
Quadriceps and Hamstrings Strength in Athletes

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Nienke W. Willigenburg, Michael P. McNally,
and Timothy E. Hewett

Introduction

Adequate quadriceps and hamstrings strength are essential for athletic performance. These two muscles are functional antagonists; contraction of the quadriceps results in knee extension, while contraction of the hamstrings results in flexion of the knee joint. Together these muscle groups control accelerations and decelerations of the shank with respect to the thigh, and sufficient strength in both muscle groups is required for running, jumping, landing, and other athletic activities. But how do we measure strength? How much strength is required? And what happens when strength deficiencies are present? In this chapter, we will first discuss a commonly used method to assess quadriceps and hamstrings strength, as well as some fre-

quently reported outcome measures. Then we will present a set of normative data for a variety of subject populations that we tested in our Biodynamics Laboratory of the Sports Health and Performance Institute at The Ohio State University (OSU). We will zoom in on a population of OSU football players to show how quadriceps and hamstrings strength relate to other functional and clinical tests. Finally, we will discuss how quadriceps and hamstrings strength may be associated with increased risk of lower extremity injury in athletes.

Assessment of Quadriceps and Hamstrings Strength in Athletes

Quadriceps and hamstrings strength in athletes can be reliably assessed using isokinetic dynamometry [1]. Isokinetic strength testing can be performed to test concentric or eccentric muscle strength at fixed angular velocities. Isometric muscle strength can be assessed at zero angular velocity with the upper and lower leg fixed in a static angle. The recorded strength is a measure of the net effect of the force developed by the quadriceps and hamstrings muscles to move the lower leg into extension and flexion. The net effect of these forces exerted around the knee joint can be recorded over a substantial range of motion (often 90°) at fixed speeds (often 60°/s and/or 300°/s). At low speeds (i.e., 0–180°/s), peak force reflects pure muscle strength, while neuromuscular control comes into play at higher speeds (>180°/s).

N.W. Willigenburg, PhD
OSU Sports Health and Performance Institute,
The Ohio State University Wexner Medical Center,
2050 Kenny Road, Suite 3100, Columbus,
OH 43221, USA
e-mail: Nienke.Willigenburg@osumc.edu

M.P. McNally, MS
Department of Orthopaedics, Ohio State University
Wexner Medical Center, 2050 Kenny Road,
Suite 3100, Columbus, OH 43220, USA
e-mail: Michael.McNally@osumc.edu

T.E. Hewett, PhD (✉)
Department of Sports Medicine,
The Ohio State University Wexner Medical Center,
2050 Kenny Road, Suite 3100, Columbus,
OH 43221, USA
e-mail: Timothy.hewett@osumc.edu

Fig. 2.1 Setup for isokinetic testing of quadriceps and hamstrings strength



Testing at higher speeds better reflects muscle function during athletic activities than testing at lower speeds [2]. Concentric exertions are often preferred over eccentric exertions for feasibility and safety reasons. However, maximal eccentric exertions may provide important additional insight in muscle function, for instance as eccentric contraction occurs in the quadriceps during landing.

The set-up of isokinetic strength testing is important for optimal, reproducible results. When testing knee strength, the knee joint is aligned with the axis of the rotating arm and the pad for the rotating arm is secured just above the malleolus of the ankle joint. Straps around the chest, waist, and thigh are tightened to limit bodily motion other than knee flexion and extension (Fig. 2.1). During the test, the subject is instructed to kick out and pull back, as hard and as fast as possible, against the resistance of the machine, which moves at the predefined speed. It is recommended to record multiple repetitions within each test, as well as multiple trials with sufficient rest in between to improve data quality. Verbal encouragement is also recommended, as it enhances performance on maximal strength tests. Given the direction of gravity, the weight of the lower limb will “assist” the hamstrings and

“counteract” the quadriceps muscles during upright seated isokinetic strength testing. Therefore, quadriceps and hamstrings peak torque should be corrected for the weight of the tested limb [3].

When assessing quadriceps and hamstrings strength in athletes, several outcome measures may be of interest. The most common measure of strength garnered from an isokinetic dynamometer is peak torque, a measure of the peak muscle force exerted during the test. Given the significant correlation between body weight and muscle strength [4–6], peak torque is often normalized to body weight. However, this normalization has been argued to overcorrect the effect of mass [6], and alternative normalization methods have been suggested [7]. Using non-normalized data can result in a high variability when comparing subjects with a wide range of body sizes, but should be appropriate for within-subjects comparisons, for instance to track an individual’s knee strength over time.

In addition to peak torque values, ratios of peak torque are often calculated. These ratios provide important information about the relative strength of different muscle groups, or muscle imbalances, and thereby facilitate comparisons between subjects without the need for normalization. One such

measure is the hamstrings-to-quadriceps ratio (H/Q ratio), calculated as the peak torque of the hamstrings divided by the peak torque of the quadriceps within the same limb (Eq. (3.1)):

$$H/Q \text{ ratio} = \frac{\text{Hamstrings peak torque}}{\text{Quadriceps peak torque}} \quad (2.1)$$

As stated before, isokinetic peak torque is often assessed using concentric contractions. As hamstrings and quadriceps muscles are antagonists to one another, simultaneous concentric contraction of both these muscles does not occur. Therefore, it may be preferred to examine eccentric hamstrings peak torque with respect to the concentric quadriceps peak torque, when assessing functional strength. This combination of

eccentric hamstrings and concentric quadriceps strength is representative for the take-off phase of a jump: the quadriceps muscles contract and the shortening muscle fibers extend the knee, while a simultaneous eccentric (lengthening) contraction of the hamstrings is required to decelerate the explosive knee extension, in order to prevent hyperextension and resulting damage to the knee joint. A reduced H/Q ratio, which may be indicative of “quadriceps dominance,” may put athletes at a higher risk for lower extremity injury [8].

