the knee is (average correlation coefficient of 0.76, 0.67 and 0.61 for a knee flexion angle of 90°, 60° and 30° respectively) in both seated and supine positions. For the hamstring muscles, validity of the HHD was highest with the hip at 0° flexion and the knee at 90° flexion (ρ=0.74, p<0.001). For the quadriceps muscles, validity was highest with the hip at 80° flexion and the knee at 90° flexion ($\rho=0.83$, $p<0.001$).

Reliability results are presented in Table 2. Relative reliability was good to excellent for all measures of isometric strength, and moderate for the hamstrings in a seated position at 30° knee flexion (ICC=0.72, $p<0.001$). Absolute reliability was mostly acceptable, except for the hamstrings in a seated position at 30° and 60° knee flexion (CV = 18.29 and 12.91, respectively). Bland Altman plots (Figure 3) do not show any systematic bias in the HHD measurement at different lengths of the hamstrings and quadriceps muscles.

Discussion

The aim of this study was to determine the validity and reliability of a HHD to assess the strength of quadriceps and hamstring muscles at different muscle lengths.

It was hypothesized that at least good validity of the HHD would be found for the knee flexors and extensors irrespective of muscle length. This hypothesis was partly verified. Validity of the HHD was moderate to high in all positions for both muscle groups, but not for the hamstrings in a seated position with the knee flexed at 30°. It was also hypothesized that validity would be lower in positions that facilitated higher peak torque generation: this was confirmed for the hamstring muscles, but not for the quadriceps muscles.

Other studies looking at the validity of the HHD in the standardized seated and flexed knee (90°) position found correlation coefficients ranging from 0.74 to 0.90 for hamstrings and quadriceps [14,19,25-27], generally with higher correlation for the quadriceps. Our results are in line with previous studies, however validity for the hamstrings was lower. One study by Whiteley et al. assessed the validity of a HHD in a seated position with the knee flexed at 30° and found a correlation coefficient of 0.55 and 0.62 for the hamstrings and quadriceps, respectively [11]. Our results are similar to those of Whiteley and colleagues, however the lower validity found in our study could be due to a difference in technique when assessing hamstring strength (belt vs handles). Using a dynamometer with attached handles potentially provides more stability for the tester, leading to higher peak force values generated by the participant. Ogborn et al. [8] assessed the validity of a externally fixated HHD to measure hamstrings isometric strength in healthy adults, in both seated and supine positions with the knee flexed at 90°. In line with our findings, they found moderate to high correlations with the IKD, with no substantial differences between the two positions.

Overall, our results show that validity of the HHD was higher for the quadriceps muscles than the hamstring muscles. In our protocol, stabilization of the participant for testing of the hamstrings was done with a belt worn around the waist of the examiner. In comparison, for the quadriceps muscle, the belt was secured around the plinth, which potentially offered more stability. The examiner may have been at a mechanical disadvantage whilst testing the hamstrings, especially in lower knee flexion angles, where it is more difficult to apply a perpendicular force to counter the participant's movement. It is known that the examiner's strength can affect muscle testing, especially when testing stronger muscle groups [16], and that testing hamstring strength with a HHD does require approximately 20 examinations of practice to be skilled [11]. In our study, an underestimation of hamstrings isometric strength may have occurred [15], hence leading to reduced validity for that muscle group.

It was hypothesized that at least good reliability of the HHD would be found for the knee flexors and extensors irrespective of muscle length. This was confirmed as reliability of the HHD was good to excellent in all positions for both muscle groups, except for the hamstrings in in a seated position with the knee flexed at 30° (ICC = 0.72, 95% CI 0.42-0.87, p<0.001). These results are particularly encouraging, especially as one week separated both testing sessions.

Reliability of the HHD in this study in the standardized seated position was excellent, as shown in previous research on healthy adults [28,29]. Sung et al. [15] assessed the reliability of the measurement of quadriceps isometric strength in healthy adults with a portable HHD anchoring system in a supine position on a hospital bed, with the knee flexed at 35°. In line with our results, they found excellent reliability (ICC = 0.98, MDC = 60.39).

