

# A Multivariate Approach to Predicting Knee Extensor Performance

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## ABSTRACT

The impact of two predictor variables (estimated knee extensor fast-twitch fiber percentage, body mass) on performance measures (vertical jump power output, leg press peak angular velocity) were examined. Subjects (25 men, 27 women) performed 5 workouts involving 2 vertical jump, leg press, and 50-repetition isokinetic tests (to estimate knee extensor fast-twitch fiber percentage). Multivariate regression determined the following significant ( $p < 0.05$ ) vertical jump equations: predicted male power output =  $-59.3464 + 1.566$  (estimated knee extensor fast-twitch muscle fiber percent) +  $15.7884$  (body mass), predicted female power output =  $36.1574 + 3.4248$  (estimated knee extensor fast-twitch muscle fiber percent) +  $9.8633$  (body mass). Leg press peak angular velocity equations were insignificant by gender; thus, pooled data yielded the following: predicted leg press peak angular velocity =  $18.6187 + 0.235$  (estimated knee extensor fast-twitch muscle fiber percent) +  $0.3801$  (body mass). Body mass explained more variance for each performance measure.

**Key Words:** fast-twitch, vertical jump, inertial resistance, body mass

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## Introduction

Exercise performance is a multivariate task whose variance may be explained by several (physiological, anthropometric, etc) factors. The knee extensor (KE) muscle group typically has a major impact on exercise performance. Physiological factors in understanding KE performance include muscle fiber percentage and area. Biopsies are used to assess muscle fiber percentage and area; however, their extraction and analysis can be painful, expensive, and time consuming, making them unrealistic to administer to large numbers of people; yet the information they offer aids performance prediction. As an alternative to bi-

opsies, an isokinetic exercise protocol was developed to estimate KE fast-twitch (FT) fiber percentage (19). The protocol involves 50 maximal-effort KE repetitions to yield a fatigue product, derived from peak torques (PT) from the first and last 3 repetitions, to estimate FT fiber percentage. Because the isokinetic protocol estimates FT percentage from maximal exercise, it may be more valid in predicting high-intensity anaerobic KE performance than biopsies (19). The protocol does not take into account muscle fiber area, which may be a bigger determinant of KE PT output.

Anthropometric variables have also been used to explain exercise performance outcomes. Differences in anthropometry between genders may explain variations in exercise performance outcomes (4). Although they are often simple to measure, anthropometric variables, such as body mass, typically have a large impact on performance (10). Body mass has been shown as a good predictor of KE power output in men and women performing a 30-second anaerobic Wingate power test (11). Body mass was even shown to be a better predictor of power output than fat-free mass or thigh volume in active men performing cycle ergometry (14). However, in comparing KE performance tests, body mass has perhaps the biggest impact on jumping tests, which involve subjects moving vertically against overcoming gravitational resistance provided by their own body mass (5). Such tests have sport-specific applications to athletes required to move vertically.

Numerous performance tests have assessed the KE, primarily involving exercise against gravitational resistance. Recently an ergometer (YoYo Inertial Technologies, Stockholm, Sweden) employing inertial resistance has been devised to exercise the KE during seated leg press repetitions. Although the impact of predictor variables on performance against gravitational resistance has been studied, their ability to explain inertial resistance exercise performance is unknown. Understanding inertial exercise has important implications to athletics and general locomotor tasks

because to initiate movement inertia or resistance to movement must be overcome. Thus, the specific aim of the current study was to examine the relative contributions of 2 predictor variables (estimated FT fiber percentage, body mass) on 2 different KE performance tests (vertical jump, seated leg press peak angular velocity). The 2 performance tests examined are different in terms of the mode of resistance used (gravitational weight bearing vs. inertial nonweight bearing) and, because they are done in the current study, anaerobic metabolic pathways (alactate vs. lactate). Gender differences for each performance test was assessed because anthropometric differences have been noted in the vertical jump (4). In addition, the strength of association between initial PT and estimated FT fiber percentage, both determined from the 50-repetition isokinetic KE test, was assessed. A low correlation may suggest KE fiber area and may explain a greater portion of the variance associated with PT measurements.

## Methods

### *Experimental Approach to the Problem*

Subjects performed 5 workouts, separated by 5–7 days of rest. Preceded by weighing subjects, workouts began with a 5-minute stationary bicycle warm-up with 1 kilopond of resistance at 70 rpm. The first workout, consisting of a 50-repetition test to estimate KE FT percentage, familiarized subjects to the isokinetic exercise protocol. The test was done as described previously (19). The order of the final 4 workouts was randomized, consisting of two 50-repetition isokinetic KE and vertical jump tests or 2 seated leg press tests done on the inertial resistance ergometer. Because the first isokinetic KE test was done only to familiarize subjects with the dynamometer's operation, these data were not analyzed.