Another ratio is calculated to compare peak torque between limbs and is referred to as the limb symmetry index (LSI). LSI is used to assess peak torque in the non-dominant relative to the dominant limb (Eq. (3.2)):

$$LSI = \frac{\text{Peak torque in non-dominant limb}}{\text{Peak torque in dominant limb}} \times 100 \% \quad (2.2)$$

Greater than 15 % difference between limbs is often considered a substantial asymmetry in healthy athletes and may put them at increased risk of injury [8]. Interestingly, such asymmetries are not uncommon in first-year professional American football players [6]. In injured subjects, LSI of the injured versus the unaffected limb can help to guide rehabilitation programs aimed at restoring symmetry between involved and uninvolved sides. LSIs of an injured population also provides further information when deciding whether athletes are ready to return to sport after recovering from an injury. An LSI of >90 % in injured athletes is typically recommended as a cutoff point when making return to sport decisions [9, 10]. Patients with this level of symmetry after rehabilitation following surgical reconstruction of their anterior cruciate ligament (ACL) demonstrated similar functional performance as healthy control subjects, while larger asymmetries were associated with reduced functional outcomes [11].

In addition to peak torque values and ratios of peak torque between muscle groups and limbs, several other outcome measures can provide

further insight into muscle function. Table 2.1 provides an overview of some commonly used variables [12]. Additional electrical stimulation of the muscles or nerves during maximal voluntary contractions can reveal the discrepancy between voluntary and “true” maximal muscle strength.

Normative Data

When evaluating strength, normative values provide a range of normal strength values for a population that can be used to compare collected data. Tables 2.2, 2.3, 2.4, and 2.5 provide means and standard deviations of quadriceps and hamstrings strength measures for active individuals with and without ACL injuries, athletes who return to sport following surgical ACL reconstruction, and NCAA Division I football athletes. Reported normative values are peak torque and H/Q ratios at 60°/s and 300°/s.

As can be appreciated in these tables, peak torque for both quadriceps and hamstrings was lower when tested at a higher speed, while H/Q ratios tended to be higher when tested at a higher

Table 2.1 Relevant outcome measures based on isokinetic strength testing [12]

Outcome measure	Interpretation
Time to peak torque	Time from the start of a muscular contraction to the moment of peak torque development; indicative of the ability to produce force quickly
Angle of peak torque	The point in the range of motion where peak torque is produced; typically in the midrange, where the length–tension relationship of the muscle is optimal
Total work	Muscular force output over the entire test. This may be a better indicator of muscle function, as torque must be maintained over the range of motion
Work fatigue	Difference between the first 1/3 and the last 1/3 of work in a test bout; indicative of fatigue development throughout the test
Average power	Total work divided by time; represents how quickly a muscle can generate force
Coefficient of variance	Reproducibility of the test based on the amount of variation between repetitions. Acceptance levels are typically $\leq 15\%$ for larger muscle groups and $\leq 20\%$ for smaller muscle groups

Table 2.2 Isokinetic quadriceps and hamstrings strength measures at 60°/s for healthy subjects

		Healthy active females ($n=8$)	Healthy active males ($n=6$)	Freshmen varsity football ($n=22$)
Age		18.4±4.6	23.7±11.2	18.0±0.7
HQ-ratio	Dominant	0.50±0.05	0.55±0.07	0.55±0.07
	Non-dominant	0.49±0.04	0.48±0.08	0.52±0.11
<i>Peak torque (Nm)</i>				
Quadriceps	Dominant	155.1±19.7	233.2±54.6	280.2±54.8
	Non-dominant	153.6±25.8	244.6±50.2	277.0±45.5
Hamstrings	Dominant	76.9±8.9	127.8±30.0	151.5±28.6
	Non-dominant	74.7±9.7	118.3±38.9	142.7±28.8
<i>Peak torque normalized to body mass (Nm/kg)</i>				
Quadriceps	Dominant	2.38±0.17	2.47±0.45	2.77±0.46
	Non-dominant	2.37±0.43	2.61±0.56	2.75±0.43
Hamstrings	Dominant	1.19±0.15	1.36±0.31	1.49±0.23
	Non-dominant	1.15±0.14	1.24±0.27	1.41±0.26

Table 2.3 Isokinetic quadriceps and hamstrings strength measures at 300°/s for healthy subjects

		Healthy active females ($n=8$)	Healthy active males ($n=6$)	Freshmen varsity football ($n=38$)
Age		18.4±4.6	23.7±11.2	18.0±0.6
HQ-ratio	Dominant	0.67±0.05	0.63±0.07	0.67±0.10
	Non-dominant	0.65±0.08	0.68±0.08	0.67±0.11
<i>Peak torque (Nm)</i>				
Quadriceps	Dominant	81.6±8.2	146.7±27.8	178.9±30.9
	Non-dominant	83.6±7.5	137.9±34.3	178.7±37.7
Hamstrings	Dominant	54.0±3.2	92.2±20.2	118.0±22.1
	Non-dominant	54.3±7.9	92.9±20.2	117.6±21.6
<i>Peak torque normalized to body mass (Nm/kg)</i>				
Quadriceps	Dominant	1.25±0.09	1.57±0.34	1.76±0.34
	Non-dominant	1.29±0.18	1.49±0.49	1.75±0.37
Hamstrings	Dominant	0.83±0.08	0.98±0.22	1.17±0.30
	Non-dominant	0.83±0.09	1.00±0.25	1.16±0.28