The practicality and cost of a HHD makes it a very attractive tool to measure strength on the field. This study has shown that clinicians can reliably use the HHD to assess isometric hamstrings and quadriceps strength in various combinations of hip and knee positions, resulting in varying muscle lengths. Overall, the values obtained with the HHD reflect the participant's peak isometric strength. However, this is not confirmed for the hamstrings in the seated position with the knee extended. It is recommended that clinicians interpret the HHD results within the context of their practice, and evaluate whether the correlations presented in this paper sufficiently give them information regarding a patient's strength without having to undergo IKD testing [11]. As has been recommended by other researchers, values obtained with the HHD should not be substituted with those of the IKD [8]. Hamstring muscle weakness has inconsistently been reported as a risk factor for hamstring injury [5,30]. The novel method of assessing muscle strength presented in this study could have represented a more clinically relevant way to identify muscle weakness. Unfortunately, the measurement of hamstring strength with a HHD in the flexed hip and extended knee position, which is associated with hamstring injuries [6], demonstrated poor validity and moderate reliability. We therefore recommend that clinicians use an IKD to establish hamstring strength of athletes who have sustained an acute hamstring injury, for this specific hip and knee position.

This study has some limitations. The population studied was young and healthy; whether the findings apply to older, sport-specific, or disease-specific populations has yet to be determined. The HHD tested for isometric strength, and it must be noted that sports injuries, especially related to