The Relationships among Isometric, Isotonic, and Isokinetic Concentric and Eccentric Quadriceps and Hamstring Force and Three Components of Athletic Performance

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Abstract:

The purpose of this study was to compare the relationships among isometric, isotonic, and isokinetic concentric and eccentric quadriceps and hamstring forces and three components of athletic performance in college-aged, male athletes. Bilateral quadriceps and hamstring muscle torque were obtained (N = 39) using a KinCom® for concentric (rate at 60°/sec and 180°/sec), eccentric (rate at 30°/sec and 90°/sec), isotonic, and isometric (knee angles at 30° and 60°) contractions. Athletic performance was assessed using vertical jump performance, 40-yard dash time, and agility run time. The best predictor of 40-yard dash time was the right peak isokinetic concentric hamstring force at 60°/sec ($R = .57$; $p < 0.05$). The best predictor of agility run time was the left mean isokinetic eccentric hamstring force at 90°/sec ($R = .58$; $p < 0.05$). There were no significant correlations between any quadriceps or hamstring force and vertical jump. It was concluded that isokinetic eccentric quadriceps and hamstring forces were no better predictors of athletic performance than muscle forces assessed in other ways. However, they may be more predictive of some specific components of performance.

Article:

The assessment of strength of the athlete in the sports medicine setting has traditionally been in one of three modes, either isometrically, isotonically, or isokinetically, using concentric muscle

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contractions. From such strength measures, attempts have been made to determine how strength relates to athletic performance. However, the results of such studies have been contradictory. Studies by Berger and Henderson (5), Cozens (10), and Mc- Clements (21) found significant correlations between isometric strength and functional performance, while others found no significant correlations (7-9,19,20,29,34). Several authors found that combinations of measures of isometric and isotonic strength correlated most highly with functional performance (5,7,10,12). Significant positive correlations were found by Minkoff (23) and Miyashita and Kanehisa (24) between strength assessed isokinetically and functional performance, while other investigators found no such correlations 19,26). Many authors (1,16,27,30) have also looked at the relationship of isokinetically assessed strength and functional performance of the athlete following injury, again with athlete following injury, again with mixed results. While researchers disagree as to the relationships of the common modes of strength assessment to functional performance, all have overlooked a fourth mode of strength assessment and its possible relationship to performance, that of eccentric strength assessment.

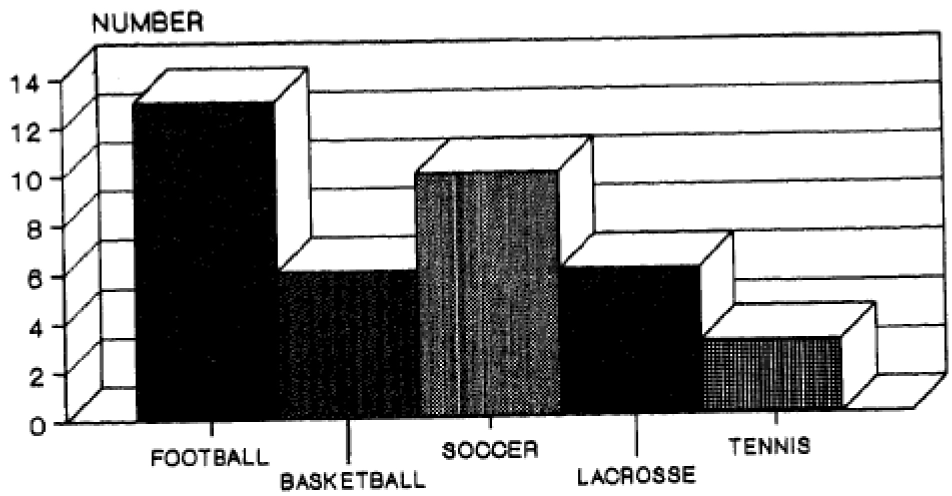

FIGURE 1: *Subjects by Sport*

Research on eccentric muscle contraction has been primarily designed to investigate its influence on the muscle's ability to develop tension during the concentric phase (2,6,14,17,18,31,32). Known as the stretch-shortening cycle, this type of contraction is common in many types of athletic activities, such as running, jumping and throwing, during which force is generated by first allowing the muscle to undergo an eccentric loading immediately followed by a concentric contraction.