Table 2.4 Isokinetic quadriceps and hamstrings strength measures at 60°/s for subjects who suffered an ACL injury

		Before surgical reconstruction		Cleared to return to sport after surgical reconstruction	
		Females (<i>n</i> =10)	Males (<i>n</i> =20)	Females (<i>n</i> =13)	Males (<i>n</i> =22)
Age		21.6±10.0	22.7±8.9	17.7±5.5	21.8±7.4
HQ-ratio	Uninvolved	0.55±0.12	0.49±0.07	0.48±0.07	0.51±0.07
	Involved	0.56±0.10	0.49±0.13	0.50±0.08	0.48±0.10
<i>Peak torque (Nm)</i>					
Quadriceps	Uninvolved	140.8±42.5	214.0±31.8	153.5±27.1	233.7±50.1
	Involved	94.1±43.0	159.0±39.8	127.8±18.9	213.7±48.6
Hamstrings	Uninvolved	76.0±24.8	105.3±20.7	73.9±13.7	117.6±26.1
	Involved	51.0±21.0	75.9±23.0	63.3±14.1	100.0±22.8
<i>Peak torque normalized to body mass (Nm/kg)</i>					
Quadriceps	Uninvolved	2.13±0.68	2.63±0.57	2.40±0.41	2.77±0.47
	Involved	1.49±0.83	1.95±0.57	2.02±0.38	2.53±0.50
Hamstrings	Uninvolved	1.16±0.45	1.30±0.32	1.15±0.16	1.40±0.30
	Involved	0.80±0.41	0.92±0.29	1.00±0.24	1.19±0.24

It is important to note that the populations of subjects before and after surgical reconstruction only partly overlap (female: *n*=4, male: *n*=10)

Table 2.5 Isokinetic quadriceps and hamstrings strength measures at 300°/s for subjects who suffered an ACL injury

		Before surgical reconstruction		Cleared to return to sport after surgical reconstruction	
		Females (<i>n</i> =10)	Males (<i>n</i> =20)	Females (<i>n</i> =13)	Males (<i>n</i> =22)
Age		21.6±10.0	22.7±8.9	17.7±5.5	21.8±7.4
HQ-ratio	Uninvolved	0.70±0.12	0.67±0.10	0.65±0.08	0.65±0.10
	Involved	0.76±0.06	0.69±0.13	0.67±0.09	0.68±0.17
<i>Peak torque (Nm)</i>					
Quadriceps	Uninvolved	81.6±21.3	122.2±20.9	84.5±13.4	139.6±24.2
	Involved	62.6±24.9	100.6±21.1	77.7±9.3	131.3±25.8
Hamstrings	Uninvolved	56.4±17.0	80.7±13.5	56.4±7.9	90.3±19.4
	Involved	48.2±18.6	68.1±12.9	53.7±8.0	87.5±21.7
<i>Peak torque normalized to body mass (Nm/kg)</i>					
Quadriceps	Uninvolved	1.24±0.39	1.50±0.33	1.32±0.15	1.66±0.27
	Involved	0.97±0.47	1.23±0.31	1.22±0.18	1.57±0.34
Hamstrings	Uninvolved	0.87±0.34	0.99±0.23	0.87±0.07	1.07±0.17
	Involved	0.73±0.36	0.84±0.18	0.83±0.09	1.05±0.29

It is important to note that the populations of subjects before and after surgical reconstruction only partly overlap (female: *n*=4, male: *n*=10)

speed. This supports previous findings in an extensive review [13], and may be explained by the increased forward momentum of the tibia at higher angular velocities, which requires increased co-activation of the hamstrings muscles to prevent anterior translation of the tibia and hyperextension of the knee joint [14]. While some subjects showed substantial side-to-side asymmetries, the LSI is small when averaged

over a group of healthy athletes. As LSIs higher or lower than 100 % are both commonly observed, a group average tends to mask the range of individual asymmetries.

Before surgical reconstruction, ACL-injured subjects show substantially reduced quadriceps and hamstrings peak torques in their involved leg, while H/Q ratios are similar between legs (see Tables 2.4 and 2.5). Rehabilitation after ACL

reconstruction is aimed at resolution of side-to-side asymmetries, and indeed the strength deficiencies in the involved limb are reduced in subjects who are cleared to return to sports.

Isokinetic Strength and Function in NCAA Division I Football Athletes

At The Ohio State University, all incoming freshmen of the college football team participate in an extensive preseason athletic screening. Isokinetic knee strength is just one of the multiple clinical, biomechanical, and functional testing stations in this athletic screening. In addition, all subjects complete an injury history questionnaire and detailed injury reports are collected over the course of the football season. This extensive database is growing each year and is used to evaluate differences between position groups, between performances on different clinical and functional tests and, eventually, for prospective analyses to identify risk factors for injury.

The following paragraphs discuss the relationships between isokinetic knee strength and three different functional screening tests, all measured in the dominant limb. First, we will describe how knee strength relates to performance on the Functional Movement Screen™ FMS™ which will emphasize the effect of normalizing strength data to body mass. Then we discuss knee strength in relation to a set of clinical hop tests, and in relation to isometric hip strength. The last portion of this section will describe the association between measures of limb asymmetry based on knee strength, hop tests, and hip strength.