sprinting, involve mechanical loads of the hamstrings which may be beyond isometric capacity [7]. From a methodological point of view, when using the HHD, the tested limb was not secured with a belt. In addition to factors mentioned earlier regarding the difficulty in testing hamstring strength, it is also possible that the participant's strength was underestimated as the limb was not secured on the plinth as it was during IKD testing. It could have been of interest to measure the inter-rater reliability of measurements with the HHD; however, this was not within the scope of this paper, and will have to be explored in future studies. Finally, one of the limitations of the correlation analyses is that a strong linear relationship is not synonymous with a strong agreement between two variables [31], which is reflected in the Bland-Altman plots and their relatively wide LOA, potentially due to the difference in measurement unit. As correlation does not imply causation, it is vital that clinicians are conscious of the error associated with correlation measures when using a HHD rather than isokinetic dynamometry with patients [11]. Nonetheless, we propose that the HHD is a suitable cost- and time-effective substitute to the IKD in the clinical setting.

Conclusions

This study suggests that the HHD is a valid and reliable alternative to the IKD to measure knee muscle isometric strength at varying lengths, however its use in a seated position with the knee extended has not been validated for the hamstrings. Clinicians can reliably use the HHD to assess isometric hamstrings and quadriceps strength at varying muscle lengths on the field in healthy adults, and these results will have to be confirmed in sport-specific populations.

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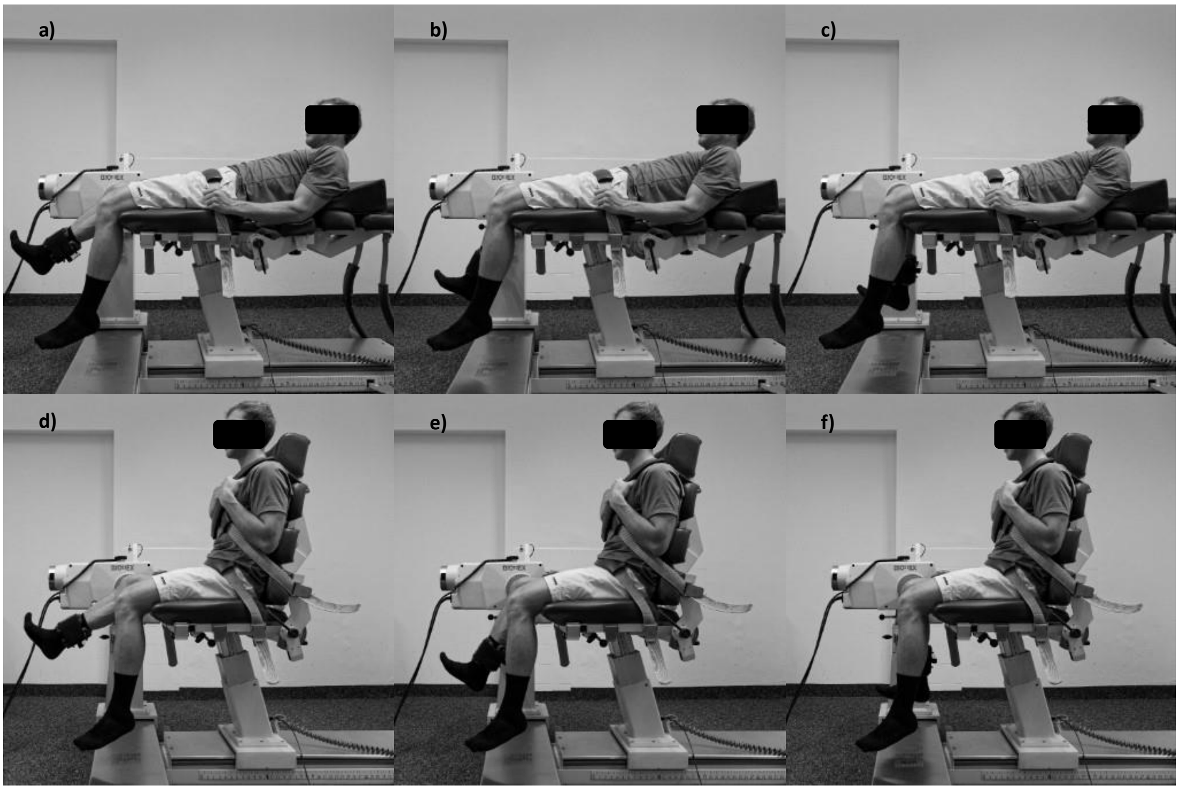