Eccentric contractions have also been shown to develop greater muscle tension (17,18) and to require less work (11) than concentric contractions. Strong correlations have also been shown between the amount of concentric and eccentric force a muscle can generate (28). However, no studies have looked at the relationship between eccentric muscle force and athletic performance. The purpose of this study was to compare the relationships among isometric, isotonic, and isokinetic concentric and eccentric quadriceps and hamstring forces and three components of athletic performance as measured by 40-yd dash time, vertical jump, and agility run time in male, college-aged, varsity athletes.

METHODS

Subjects for this study were male, varsity athletes (N = 39) from five different sports (Figure 1) at the University of Virginia. The mean age was 20.1 ± 1.2 years. The mean height was 186.4 ± 8.5 cm, and the mean weight was 89.9 ± 17.6 kg. All subjects were healthy volunteers, with no history of previous or cur- rent knee pathology resulting in chronic disability, functional instabil- ity, or surgical intervention.

Testing Sequence

All subjects were tested in three sessions in the following sequence:

Session 1—Subjects personal data, including age, height, and weight, were recorded. Each subject signed a consent to participate form, approved by the human subject's review board at the University of Virginia. Subjects were then introduced to the testing procedures on the equipment and ran through a practice test in order to become familiarized with the testing equipment. Ses- sion 2—Subjects were tested on the KinCom® using the established protocol (see Testing Protocol). Session 3—Subjects were introduced to and tested on the three functional per- formance tests using the established protocol (see Testing Protocol).

Subjects were given 48 hours between sessions two and three to minimize the effects of any muscle soreness that might result following eccentric testing on the KinCom.

Testing Protocol

All subjects underwent training during session one to familiarize them with the KinCom and the testing procedure. During this session, the subjects were allowed to practice on the KinCom until they felt comfortable with the equipment. They then were tested in a mock testing session, identical to the testing procedures to be used during the study. For session two, all subjects were tested on the KinCom for bilateral quadriceps and hamstring strength using the following protocol:

1) *Isokinetic Testing*—Following warm-up of three submaximal contractions, each subject gave a maximal concentric quadriceps contraction at 60°/sec, which was followed by a maximal eccentric quadriceps contraction at 30°/sec. This sequence was repeated until three consistent force curves were reproduced. Isokinetic speeds were then increased to 180 °/sec concentrically and 90 °/sec eccentrically, and the sequence was repeated.

2) *Isotonic Testing*—Following warm-up of three submaximal isotonic contractions, each subject was asked to extend his knee through a range of motions from —80 - —10° of knee extension (0° extension being full knee extension without hyperextension) at an initial resistance in newtons equal to 25 percent of the subject's body weight. Knee range of motion was determined goniometrically. Following the successful completion of one full repetition, additional resistance of 5 newtons, or a multiple thereof, was added. The repetition was repeated until the subject was no longer able to complete one full repetition. For knee flexion, the range of motion for one repetition was from -10° - —80 ° knee extension.

3.) *Isometric Testing*—Following warm-up of three submaximal isometric contractions, each subject extended his knee to a position of 60° of flexion and was asked to hold a maximal isometric quadriceps contraction for five seconds. Each subject then extended his knee to 30° of flexion and held a maximal isometric quadriceps contraction for five seconds. Following a one-minute rest, each subject was asked to repeat the maximal contractions at each of the specified angles.

Following completion of testing of one quadriceps, the sequence was repeated for the opposite hamstring. Sequence of testing for appropriate muscle groups was either left quadriceps, right hamstrings, right quadriceps, left hamstrings or right quadriceps, left hamstrings, left quadriceps, right hamstrings, to which subjects were randomly assigned.