Quadriceps and Hamstrings Strength vs. Functional Movement Screen™

The FMS™ was introduced as an approach to predict athletic performance [15]. The FMS™ consists of seven fundamental movement tasks, scored on a scale from 0 to 3 based on task execution (i.e., mobility, stability, and compensatory movements), with the aim to pinpoint deficient areas of mobility and stability that may be over-

looked in an asymptomatic active population [16]. While performance on the FMS™ combines multiple aspects of athletic function (strength, balance, stability, mobility), one could hypothesize that football players with higher quadriceps and hamstrings strength could perform better on the FMS™.

Pearson's correlation coefficients were calculated between non-normalized peak torques and FMS™ scores and a negative association was observed between performance on the FMS™ and quadriceps strength tested at 300°/s, while no significant correlation was observed between FMS™ scores and hamstrings strength or quadriceps strength tested at a lower speed (Fig. 2.2). This indicates that football players with greater quadriceps strength at high speeds perform worse on the FMS™. However, when we normalized the knee strength data to body mass, this significant correlation was not observed (Fig. 2.3). Apparently, heavier players exhibited greater knee strength, and obtained lower scores on the FMS™. Indeed, a significant correlation between FMS™ scores and body mass index ($r=-0.41$, $p=0.01$) was observed in this data set. These results support previous findings that lower FMS™ scores are associated with a higher body mass index [17], rather than with stronger quadriceps muscles. This example illustrates how the choice whether or not to normalize quadriceps and hamstrings strength data can substantially affect clinical findings.

Quadriceps and Hamstrings Strength vs. Clinical Hop Tests

Hop tests are clinical measures commonly used to assess athletic performance and side-to-side asymmetries in a simple and dynamic manner. Our football players performed a set of four single-leg hop tests: a single hop for distance, a triple crossover hop for distance, a triple hop for distance, and a 6 m timed hop (Fig. 2.4).

Performance on the triple hop for distance was significantly correlated with all body mass-normalized isokinetic peak torque values except for hamstrings strength tested at a low speed (Fig. 2.5). This indicates that athletes with

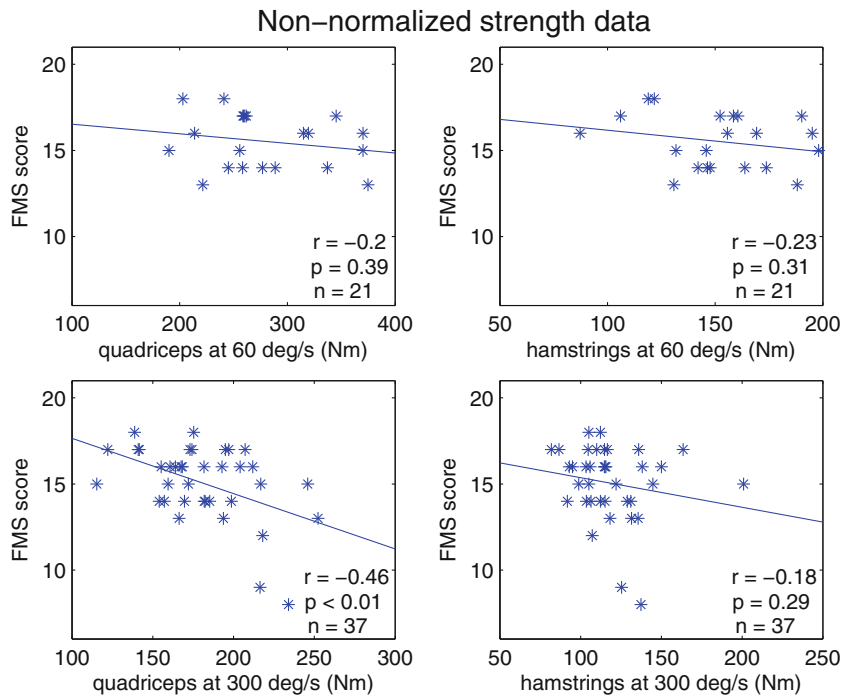


Fig. 2.2 Correlations between non-normalized knee strength and FMS scores

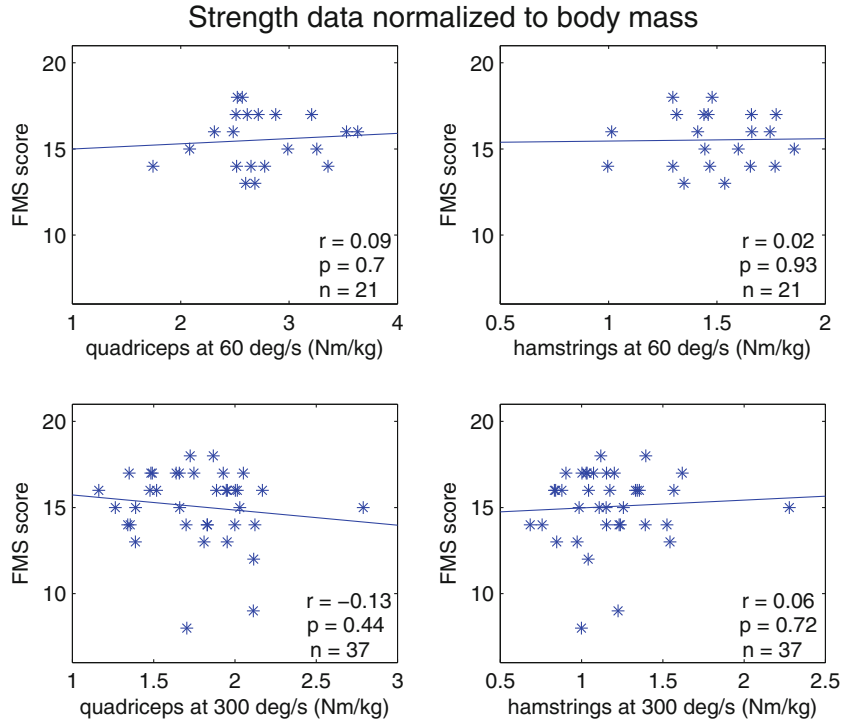


Fig. 2.3 The significant correlation between quadriceps strength at 300°/s and FMS score is no longer observed after normalization of peak torque to body mass