To establish test-retest reliability, data from the final 2 isokinetic tests and the vertical jump and leg press tests were analyzed using intraclass correlations. If the analyses yielded high intraclass values, those data were pooled to determine average values for each of the 3 tests. To address the specific aim of the current study, the relative contributions to each criterion measure (vertical jump, seated leg press peak angular velocity) provided by the independent variables (estimated KE FT fiber percentage, body mass) were determined with multivariate regression. Gender differences will be assessed initially, with significance resulting in different prediction equations by gender for a given performance test. Nonsignificant analyses by gender will then be reexamined by pooling male and female data. A Pearson product-moment correlation will assess the strength of association between PT from the first 3 repetitions and estimated KE FT fiber percentage, both determined from the isokinetic tests. An insignificant correlation suggests other factors,

such as muscle fiber cross-sectional area, and explains more of the variance associated with KE PT. Alpha values of 0.05 will establish significance for each statistical test.

### *Subjects*

Healthy, college-age volunteers (25 men, 27 women) with no current musculoskeletal injuries provided written consent to participate in a project approved by the local Human Subject Committee. General subject characteristics (mean  $\pm$  SEM) for men (age  $23.3 \pm 0.8$  years, body mass  $89.11 \pm 4.1$  kg) and women (age  $22.0 \pm 0.3$  years, body mass  $59.94 \pm 2.2$  kg) were collected prior to the first workout, with a greater range of body masses in men ( $143.33$ – $69.55$  kg) than women ( $90.45$ – $45.91$  kg).

### *Test Estimating KE FT Fiber Percentage*

Seated upright on an isokinetic dynamometer (System 3, Biodex Corp., Shirley, NY), subjects exercised their left quadriceps from  $90^\circ$  (lower leg perpendicular to femur) of knee flexion through  $0^\circ$  (full extension) of motion to estimate KE FT fiber percentage. For each subject, dynamometer dimensions were held constant across workouts so that the powerheads' shaft was aligned through the left knee's frontal axis of rotation. To eliminate extraneous body movement when measuring KE torque, Velcro strapping was placed across the pelvis and the left distal femur and tibia to secure the left limb to the dynamometer's attachment arm. Subjects kept their arm folded across their chest during testing. In the dynamometer's passive mode, 50 maximal-effort left leg KE repetitions were done at a constant angular velocity of  $3.14 \text{ rad}\cdot\text{s}^{-1}$  without subjects' pacing themselves. Subjects exerted no knee flexor torque as the dynamometer's attachment arm returned to the starting position. PT from the initial and final 3 repetitions were averaged and the difference was used to calculate FP. FT fiber percentage was estimated with the following equation:  $0.9 \times (\text{FP}) + 5.2 = \text{FT}\%$  (19).

### *Test Measuring Vertical Jump Peak Power Output*

Five minutes following the isokinetic KE test, subjects performed a series of standing vertical jumps. With 1 shoulder next to a wall, each subject held a piece of chalk in their hand closest to the wall and marked the wall with this shoulder in a position of terminal elevation. Without a running start, subjects flexed their knees and hips and then jumped as high as possible. With their shoulders completely flexed overhead and elbows extended at the highest point in the jump, subjects again marked the wall. Vertical displacement, measured in meters, was the distance between markings. Subjects performed 3–5 jumps per workout. Peak power output, measured in watts, was calculated using the following equation:  $61.9 \times \text{jump height (cm)} + 36.0 \times \text{body mass (kg)} + 1,822$  (5).

**Table 1.** Peak torque (PT) averaged from the first and final 3 repetitions to estimate knee extensor fast-twitch (KE FT) fiber percentage.\*

Subject's gender	PT: first 3 repetitions (N·m)	PT: final 3 repetitions (N·m)	Estimated KE FT %
M	361.48	176.13	51.39
M	246.6	81.68	65.38
M	262.9	76.67	68.96
M	221.43	82.9	61.25
M	208.32	52.32	72.45
M	249.5	76.12	67.45
M	256.82	103.35	59
M	214.83	70.45	65.91
M	298.07	87.78	68.36
M	377.83	182.13	51.73
M	299.98	112.3	60.8
M	267.33	116.12	55.18
M	294.83	92.15	67.05
M	219.45	90.05	58.44
M	268.75	122.7	54.16
M	177.37	74.57	57.4
M	310.18	112.4	62.58
M	356.33	137.73	60.2
M	320.45	142.06	55.3
M	275.86	120.18	55.9
M	345.21	128.22	61.77
M	255.32	114.02	55.01
M	224.67	109.35	51.4
M	319	126.87	59.41
M	281.15	100.23	63.11
F	165.98	74.21	54.96
F	178.23	64.61	62.6
F	175.16	35.38	77.02
F	112.13	58.78	48.02
F	108.6	64.71	41.6
F	123.65	66.21	47.1
F	141.25	41.52	68.74
F	116.58	63.54	46.17
F	135.69	65.36	51.85
F	155.47	64.53	57.84
F	151.08	50.48	67.82
F	162.8	71.54	55.69
F	213.07	90.97	56.81
F	122.92	44.93	62.27
F	112.73	43.48	60.46
F	170.1	70.95	57.59
F	115.67	42.3	62.29
F	189.15	122.68	36.64
F	153.82	60.25	60.01
F	138.05	68.62	50.66
F	135.35	61.9	54.04
F	106.78	53.38	50.44
F	121.47	60.18	50.6
F	87.78	44.45	49.58
F	92.13	39.5	56.61
F	94.9	38.9	58.31
F	127.77	65.87	48.76
<i>n</i> = 52, mean ± SEM	204.27 ± 11.36	83.03 ± 4.80	57.77 ± 1.08
Men	276.55 ± 10.40	107.54 ± 6.25	60.38 ± 1.18
Women	137.34 ± 6.06	60.34 ± 3.50	55.35 ± 1.66
<i>n</i> = 52, range	377.83–87.78	182.13–35.38	77.02–36.64
Men	377.83–177.37	182.13–52.32	72.45–51.39
Women	213.07–87.78	122.68–35.38	77.02–36.64