Subjects were positioned supine for quadriceps testing with the knee to be tested flexed to 90° to begin the test. Subjects were stabilized with a belt across the pelvis, a Velcro strap just proximal to the knee being tested, and a Velcro strap securing the leg to the shin pad and lever arm of the KinCom®. Subjects were positioned prone for hamstring testing, with the knee to be tested beginning in extension. Stabilization for hamstring testing was identical to that for quadriceps testing.

The length of the KinCom® lever arm was recorded for each subject and duplicated for each testing position. Pre- and post-testing internal calibration procedures of the KinCom® were followed according to manufacturer's recommendations prior to each knee motion change.

Functional Testing
Each subject performed the following three functional performance tests:

1) Vertical Jump. Subjects' reach height at maximal arm reach was measured in centimeters. After chalking his fingertips, each subject was given three vertical jumps from a standing start for maximal height. Subjects had a one-minute rest between jumps. The highest fingerprint was measured in centimeters. The subject's maximal arm reach height was subtracted from this. The resultant figure was the subject's vertical jump height in centimeters.

2) Forty-yard dash. Each subject was timed to the nearest .01 second for a 40-yard dash. Subjects were given two trials, with a minimum of 5 minutes rest between trials, and the best time reported.

3) Agility run. Each subject ran a multiple, figure-eight course around cones set 10 yards apart (Figure 2). Subjects were timed to the nearest .01 second for the run, using a mat switch to start and stop the timer. Subjects were given one practice run and two trials, with a minimum of 5 minutes rest between trials. The best time for the run was reported.

Test-Retest Reliability of the Agility Run Test
The agility run test was repeated by nine of the original subjects to determine the test-retest reliability. A two-tailed t-test was used to determine if significant differences existed between tests. There were no significant differences between tests with a mean difference between times of 1.67 percent. The correlation between agility run times was R = .95, with an R2 = .90 and a

standard error of estimate of t .28. Because the 40-yard dash and vertical jump are common performance measures (22,25), no test-retest reliability determination was performed.

Statistical Analysis

Average and peak force to body weight values were determined for each of the four muscles tested in each of the four test modes (isometric, isotonic, isokinetic concentric, and isokinetic eccentric). Performance values were recorded for the 40-yard dash, vertical jump, and agility run. The mean of each group of force variables was then correlated with the group mean for each performance variable (40-yard dash time, vertical jump, and agility run time). Force variables were then entered in a stepwise fashion into a regression equation according to the ranking of their correlation with each performance measure.

Force variables that were significantly correlated ($p < 0.05$) with each performance variable were used to formulate a prediction equation for that performance measure, as long as the force variable contributed significantly to the regression equation. Those that did not significantly contribute to the equation were dropped.

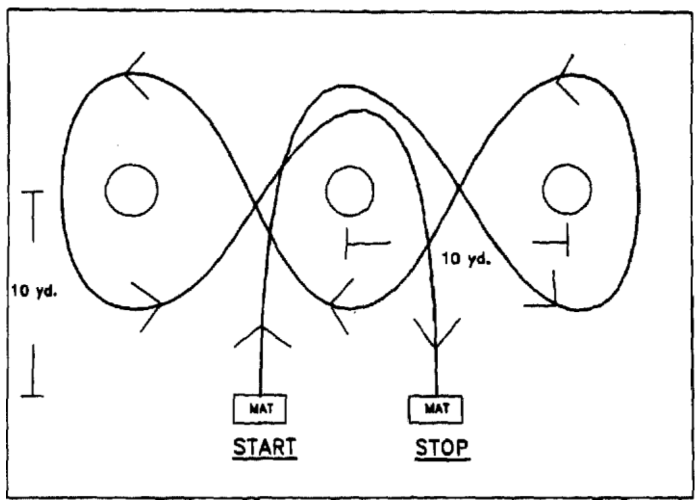

FIGURE 2: Agility run course.