stronger thigh muscles landed their third hop further than athletes with weaker thigh muscles (normalized to body mass). Interestingly, the strongest correlations were observed for both quadriceps and hamstrings peak torque measured at 300°/s. This supports previous findings that testing at a higher speed better reflects dynamic

athletic performance [2]. The relationship between quadriceps strength and triple hop distance may be most intuitive, given the quadriceps' function of extending the knee joint for a powerful take-off. However, the biarticular hamstrings muscles originate on the pelvis and insert on the tibia and fibula, and thus span both the knee joint, where they act as flexors, and the hip joint, where they act as extensors. Stronger hamstrings can therefore improve hop performance by generating large hip extension moments during take-off and by stabilizing the knee during landing.

Table 2.6 shows the correlations between isokinetic peak torque and all hop tests. The lack of significant correlation between single hop distance and knee strength may be due to the limited amount of data. The crossover hop requires substantial coordination and balance skills as it involves frontal plane displacement in addition to sagittal plane movements. This may explain the lack of significant correlation between quadriceps and hamstrings peak torque and performance on the crossover hop for distance.

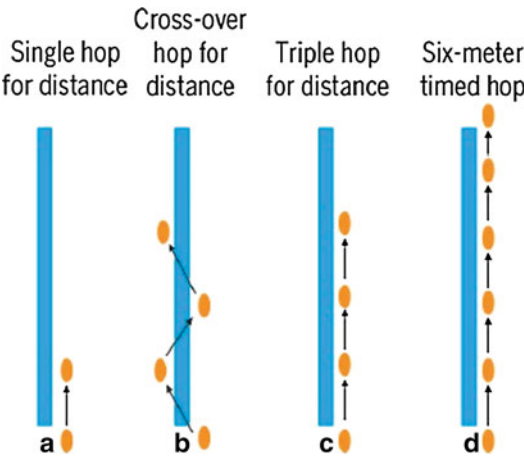


Fig. 2.4 Hop tests

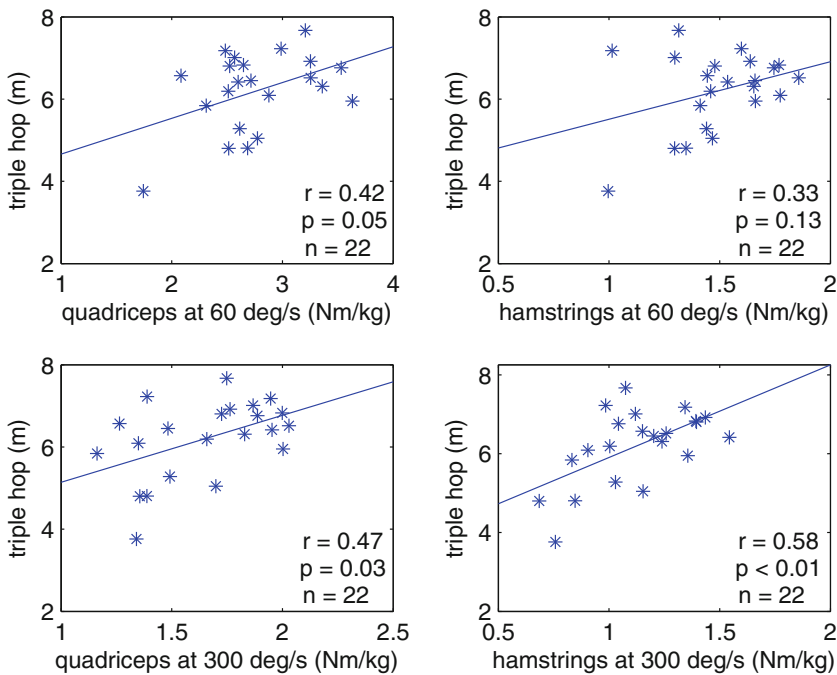


Fig. 2.5 Performance on the triple hop for distance is positively correlated with most isokinetic knee strength measures

Table 2.6 All correlations between isokinetic quadriceps and hamstrings strength and hop test performance

Peak torque normalized to body mass	Single hop			Triple hop			Crossover hop			6 m timed hop		
	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>
Quad_60°/s	ND	ND	ND	0.42	0.05	22	0.31	0.16	22	-0.45	0.04	22
Quad_300°/s	0.00	0.99	11	0.47	0.03	22	0.21	0.23	33	0.01	0.98	32
Ham_60°/s	ND	ND	ND	0.33	0.13	22	0.26	0.25	22	-0.38	0.08	22
Ham_300°/s	0.22	0.52	11	0.58	<0.01	22	0.30	0.10	33	-0.25	0.16	32

Note that difference between positive and negative correlation coefficients between the normalized and non-normalized peak torque
ND no data
Values in bold represent significant effects

Quadriceps and Hamstrings Strength vs. Hip Abduction Strength

The contribution of the hip musculature is often overlooked when assessing knee strength and control. The muscles surrounding the hip joint play a significant role in controlling the position of the femur during dynamic tasks [18]. The following section presents hip strength data collected using a custom load cell device. The load cell, placed between two straps surrounding the distal portions of the thighs, recorded maximal force while the thighs were abducted and externally rotated in both side-lying and standing postures (Fig. 2.6). The following knee isokinetic and hip isometric strength data are normalized to body mass.

