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The Relationship Between Lower Extremity Isokinetic Work and Single-Leg Functional Hop-Work Test

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Context: Lower extremity functional testing assesses strength, power, and neuromuscular control. There are only moderate correlations between distance hopped and isokinetic strength measures. ***Objective:*** Determine if incorporating body weight in the single-leg hop for distance increases the correlation to isokinetic measures. ***Study Design:*** Correlational study. ***Setting:*** Musculoskeletal laboratory. ***Participants:*** 30 healthy college students; 15 men and 15 women; ages 18 to 30 years. ***Main Outcome Measures:*** Isokinetic average peak torque and total work of quadriceps and hamstrings and single-leg hop work and distance. ***Results:*** Significant correlations include hop work to total-work knee extension ($r = .89$), average peak-torque knee extension ($r = .88$), distance hopped to total-work knee extension ($r = .56$) and average peak-torque knee extension ($r = .63$). Correlations involving hop work were greater than distance hopped ($P < .05$). ***Conclusions:*** Use of body weight in the assessment of distance hopped provides better information about the patient's lower extremity strength and ability than the distance hopped alone. ***Key Words:*** knee, strength, functional outcome measure

The use of functional testing is recommended as one component of a battery of tests to evaluate a patient's ability to return to full physical activity.[1] These tests are considered objective tools to evaluate a patient's total leg function. This encompasses several components such as strength, mobility, balance, and neuromuscular control of the trunk, hip, knee, ankle, and foot.[2-5] Functional testing has been found to be reliable and has demonstrated the ability to detect functional limitations in a variety of knee patients.[2,4,6-11]

Isokinetic testing is a valuable tool to specifically assess dynamic muscle performance. Assessment of force production is an important component in helping clinicians decide when return to full physical activities should be allowed.[1,2,5,7,8,12-16] In an effort to be clinically efficient and because of a lack of available equipment, functional tests are sometimes used to assess leg strength, particularly of the knee extensors.

The relationship between functional testing and leg strength has been investigated by several authors, who found a wide range of correlations from $r = .38$ to

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$r = .78$.[2,4,5-8] Most commonly the distance hopped is related to the maximal force produced on an isokinetic dynamometer. One explanation offered for this wide variation suggested that studies using reciprocal leg motion simulating a normal neuromotor input tend to yield higher correlations between functional-hop measures and isokinetic measures.[15]

Another potential explanation for the moderate relationships is that they result from using 2 different units of measure in the 2 tests. The single-leg hop test measures the distance a person moves horizontally during a dynamic weight-bearing activity, and isokinetic peak torque is tested via a non-weight-bearing test that measures maximal force or torque generated at a constant speed. Work that is the product of force multiplied by distance is a value that incorporates both components of these 2 measures. Previous research has found the relationship between the work (force × distance) done during a vertical jump and in an isokinetic test to be stronger than the distance jumped alone.[17,18] It has been suggested that incorporating weight into a jump-distance measure differentiates performance abilities.[18] A heavy person jumping the same distance as a light person is generating more force with the lower extremity muscles to move the load the same distance as the light individual. Therefore, if a clinician is attempting to assess strength with functional testing instead of the more traditional and preferred method using an isokinetic measure, the patient's body weight might need to be taken into consideration. Therefore, the purpose of this study was to assess whether a functional measure of work (work done during a single-leg hop for distance) correlates more strongly with dynamic isokinetic strength measures than does distance hopped alone.

Methods

This correlational study design was approved by the University of Kentucky institutional review board.

Subjects

Fifteen healthy men (height 1.8 ± .08 m, 87.8 ± 16.5 kg) and 15 healthy women (height 1.66 ± .06 m, 66.7 ± 14.7 kg) between 18 and 30 years of age (mean = 21.9, SD = 1.45) volunteered to participate in this study. These individuals (height = 1.7 ± .1 m, mass = 77 ± 19 kg) from the University of Kentucky physical therapy program had no recent history of lower leg injury. Before data collection, subjects read and signed an informed consent in accordance with the University of Kentucky's institutional review board, and all subjects' rights were protected.

Instrumentation

The Biodex System 3 was used to measure the isokinetic force generation of the dominant lower extremity (Biodex Corp, Shirley, NY). The speed was standardized at 60°/s.[2,3,8] Single-leg hop for distance was measured by a pocket tape measure (in centimeters). Body weight was measured with a standard physician's scale (Seca Corp, Bradford, Mass).

Procedures

All subjects participated in 1 session that consisted of both Biodex isokinetic and single-leg hop-for-distance testing. Leg dominance was determined by asking the subjects which leg they would use to kick a soccer ball.[7,8] Each subject's height and weight were measured and recorded before warm-up. The warm-up included 5 minutes on a stationary bicycle and was followed by stretching of the gluteus maximus, hamstrings, quadriceps, and gastrocnemius.[8,15] In order to counterbalance the study, half the subjects began testing on the isokinetic device. To maintain consistency, the same examiner read the same instructions to each participant before beginning each test, and no verbal encouragement was given during testing trials.