RESULTS

Prediction of 40-yard Dash Time

In all instances, only one significantly correlated quadriceps or hamstring force contributed significantly to each prediction equation for 40-yard dash time. Forces that correlated significantly with 40-yard dash time and were used in the regression equations were right peak isokinetic concentric hamstring force at 60° / sec ($R = .57$, $p < 0.0002$); right average isokinetic concentric hamstring force at 60°/sec ($R = .55$, $p < 0.0003$); right peak isokinetic eccentric hamstring force at 30 Vsec ($R = .43$, $p < 0.008$); right average isokinetic eccentric hamstring force at 30°/sec ($R = .44$, $p < 0.006$); right peak isometric hamstring force at 30° knee flexion ($R = .40$, $p < 0.01$); left average isometric hamstring force at 30° knee flexion ($R = .40$, $p < 0.01$); and right isotonic hamstring force for 1 RM ($R = .43$, $p < 0.007$). Stepwise regression data for muscle forces used to predict 40- yard dash time are presented in Table 1. Regression equations for 40- yard dash time using the above force variables are presented in Table 2.

Prediction of Vertical Jump

There were no quadriceps or hamstring forces measured, either singly or in combination, that were predictive of vertical jump at a significance level of $p < 0.05$. Therefore, no regression equations were generated for vertical jump.

Prediction of Agility Run Time

As with prediction of dash time, there was never more than one significantly correlated quadriceps or hamstring force that contributed significantly to the regression equation for agility run time. Significantly correlated forces with agility run time were left peak isokinetic concentric hamstring force at 60°/sec ($R = .52$, $p < 0.0009$); right average isokinetic concentric hamstring force at 60°/sec ($R = .55, p < 0.0003$); left peak isokinetic eccentric hamstring force at 90°/sec ($R = .52$, $p < 0.0008$); left average isokinetic eccentric hamstring force at 90°/sec ($R = .58$, $p < 0.0001$); left peak isometric hamstring force at 30° knee flexion ($R = .50$, $p < 0.001$); left average isometric hamstring force at 30° knee flexion ($R = .50$, $p < 0.001$); and right isotonic quadriceps force for 1 RM ($R = .43$, $p < 0.007$). Stepwise regression data for muscle forces used to predict agility run time are presented in Table 3. Regression equations generated for agility run time are presented in Table 4.

DISCUSSION

Comparison of the present findings with other studies of muscle strength and performance is difficult because of the lack of consistency in testing speeds and subject testing positioning between studies. Furthermore, the assumption of equivalency between strength assessment modes performed on a KinCom® and other isokinetic devices or with other exercise apparatuses is not well-established in the research literature.

Previous research has been conducted regarding the relationships of muscle strength and athletic performance. However, most studies have looked at strength assessed isokinetic concentrically, isotonically, or isometrically, with little research comparing muscle strength assessed isokinetic eccentrically to athletic performance. Bennett and Stauber (4) looked at isokinetic concentric and eccentric quadriceps peak torque in subjects experiencing anterior knee pain resulting in functional disability. They noted a deficit in eccentric quadriceps torque in these subjects, which abated following rehabilitation with eccentric exercise, along with anterior knee pain and resultant functional disability. However, assessment of functional ability in these subjects was subjective, as was the noted improvement in function.

Variable	Multiple R	R^2	AdjR^2	F	SigF	Fchange	SigChange
RPCONH60	.57	.33	.31	17.32	0.000	17.32	0.000
RACONH60	.55	.30	.28	15.60	0.000	15.60	0.000
RPECCH30	.43	.18	.16	7.93	0.008	7.93	0.008
RAECCH30	.44	.19	.17	8.59	0.006	8.59	0.006
RPISOMH30	.40	.16	.14	7.01	0.012	7.01	0.012
LAISOMH30	.40	.16	.14	6.83	0.013	6.83	0.013
RISOTH	.43	.18	.16	8.14	0.007	8.14	0.007