Less than half of the correlations between isokinetic knee strength and isometric hip strength were significant (Table 2.7). In other words, athletes with strong (or weak) quadriceps or hamstrings do not necessarily have strong (or weak) hip muscles as well. The standing isometric hip abduction test showed the strongest association with isokinetic knee strength, with significant correlations ranging from 0.39 to 0.52 for all peak torque measures except quadriceps strength tested at 60°/s (Fig. 2.7). The hamstrings peak torque at 300°/s showed the strongest association with isometric hip strength, with significant correlation coefficients ranging from 0.43 to 0.52 for all hip strength measures except the standing external rotation test. The finding that hip and knee

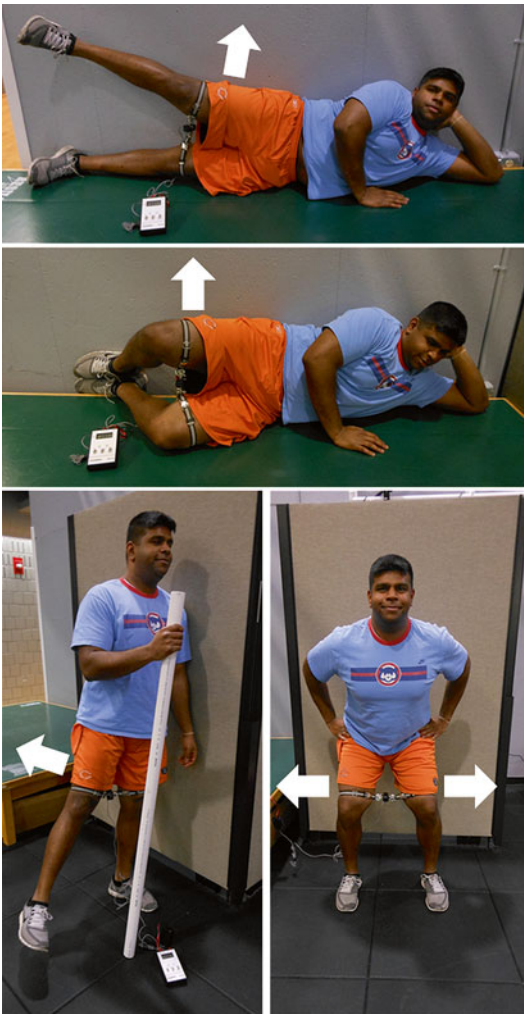


Fig. 2.6 Isometric hip abduction and external rotation strength test

Table 2.7 Correlations between isokinetic quadriceps and hamstrings strength and isometric hip strength

Peak torque normalized to body mass	Side-lying hip abduction			Side-lying hip external rotation			Standing hip abduction			Standing hip external rotation		
	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>	<i>r</i>	<i>p</i>	<i>n</i>
Quad_60°/s	0.35	0.11	22	0.29	0.18	22	0.29	0.19	22	0.41	0.06	22
Quad_300°/s	0.37	0.04	31	0.41	0.02	32	0.39	0.03	32	0.36	0.03	35
Ham_60°/s	0.36	0.10	22	0.32	0.14	22	0.46	0.03	22	0.42	0.05	22
Ham_300°/s	0.51	<0.01	31	0.43	0.01	32	0.52	<0.01	32	0.24	0.17	35

All strength measures are normalized to body weight
Values in bold represent significant effects

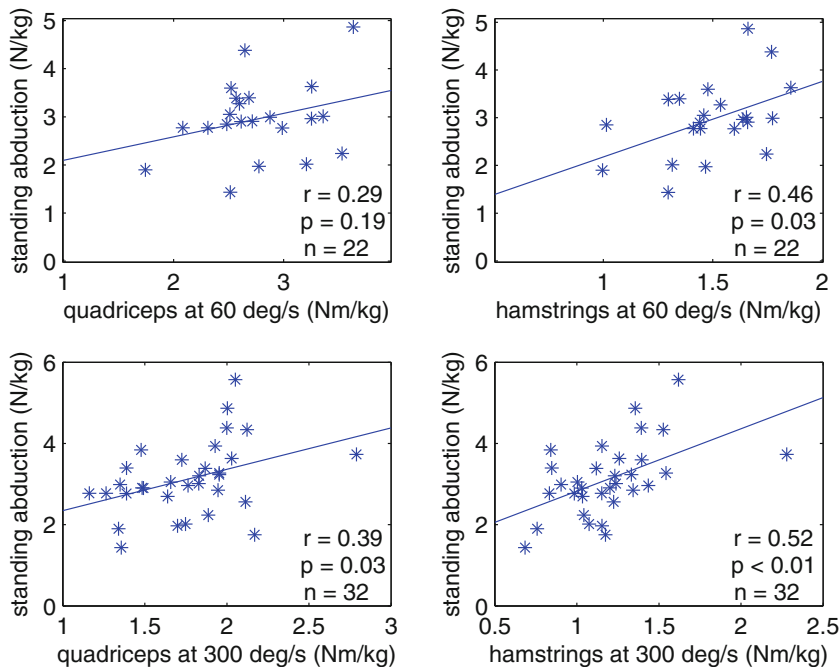


Fig. 2.7 Mostly positive, but moderate correlations between hip and knee strength. Both strength measures are normalized to body mass

strength are only partially and moderately correlated indicates that improvement of hip and knee strength requires function-specific training of each muscle group.