Subjects were positioned according to the Biodex System 3 manual with hips and knees flexed to approximately 90° and with the lateral femoral epicondyle aligned with the central axis of the dynamometer. The subjects were stabilized with 1 pelvic, 1 thigh, 1 ankle, and 2 trunk (crisscrossing) straps and were asked to position both arms across the chest during testing.[19] Gravity correction was performed for each subject tested, following the procedure outlined by the Biodex System 3 manual.[19] Three to 5 submaximal practice trials were performed before 3 maximal concentric–concentric contractions of the quadriceps and hamstrings. A speed of 60°/s was used.[2,3,8] Data calculated by the Biodex System 3 software included average peak torque and total work for both knee flexion and extension of the dominant leg for each subject.

For the single-leg hop test, subjects performed a practice trial of 3 single-leg hops with the dominant leg. Subjects were instructed to allow their arms to move freely and to maintain balance for 3 seconds on landing on the dominant leg. Each subject wore athletic shoes, and, for measurement accuracy, chalk was applied to the heel of the subject's shoe.[2,7,8,10,16] To begin the testing for data collection, each subject was asked to place his or her heel at 0 cm on a tape measure that was secured to floor. The subjects performed 3 maximum efforts, and the examiner documented the distance hopped for all 3 trials and then averaged the trials. The distance hopped was measured to the nearest millimeter from the chalk mark on the tape measure. After each trial, the examiner erased the chalk on the floor to minimize any visual cues. A single examiner recorded all single-leg test measurements to minimize variation among different examiners.

Data Reduction

The Biodex System 3 software computed total work and average peak-torque values. According to the Biodex System 3 manual,[19] total work is computed as follows:

$$\text{Work (delta)} = \{\text{torque } (@\ t) - 1/2[\text{torque } (@\ t) - \text{torque } (@\ t-1)]\} \times [\text{position } (@\ t) - \text{position } (@\ t-1)]$$

Work is the sum of the contributions of each graph segment (deltas). The torque, or force, measured at a point in time (*t*) is represented by a segment of the graph. Each of the segments is summed over a half repetition to obtain the total work.[19]

Average peak torque is calculated by taking the peak torque for each repetition of a set and dividing by the 3 repetitions performed. Hop work was derived using the standard formula for work. Our term hop work was computed by multiplying the subject's body weight (Newtons) by the average distance hopped (meters) on 1 leg during 3 trials:

$$\text{Work} = \text{force (body weight)} \times \text{distance}$$

Statistical Analysis

To determine which functional measures correlated best with the isokinetic measures of average peak torque and total work, a bivariate Pearson correlational-coefficient matrix was calculated using SPSS version 11.5 (Chicago, Ill). The single-leg hop-test measures of distance and hop work were correlated to knee-extension and -flexion isokinetic measures of average peak torque and total work. Using the correlation guide documented by Guilford[20] and Domholdt,[21] we determined that a correlation in a high to very high range ($r > 0.7$) was meaningful for this project with the alpha level set at $P < .05$.[20,21]

To determine whether the degree of correlation between 2 variables was different, a Fisher Z transformation and related 95% confidence interval were established.[22] The sampling distribution of the transformed Z score approaches normal distribution for comparison more rapidly than from a bivariate distribution r, which allows for statistical comparisons between correlations, even if the sample is small (n = 30). A correlation-coefficient dependent t test with the alpha level set at $P < .05$ was used to determined differences between correlations.[22]

Results

Descriptive analysis of all data collected is presented in Table 1, by male and female participants. The results of the bivariate correlations, Z values, and 95% confidence intervals are presented in Table 2. The correlation between hop work and knee-extension total work was very high ($r = .89$), and the correlation between distance hopped and knee-extension average peak torque was moderate ($r = .63$; Table 2).[20,21] Direct comparison of the transformed Z scores of these correlations using a t test demonstrated that the hop-work to knee-extension total-work correlation was significantly greater than the hop-distance to knee-extension average-peak-torque correlation ($t = 2.6$, $P < .05$). The correlation of hop-work to knee-extension total work ($r = .89$) was found to be significantly greater than the correlation of distance hopped to knee-extension total work ($r = .56$, $t = 2.64$, $P < .05$). The same was true for knee-flexion total-work correlations ($t = 2.36$, $P < .05$). The correlation between hop work and knee-extension average peak torque ($r = .88$) was greater than the correlation between distance hopped and knee-extension average peak torque ($r = .63$) but did not reach statistical significance ($t = 1.65$, $P > .05$). No significant differences were found for flexion average-peak-torque correlations between hop work and distance hopped (Table 2).