RPCONH60 = right peak isokinetic concentric hamstring force at 60°/sec
RACONH60 = right average isokinetic concentric hamstring force at 60°/sec
RPECCH30 = right peak isokinetic eccentric hamstring force at 30°/sec
RAECCH30 = right average isokinetic eccentric hamstring force at 30°/sec
RPISOMH30 = right peak isometric hamstring force at 30° knee flexion
LAISOMH30 = left average isometric hamstring force at 30° knee flexion
RISOTH = right isotonic hamstring force for 1 rm

TABLE 1: *Stepwise regression data for muscle forces predicting 40-yard dash time.*

Force Measurement	Regression Equation	Standard Error
	DASH =	
Isokinetic concentric		
Peak force	−.25(RPCONH60) + 6.35	.27
Average force	−.33(RACONH60) + 6.29	.26
Isokinetic eccentric		
Peak force	−.14(RPECCH30) + 5.79	.28
Average force	−.21(RAECCH30) + 5.92	.28
Isometric		
Peak force	−.16(RPISOMH30) + 5.93	.29
Average force	−.16(LAISOMH30) + 5.79	.29
Isotonic	−.19(RISOTH) + 5.89	.28

RPCONH60 = right peak isokinetic concentric hamstring force at 60°/sec
RACONH60 = right average isokinetic concentric hamstring force at 60°/sec
RPECCH30 = right peak isokinetic eccentric hamstring force at 30°/sec
RAECCH30 = right average isokinetic eccentric hamstring force at 30°/sec
RPISOMH30 = right peak isometric hamstring force at 30° knee flexion
LAISOMH30 = left average isometric hamstring force at 30° knee flexion
RISOTH = right isotonic hamstring force for 1 rm

TABLE 2: *Regression equations for predicting 40-yard dash.*

Variable	Multiple *R*	R^2	AdjR^2	*F*	SigF	Fchange	SigChange
LPCONH60	.52	.28	.25	13.23	0.001	13.23	0.001
RACONH60	.55	.31	.29	15.79	0.000	15.79	0.000
LPECCH90	.52	.27	.25	13.46	0.001	13.46	0.001
LAECCH90	.58	.33	.32	18.08	0.000	18.08	0.000
LPISOMH30	.50	.25	.23	11.91	0.001	11.91	0.001
LAISOMH30	.50	.25	.23	12.13	0.001	12.13	0.001
RISOTQ	.43	.19	.16	8.22	0.007	8.22	0.007

LPCONH60 = left peak isokinetic concentric hamstring force at 60°/sec
RACONH60 = right average isokinetic concentric hamstring force at 60°/sec
LPECCH90 = left peak isokinetic eccentric hamstring force at 90°/sec
LAECCH90 = left average isokinetic eccentric hamstring force at 90°/sec
LPISOMH30 = left peak isometric hamstring force at 30° knee flexion
LAISOMH30 = left average isometric hamstring force at 30° knee flexion
RISOTQ = right isotonic quadriceps force for 1 rm

TABLE 3: *Stepwise regression data for muscle forces predicting agility run time.*

The present study indicated that specific hamstring forces were more predictive of 40-yard dash time and agility run time than variously measured quadriceps forces. Of the various hamstring forces, the peak isokinetic concentric hamstring force at 60°/sec was the most predictive (R2 = .33) of 40-yard dash time, while the average isokinetic eccentric hamstring force at 90°/sec was most predictive (R2 = .33) of agility run time.

It is probable that the eccentric hamstring force was more predictive of agility run time because of the necessity for rapid acceleration and deceleration of the body during the activity. This rapid alternating acceleration and deceleration of the body is not required for sprinting, so it is not surprising that eccentric hamstring force was not the best predictor of dash time. However, it is unclear as to why concentric hamstring force was a better predictor of dash time than quadriceps force.