Figure 1. Participant setup for isokinetic dynamometry with: a) 0° hip flexion and 30° knee flexion, b) 0° hip flexion and 60° knee flexion, c) 0° hip flexion and 90° knee flexion, d) 80° hip flexion and 30° knee flexion, e) 80° hip flexion and 60° knee flexion, f) 80° hip flexion and 90° knee flexion.

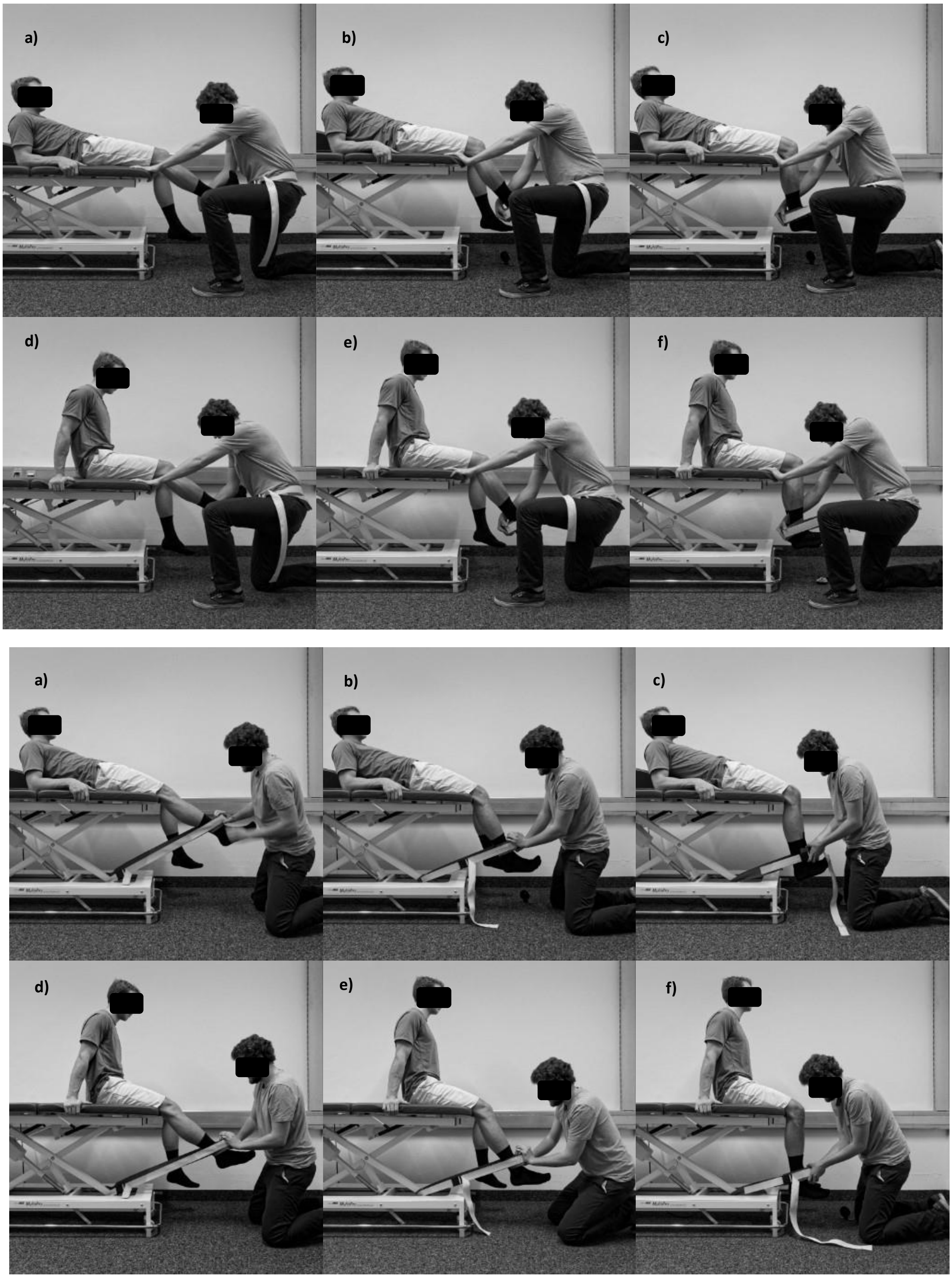
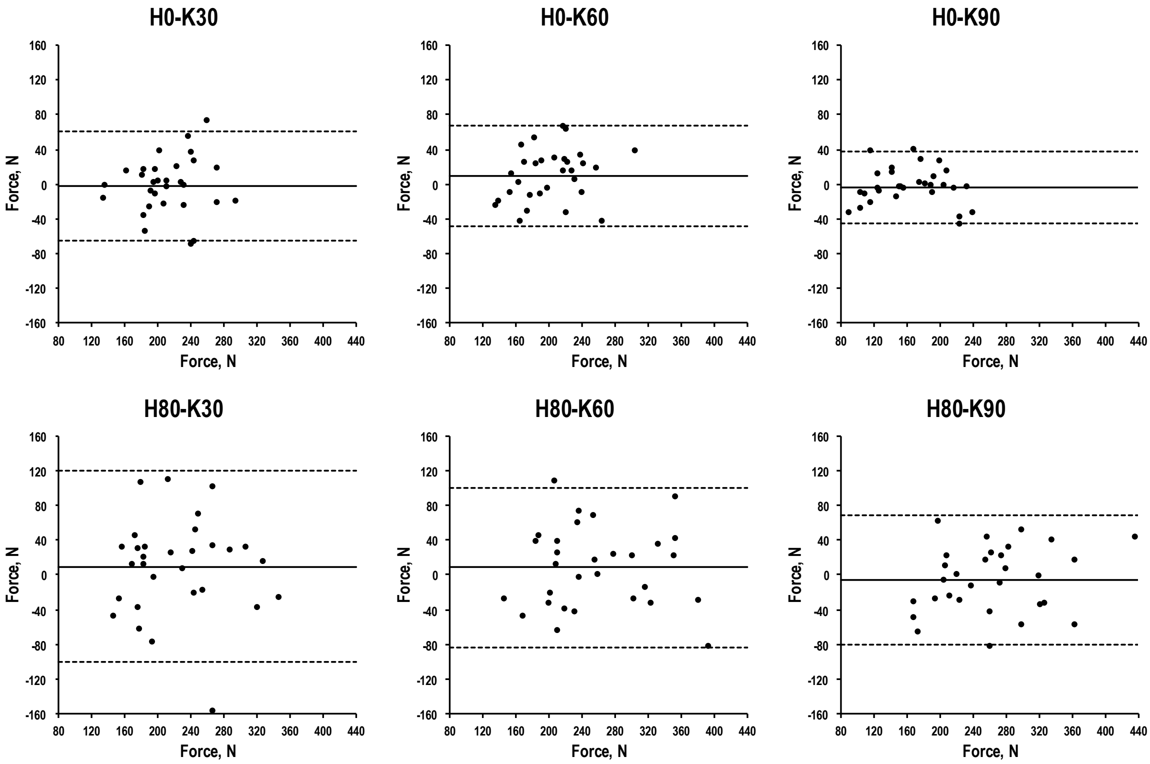
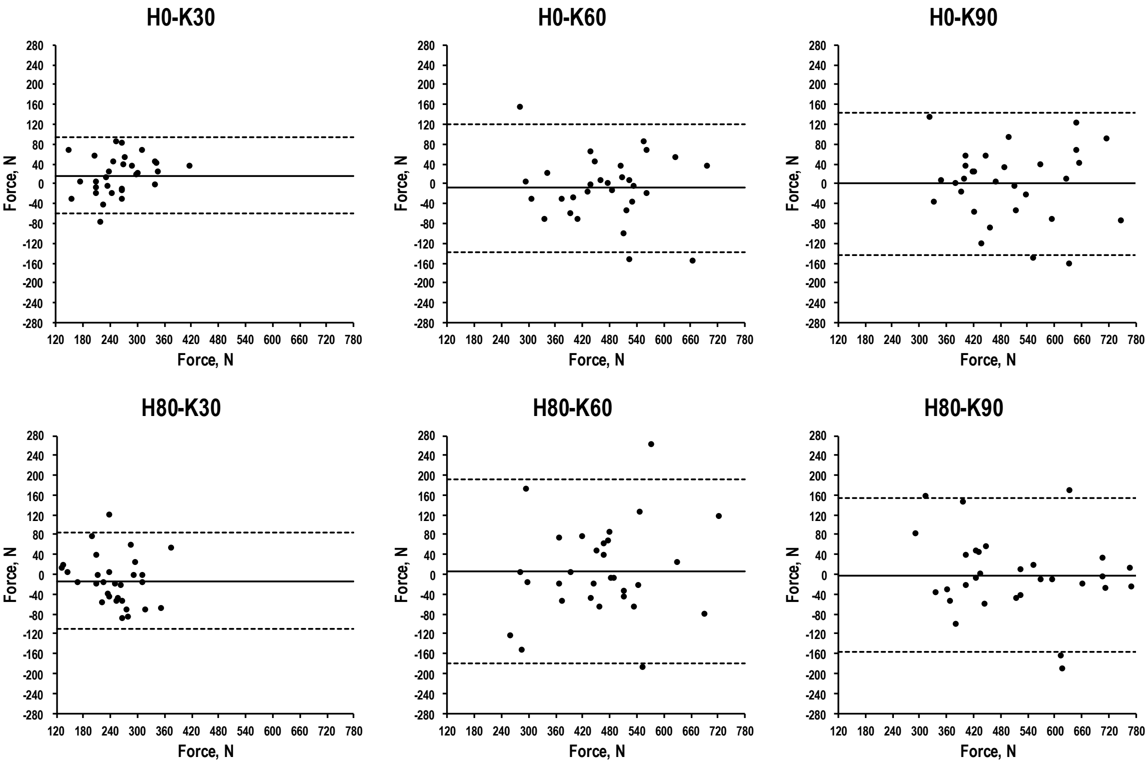