Table 1 Descriptive Data for All Isokinetic and Single-Leg-Hop Measurements, Mean (SD)

	Men	Women	Total
Weight (Newtons)	859.7 (161.8)	652.6 (143.6)	756.2 (183.5)
Average distance hopped (m)	1.77 (0.24)	1.32 (0.25)	1.55 (0.33)
Hop work (N · m)	1514.3 (304.2)	857.2 (194.0)	1185.7 (417.8)
Total work extension (N · m)	623.9 (149.6)	385.5 (80.1)	504.7 (169.1)
Total work flexion (N · m)	367.3 (83.9)	228.4 (50.4)	297.9 (98.1)
Average peak-torque extension (N · m)	201.4 (45.6)	125.4 (25.4)	163.4 (53.0)
Average peak-torque extension (% body weight)	77.4 (16.3)	63.5 (8.7)	70.4 (14.6)
Average peak-torque flexion (N · m)	101.6 (21.5)	63.7 (11.7)	82.6 (25.7)
Average peak-torque flexion (% body weight)	39.7 (10.4)	32.7 (7.0)	36.2 (9.4)

Table 2 Single-Leg Hop for Distance and Hop Work*

	Single-Leg Hop for Distance			Hop Work		
	r	95% CI	*Z* transform	*r*	95% CI	*Z* transform
Total work extension (N · m)	.56	.250–.765	0.633	.89	.780–.945	1.422†
Average peak-torque extension (N · m)	.63	.350–.805	0.741	.88	.760–.940	1.376†
Total work flexion (N · m)	.57	.250–.770	0.648	.77	.478–.885	1.020
Average peak-torque extension (% body weight)	.72	.350–.805	0.908	.63	.485–.855	0.741

*All *r* values are significant at a level of $P < .05$.

†Indicates hop-work correlation significantly greater than distance to the isokinetic measure ($P < .05$).

Comments

The primary intent of this study was to determine whether using a parameter of work, by including a subject's body weight, would yield a higher correlation between functional and isokinetic strength testing than the commonly used parameter of distance hopped. Stronger correlations were found between functional-test scores using the units of work and isokinetic-strength values. The measure of work is referred to as total work in the isokinetic literature[3] and is considered the area under the curve or described as the force applied over the entire arc of motion.[23] Work has also been described as the action of a force over a specific distance and has been referred to as the product of muscle force exerted through specific ranges of motion.[24] Conversely, peak torque represents the highest torque output generated by an activating muscle at a single moment in time or at a specific angle through a range of motion. Average peak torque represents the average of a series of peak torques generated over multiple repetitions.[23]

Both work and peak torque have been found to be reliable measures of muscle performance.[14,25] Kannus[23] has reported isokinetic total work to be highly correlated to peak-torque measurements for knee flexion and extension in patients with various knee injuries. He concluded that the high correlations suggested that total work added little new information from that of peak torque.[23,26] Others, however, have suggested that total work is a better representation of muscle function than peak torque is and should not be replaced by peak torque as the definitive measure.[19,27] Iossifidou and Baltzopoulos[27] examined peak-torque power and work and concluded that work should not be replaced by peak torque because work depends on range of motion and adds information about muscle and joint function throughout an identified range of motion when compared with peak moment.[19,27] We expected that there would be a higher correlation when the units of measure were the same, but even for hop work to average peak torque there was a high correlation ($r = .88$). The high correlation between work and peak-torque measures previously reported might explain why functional hop work was highly correlated with both isokinetic average peak torque and total work in this study.

The single-leg hop test is considered a functional, 1-time maximal effort used to assess performance.[28] Typically, functional tests such as single-leg hop for distance are used clinically to compare involved- and uninvolved-leg performance with the relative performance calculated using a limb-symmetry index. The limb-symmetry index represents the involved leg's performance as a percentage of that of the uninvolved leg.[2] For example, an individual who performs a 0.75-m single-leg hop test on the involved leg and 1.0-m hop on the uninvolved leg would have 75% limb symmetry. An 85% limb-symmetry index has been recommended as a standard for normal function.[2] An assumption is made that the uninvolved leg is normal. This might not be true in an individual who has recently undergone a knee injury. A recent study has demonstrated muscle inhibition of both legs after acute ACL injury.[29] Assuming normal performance based on symmetry alone might not provide the clinician with all pertinent information necessary to make a decision regarding return to full function. The patient's ability based on normative values for his or her age, height, and weight might need to be assessed. At present the normative information available in the literature reports either symmetry or actual distance hopped or jumped.[2,12]

The inclusion of a subject's weight in assessment of either vertical jump or horizontal hop distance appears to indicate strength abilities that distance alone cannot explain. Tsiokanos et al[18] found that including a subject's body weight and the calculation of total work during single- and double-leg vertical jumps resulted in higher correlations with isokinetic peak torque than did distance jumped. They concluded that by calculating total work during a vertical jump, one can identify a greater jumping ability in 2 subjects who jump the same distance but weigh different amounts.[18] The results of the present study support these previous findings because our correlations including body weight were significantly higher than the distance hopped alone. We initially expected this to occur because we are comparing similar measures of work to work instead of distance to force. Nonetheless, our results support the idea that hop work correlates to a significantly greater degree to both work and average peak torque. Because work is calculated as force multiplied by distance moved, the inclusion of work units in single-leg hop tests might provide a better representation of muscle function through the entire range of motion.