The results of this study also indicated no significant correlations ($p < 0.05$) between any measure of quadriceps or hamstring strength and vertical jump. While this is in contrast to the findings of Considine and Sullivan (9), McClements (21), Wiklander and Lysholm (35), and Genuario and Dolgener (13), several other studies would appear to support these results. Smith (29) and Clarke (7) found no significant correlation between quadriceps and hamstring strength and vertical jump. In a study using highly trained, male volleyball players, Viitasalo (34) showed no significant correlations between maximum isometric knee extension strength and various vertical jumping measures. He suggested that, among highly trained athletes, the maximal static force of the knee extensors seemed not to be an important variable in explaining interindividual differences in vertical jumping. The same may be said of the results in the present investigation. However, in subjects who are not well-trained, strength may play a more important role.

Force Measurement	Regression Equation Agility =	Standard Error
Isokinetic concentric		
Peak force	−.44(LPCONH60) + 14.39	.55
Average force	−.69(RACONH60) + 14.65	.54
Isokinetic eccentric		
Peak force	−.35(LPECCH90) + 13.94	.55
Average force	−.52(LAECCH90) + 14.23	.53
Isometric		
Peak force	−.35(LPISOMH30) + 13.96	.56
Average force	−.42(LAISOMH30) + 13.95	.56
Isotonic	−.36(RISOTQ) + 13.85	.58

LPCONH60 = left peak isokinetic concentric hamstring force at 60°/sec
RACONH60 = right average isokinetic concentric hamstring force at 60°/sec
LPECCH90 = left peak isokinetic eccentric hamstring force at 90°/sec
LAECCH90 = left average isokinetic eccentric hamstring force at 90°/sec
LPISOMH30 = left peak isometric hamstring force at 30° knee flexion
LAISOMH30 = left average isometric hamstring force at 30° knee flexion
RISOTQ = right isotonic quadriceps force for 1 rm

TABLE 4: *Regression equations for predicting agility.*

Several studies have shown that by strengthening the extensor muscles of the hip and/or knee, performance in the vertical jump is significantly improved (3,30,33,35). However, it is obvious that other neuromuscular, anatomical, and performance factors besides quadriceps and/or hip extensor strength must be considered for prediction of performance in the vertical jump in the trained athlete.

One factor that may have influenced the relationship of quadriceps and hamstring force to the measures of performance in the present study as compared to previously cited studies was the testing position of the subjects for strength testing. In this study, subjects were positioned supine, with the test knee flexed to 90° for testing quadriceps strength. Subjects were positioned prone, with the knee to be tested in extension for evaluating the hamstrings. A more standard testing position for the quadriceps and hamstrings is with the subject seated with hips and knees flexed. Houtz (15) showed significant differences in peak torque production for both the quadriceps and hamstrings when the testing position changed from seated to supine with the knee flexed to prone with the knee extended. This was attributed to a change in the length-tension relationship of the biarticular muscles being tested as the position of the hip changed. However, in terms of relating hip and knee testing position to hip and knee functional position, the supine and prone testing positions more closely resemble the hip and knee position during function than the seated position, and it is a more logical way to evaluate muscle strength as it relates to function. This difference in subject positioning would perhaps explain some of the differences in results from previous studies.

SUMMARY

When comparing significant quadriceps and hamstring force variables taken from individual regression equations, one could not say eccentric forces were more predictive of 40-yard dash time than any of the other three modes of strength testing. However, it appears that of the forces measured, eccentric forces are the best predictors of agility run time. This does not imply that these prediction equations are a valid means of assessing performance. When one looks at the R2 adjusted for sample size (range for dash: .136—.306; for agility: .163—.316), it is apparent that while the correlations are significant at the $p < 0.05$ level, very little of the shared variance between muscle force and performance is explained by the regression equation.

CONCLUSION

Based on the results of this study, one must conclude that there is little, if any, functional relationship between the ability to generate quadriceps or hamstring force (as measured in this study) and the ability to run the 40-yard dash, vertically jump, or run the agility run.

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