Limb (A)symmetry

Asymmetries between limbs in strength and function may affect athletic performance. Moreover, limb asymmetry is a risk factor for lower extremity injury [8]. The LSI (Eq. (3.2)) quantifies the difference between limbs. In other words, it indicates how good (or bad) performance with the

non-dominant (or injured) limb is with respect to the dominant (or unaffected) limb. LSIs can be calculated for each single-leg task that is performed on both legs. In this section, we discuss how the LSIs that were calculated based on the previously described tests (i.e., isokinetic hamstrings and quadriceps strength, functional hop tests, and isometric hip strength) relate to each other in our population of freshmen collegiate football athletes.

LSI for quadriceps strength was significantly correlated to LSI for hamstrings strength, both at 60°/s ($r=0.48$, $p=0.02$, $n=22$) and at 300°/s ($r=0.46$, $p<0.01$, $n=38$). This indicates that the

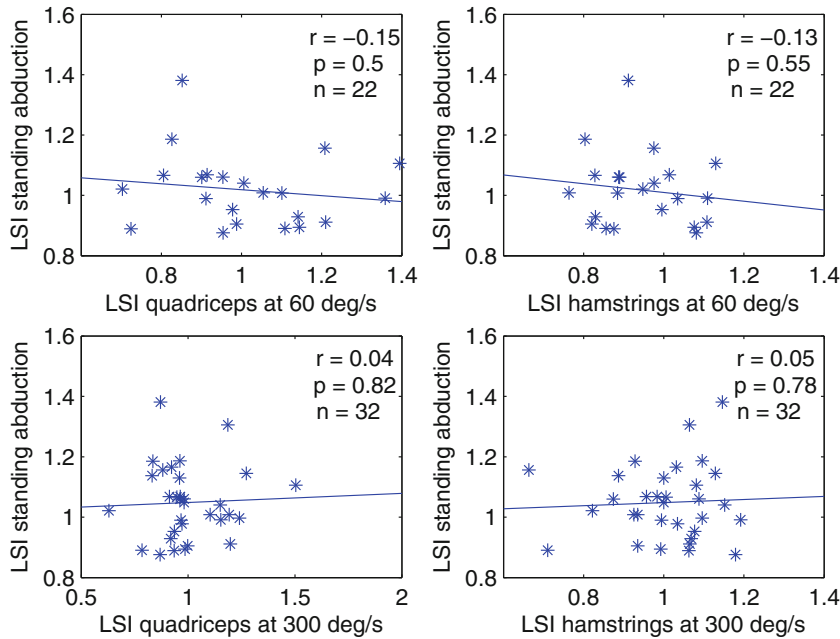


Fig. 2.8 Limb asymmetry based on knee strength measures does not correlate with limb asymmetry based on hip strength measures

asymmetry between limbs is (at least partly) consistent between knee flexors and extensors. Another significant correlation was observed between LSI for quadriceps strength tested at the higher and the lower speed ($r=0.65$, $p<0.01$, $n=22$). This indicates that subjects with quadriceps asymmetry at the low speed also tended to show quadriceps asymmetry at the high speed (although the absolute values of the LSI may differ between speeds). Interestingly, no such correlation was observed for the hamstrings muscles ($r=0.30$, $p=0.17$, $n=22$), which indicates that LSIs based on hamstrings strength were inconsistent between speeds of testing. Fast hamstring contractions are less common in most sports than explosive quadriceps contractions, therefore, athletes may have difficulty with rapid hamstring activation during the test at the high speed.

While asymmetries in knee strength seem to be related, this does not necessarily indicate that similar asymmetries will be seen within the hip musculature (Fig. 2.8). No significant correlations were observed between LSI based on knee strength and LSI based on hip strength. Similarly, no significant correlations were observed between LSIs calculated from isokinetic knee

strength measures and LSIs calculated from any of the functional hop tests. These results indicate that strength asymmetries in the quadriceps and hamstrings muscles do not directly translate to functional asymmetries in athletic tasks. Therefore, these separate assessments of limb asymmetry cannot substitute one another, and they provide insight in different aspects of discrepancies between limbs.

Deficiencies in Quadriceps and Hamstrings Strength as a Risk for Injury

Several studies have associated deficiencies in quadriceps and hamstrings strength with increased risk for lower extremity injuries [8, 19–22]. However, other studies reported no significant association between strength deficiencies and injury risk [23–25]. These inconsistent findings likely result from the variety of research protocols (i.e., speed of isokinetic testing, concentric or eccentric contractions), outcome measures (i.e., peak torque, HQ-ratio, asymmetry measures), research populations (i.e., male vs.

female athletes and different sports), and reported injuries (i.e., injuries in general, all lower extremity injuries, specific injuries such as hamstrings strains or ACL ruptures) in these studies.