The ability of an individual to perform a hop or jump test depends on several factors: flexibility, balance, and neuromuscular control. The resultant of moving a load a large distance appears to primarily depend on the strength of the lower extremity muscles to control motion during the preparatory squat and to produce a strong concentric contraction against the load of body weight. The ability to control and move these loads might be more important indicators of function during rehabilitation than symmetry alone is.

Although previous researchers have used work units, they have not compared work of the single-leg hop test and total-work units of isokinetic tests.[2,7,9,15] In this study, work performance was measured. Angular isokinetic testing typically measures the force generated by a specific muscle.[30] Because the Biodex System is capable of calculating total work performed by a specific muscle during angular motion, a comparison of total work produced by a specific muscle with the work performed during a single-leg hop test might give the examiner a better representation of the role played by the muscle in the functional activity (to enable clinicians to more quickly convert distance hopped to work units, Table 3 presents a work table in English units).

For this reason, we believe that the use of hop work, which takes into consideration the weight of the individual, more accurately reflects a subject's ability to perform a functional hop test through using the synergy of muscles necessary for optimal performance.

The use of the *Z*-transformation analysis allows for the correlations to be statistically compared despite a subject pool of only 30.[22] It adds validity to the higher correlations found using the hop-work measure. The results of the current study support the reasonable correlations between average peak torque and distance found in previous studies. Although the correlation between average peak torque and distance has been used reliably in the past, the higher correlations obtained with the use of work units including the subject's weight combined with the statistical support of the Fisher *Z* transformation and corresponding 95% confidence intervals yield a more powerful statement of the relationship between the single-leg hop and isokinetic tests.

The major limitation of this study is that it is only generalizable to a young, healthy population. Further studies are needed to establish normal or expected

Table 3 Single-Leg Hop-Work Chart (in foot-pounds*)

	Distance Jumped (ft)										
Weight (lb)	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
110	110	165	220	275	330	385	440	495	550	605	660
115	115	172.5	230	287.5	345	402.5	460	517.5	575	632.5	690
120	120	180	240	300	360	420	480	540	600	660	720
125	125	187.5	250	312.5	375	437.5	500	562.5	625	687.5	750
130	130	195	260	325	390	455	520	585	650	715	780
135	135	202.5	270	337.5	405	472.5	540	607.5	675	742.5	810
140	140	210	280	350	420	490	560	630	700	770	840
145	145	217.5	290	362.5	435	507.5	580	652.5	725	797.5	870
150	150	225	300	375	450	525	600	675	750	825	900
155	155	232.5	310	387.5	465	542.5	620	697.5	775	852.5	930
160	160	240	320	400	480	560	640	720	800	880	960
165	165	247.5	330	412.5	495	577.5	660	742.5	825	907.5	990
170	170	255	340	425	510	595	680	765	850	935	1020
175	175	262.5	350	437.5	525	612.5	700	787.5	875	962.5	1050
180	180	270	360	450	540	630	720	810	900	990	1080
190	190	285	380	475	570	665	760	855	950	1045	1140
200	200	300	400	500	600	700	800	900	1000	1100	1200
210	210	315	420	525	630	735	840	945	1050	1155	1260
220	220	330	440	550	660	770	880	990	1100	1210	1320
230	230	345	460	575	690	805	920	1035	1150	1265	1380
240	240	360	480	600	720	840	960	1080	1200	1320	1440

*1 foot-pound = 1.3558 N · m.

performance levels based on body size. Further studies are also needed to compare work performance in the single-leg hop test with isokinetic testing in people who present with a variety of knee pathologies and functional limitations to determine whether this measure will better identify patients with diminished functional performance.

Measurements of work units might give clinicians an understanding of the performance of the muscle studied while considering the size of the subject. For clinicians who do not have access to an isokinetic device, functional tests such as the single-leg hop can be used to evaluate a patient's functional muscle performance without equipment limitations. The results of this study support the idea that a single-leg hop score incorporating the body weight of the individual more closely represents the force a muscle can generate throughout the range of motion and at peak values. Therefore, if functional tests are used to assess knee-muscle strength, a better representation of the ability of an individual to generate force is indicated by the product of the distance hopped and the body weight of the individual.

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