Figure 2. Participant setup for HHD of the hamstring muscles (top) and of the quadriceps muscles (bottom) in a) 0° hip flexion and 30° knee flexion, b) 0° hip flexion and 60° knee flexion, c) 0° hip flexion and 90° knee flexion, d) 80° hip flexion and 30° knee flexion, e) 80° hip flexion and 60° knee flexion, f) 80° hip flexion and 90° knee flexion.



(a)



(b)

Figure 3. Bland-Altman plots with limits of agreement for the peak torque measurement of hamstrings (a) and quadriceps (b) with the HHD. H = hip joint angle; K = knee joint angle

Muscles	Joint position: Hip	Joint position: Knee	PF HHD (N)	Normalised PF HHD (N/kg)	PT IKD (Nm)	Normalised PT IKD (Nm/kg)	Correlation coefficient	Lower 95CI	Upper 95CI	p
Hamstrings	0°	30°	169.85 (36.88)	2.47 (0.48)	65.12 (22.33)	0.93 (0.25)	0.60[a]	0.29	0.79	<0.001
	0°	60°	171.75 (37.47)	2.50 (0.49)	51.98 (20.99)	0.74 (0.24)	0.67[a]	0.39	0.83	<0.001
	0°	90°	166.96 (45.25)	2.41 (0.51)	40.98 (15.24)	0.58 (0.17)	0.74[a]	0.50	0.87	<0.001
	80°	30°	175.43 (60.63)	2.55 (0.82)	95.51 (28.36)	1.37 (0.31)	0.35[b]	-0.02	0.63	0.061
	80°	60°	228.07 (69.83)	3.31 (0.94)	89.55 (26.82)	1.29 (0.31)	0.53[b]	0.20	0.75	0.003
	80°	90°	169.85 (36.88)	3.87 (0.80)	77.20 (26.05)	1.10 (0.29)	0.64[b]	0.37	0.81	<0.001
Quadriceps	0°	30°	297.93 (60.79)	4.33 (0.70)	84.40 (21.31)	1.21 (0.20)	0.79[b]	0.60	0.90	<0.001
	0°	60°	501.96 (114.92)	7.26 (1.22)	170.06 (52.38)	2.44 (0.54)	0.73[a]	0.49	0.86	<0.001
	0°	90°	501.90 (124.27)	7.22 (1.13)	214.36 (76.71)	3.07 (0.82)	0.82[a]	0.65	0.91	<0.001
	80°	30°	301.37 (71.39)	4.37 (0.90)	72.96 (19.81)	1.05 (0.21)	0.69[b]	0.44	0.84	<0.001
	80°	60°	483.29 (118.85)	7.00 (1.35)	157.78 (43.14)	2.27 (0.41)	0.75[b]	0.53	0.87	<0.001
	80°	90°	513.29 (153.32)	7.39 (1.71)	214.56 (77.53)	3.07 (0.83)	0.83[a]	0.66	0.92	<0.001

Table 1. Validity of HHD for hamstring and quadriceps muscles at various lengths.

Peak force (PF) and peak torque (PT) values are presented as mean (SD); HHD: handheld dynamometer second trial; IKD: isokinetic dynamometer; [a] Spearman ρ, [b] Pearson r; lower 95CI: lower 95% confidence interval of the correlation coefficient; upper 95CI: upper 95% confidence interval of the correlation coefficient.

Muscles	Joint position		HHD1 (N)	HHD2 (N)	ICC	p	SEm (N)	MDC (N)	CV (%)
	Hip	Knee							
Hamstrings	0°	30°	167.88 (40.87)	169.85 (36.88)	0.80 (0.57-0.90)	<0.001	17.54	48.61	9.97
	0°	60°	181.27 (43.38)	171.75 (37.47)	0.83 (0.65-0.92)	<0.001	16.51	45.78	10.77
	0°	90°	163.88 (44.07)	166.96 (45.25)	0.94 (0.88-0.97)	<0.001	10.85	30.07	7.64
	80°	30°	184.96 (59.30)	175.43 (60.63)	0.72 (0.42-0.87)	<0.001	31.62	87.64	18.29
	80°	60°	236.79 (68.61)	228.07 (69.83)	0.87 (0.73-0.94)	<0.001	24.96	69.18	12.91
	80°	90°	260.91 (71.23)	266.51 (63.36)	0.91 (0.82-0.96)	<0.001	19.77	54.79	9.08
Quadriceps	0°	30°	314.99 (71.22)	297.93 (60.79)	0.89 (0.76-0.95)	<0.001	21.66	60.03	8.21
	0°	60°	493.90 (107.79)	501.96 (114.92)	0.91 (0.80-0.96)	<0.001	34.16	94.68	7.12
	0°	90°	501.81 (119.52)	501.90 (124.27)	0.90 (0.79-0.95)	<0.001	38.17	105.79	8.07
	80°	30°	287.63 (62.30)	301.37 (71.39)	0.84 (0.66-0.92)	<0.001	27.22	75.44	9.64
	80°	60°	489.26 (134.01)	483.29 (118.85)	0.84 (0.67-0.93)	<0.001	50.02	138.66	10.84
	80°	90°	511.06 (137.45)	513.29 (153.32)	0.92 (0.84-0.96)	<0.001	40.40	111.99	8.65

Table 2. Reliability of hamstrings and quadriceps peak force measurement with HHD at various lengths. Peak force values are presented as mean (standard deviation).

HHD1: Handheld dynamometer peak torque first trial; HHD2: Handheld dynamometer peak torque second trial; ICC: intra-class correlation coefficient, presented as ICC value (lower 95% confidence interval - upper 95% confidence interval); SEm: standard error of measurement; MDC: minimum detectable change; CV: coefficient of variation.