Hamstrings Strain-Type Injuries

Four recent reviews [26–29] discuss the risk factors for hamstrings strain, concluding that current evidence for isokinetic strength measures as predictors of hamstrings injuries is inconsistent. Freckleton and Pizzari [27] performed several meta-analyses of prospective studies investigating the role of isokinetic knee strength as a risk factor for hamstrings injury. They calculated the standardized mean difference (SMD) and its 95 % confidence interval (CI) by dividing the injured and non-injured group means by the pooled standard deviation (SD), thus providing a measure of the difference between players who went on to suffer a hamstrings injury and those who remained injury free. No difference between injured and uninjured athletes was observed in concentric H/Q ratio at 60°/s (SDM=−0.50, 95 % CI=−1.17 to 0.18, $p=0.15$, based on five studies and 216 subjects). Another meta-analysis did not support concentric hamstrings peak torque as a risk factor for hamstrings strain (SMD=−0.24, 95 % CI=−0.85 to 0.37, $p=0.44$, based on 4 studies and 195 participants). However, a meta-analysis of these same studies showed that a high quadriceps peak torque was a significant risk factor for hamstrings muscle strain-type injuries (SMD=0.43, 95 % CI=0.05–0.81, $p=0.03$). Next to age and previous hamstrings injury, quadriceps peak torque was the only strength based factor consistently associated with hamstrings strain-type injuries [27].

In a more recent study, Zvijac and colleagues [6] collected isokinetic quadriceps and hamstrings strength at the National Football League (NFL) Scouting Combine, and all 32 NFL teams identified players who suffered hamstring injuries during their first season ($n=203$, of which 164 had usable strength data). In contrast to previous reports, neither quadriceps nor hamstrings strength was predictive of hamstrings injury in first-year professional football players. None of the knee strength measures (quadriceps and ham-

strings peak torque, H/Q ratio, and side-to-side asymmetry) were different between injured and uninjured limbs, or between injured and uninjured control players [23].

One of the largest prospective studies not only tested preseason isokinetic strength (both concentric and eccentric) in professional soccer players, but also included an intervention to resolve any existing strength imbalances [19]. Athletes in the intervention group participated in a hamstrings conditioning program, consisting of manual, isotonic or isokinetic strengthening, and a subset of players underwent subsequent isokinetic testing until the strength imbalance was resolved. Out of 462 players who completed the study, 35 hamstrings injuries were reported. Soccer players were considered to have preseason “strength imbalances” if they showed significant deficiencies in at least two out of seven parameters that reflected side-to-side hamstring strength asymmetries and H/Q ratios at different speeds and modes of testing. The frequency of hamstrings injury during the season was lowest (4.1 %) in soccer players with no preseason strength imbalance, while the injury frequency was highest in players with untreated strength imbalances (16.5 %). The group who participated in the hamstrings conditioning program with repeated follow-up isokinetic tests to verify the efficacy of the intervention, had an injury frequency of 5.7 %, not statistically different from that in the group without preseason strength imbalances. In the athletes who participated in the intervention without repeated follow-up isokinetic tests, the frequency of hamstrings injuries remained elevated (11 %). These results indicate that the incorporation of a combination of strength imbalances may be more valuable than a single parameter when assessing risk of hamstrings injury, and that adequate training may help to reduce injury risk by normalizing these imbalances.

Anterior Cruciate Ligament (ACL) Injuries

One of the primary functions of the ACL is to restrain anterior translation of the tibia with respect to the femur. Activation of the hamstrings

muscles supports the ACL in this function. In vitro, strain on the ACL was substantially reduced with simultaneous activation of hamstrings and quadriceps muscles, compared to activation of the quadriceps muscles alone [30, 31]. These and other findings [32–34] imply that deficiencies in hamstrings strength may increase the risk of ACL injury.

Söderman and colleagues [22] studied risk factors for lower extremity injuries in 146 female soccer players, with five of these athletes ultimately suffering an ACL injury. A lower H/Q ratio was a significant predictor for traumatic injuries of the lower extremity in general. While this number of ACL injuries was too small for accurate statistical analyses, all of the ACL-injured soccer players showed preseason concentric H/Q ratios <0.55 in the injured limb, which was lower than the H/Q ratio in the uninjured side [22]. Myer and colleagues (2009) studied risk factors for ACL injury in female soccer and basketball players. The 22 athletes who sustained ACL injuries showed a combination of decreased hamstrings strength, but similar quadriceps strength when compared to male athletes. In contrast, female athletes who did not suffer ACL injuries showed decreased quadriceps strength, but similar hamstrings strength compared to male controls. While no significant differences between injured and uninjured female athletes were observed, these findings indicate that “quadriceps dominance” may be a risk factor for ACL injury [21]. Moreover, a recent study showed that insufficient hamstrings strength compromised landing technique in adolescent girls, resulting in high-risk biomechanical movement patterns [35]. Without providing direct statistical evidence, the results of these studies tend to support the theory that deficiencies in hamstrings strength may increase the risk for ACL injury. And indeed, our neuromuscular training program aimed at prevention of ACL injuries has been successful in both improving hamstring strength [36] and reducing ACL injury risk [37].

Summary

Quadriceps and hamstrings strength are usually quantified by the peak torque during maximal voluntary isokinetic contractions. Ratios of peak

torque are used to assess limb asymmetry and hamstrings strength relative to quadriceps strength. Peak torque is affected by the mode and speed of testing, and whether or not to normalize peak torque (e.g., to body mass) is an important consideration. Positive, but moderate correlations were observed between knee strength and triple hop distance and between knee strength and hip strength in a population of collegiate freshmen football players. No significant correlation was observed between knee strength and FMS™ performance, or between limb symmetry indices based on different strength and functional tests. Deficiencies in quadriceps and hamstrings strength may increase the risk of lower extremity injuries, but large prospective studies are needed to determine which measures of strength are the best predictors for specific injuries and to optimize injury prevention strategies.

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