\* Data were averaged from second and third 50-repetition isokinetic workouts to determine mean ± SEM and range values for men (*n* = 25), women (*n* = 27), and total subject sample.

### Test Measuring Leg Press Peak Angular Velocity

Two workouts were done to determine peak angular velocity from 8 seated leg press repetitions. Following the warm-up, repetitions started with hips and knees flexed 130° and 100°, respectively, as subjects exerted maximal KE forces against inertial resistance. With a single flywheel marked with reflective tape, angular velocities resulting from KE forces overcoming inertial resistance were recorded with a light sensor and on-line software (MP100, Biopac Systems Incorporated, Santa Barbara, CA) at 10 Hz. From each 8-repetition workout, peak angular velocity in rad·s<sup>-1</sup> was determined. Greater peak angular velocities resulted in increased rates at which the cord rewrapped around the axle to return the footplate to the starting position to begin the next repetition. As the cord rewrapped around the axle, subjects exerted no eccentric KE forces to decelerate the footplates' return.

### Results

Intraclass correlations showed high estimated KE FT fiber percentage ( $r = 0.68$ ), vertical jump peak power ( $r = 0.99$ ), and seated leg press peak angular velocity ( $r = 0.81$ ) values. Intraclass correlation values appeared to vary inversely with exercise duration because shorter performance times (e.g., vertical jump) yielded higher values. Data for each test were averaged across workouts for multivariate regression analysis. PT from the first and last 3 repetitions, used to estimate KE FT fiber percentage, are provided for each subject (Table 1). PT values from the first 3 repetitions and estimated KE FT fiber percentage showed a non-significant ( $r = 0.267$ ,  $p > 0.05$ ) correlation.

Examining the effect of the two independent variables on vertical jump power output in women led in high  $F$  (18.52,  $p < 0.05$ ) and multiple  $R^2$  (0.6069) values resulting in the following prediction equation: female vertical jump power output' = 36.1574 + 3.4248 (estimated KE FT fiber %) + 9.8633 (body mass). Performing the same analysis in men, high  $F$  (79.55,  $p < 0.05$ ) and multiple  $R^2$  (0.8785) values yielded the following prediction equation: male vertical jump power output' = -59.3464 + 1.566 (estimated KE FT %) + 15.7894 (body mass). Because of higher slopes for body mass and low correlations between independent variables, it appears body mass explained more of the variance associated with vertical jump power output (7). In contrast, seated leg press peak angular velocity did not show statistical significance by gender using the 2 independent variables in multivariate analysis. Pooling male and female data, multivariate analysis predicting seated leg press peak angular velocity from the 2 criterion variables yielded high  $F$  (29.27,  $p < 0.05$ ) and multiple  $R^2$  (0.5444) values and the following equation: leg press peak angular velocity' = 18.6187 + 0.235 (estimated KE FT %) + 0.3801 (body mass). Through

a non-weight-bearing performance test, body mass still provided a greater relative contribution toward predicting leg press peak angular velocity on the basis of its greater slope and modest correlation between independent variables, although its impact appeared greater for the vertical jump (7).

### Discussion

Because so many factors impact anaerobic KE performance beyond those examined in this study, it is difficult to develop a single prediction equation to address this issue. Thus, more work in this area is needed. The 50-repetition isokinetic test estimated KE FT fiber percentage through exercise-induced fatigue and does not calculate fiber area (19). Table 1 values, obtained from a large sample of untrained subjects, shows a wide distribution of PT and estimated KE FT fiber percentages. The correlation between initial PT and estimated KE FT fiber percentage was insignificant, suggesting high PT values may not have yielded high KE FT fiber estimates. FT fiber area, which may have explained more of the variance associated with Table 1 PT values, can not be measured with the isokinetic test and is thus unaccounted for in the current study.

Anthropometric measures such as body mass were among the first predictor variables to explain exercise performance. Anaerobic power outputs from 30-second Wingate tests in 18 female and 19 male subjects showed thigh volume and body mass accounted for 74 and 71% of the variance for peak and mean power, respectively (11). Adding lean body mass as a third predictor variable increased the explained variation in peak and mean power only 5% (11). Examining 4 anaerobic power tests in untrained men and women showed anthropometric measures exerted a relatively large influence on performance (10). Removing anthropometric measures greatly reduced but did not remove significant differences in power output between genders (10). Isometric muscle strength in 100 young men showed a greater proportion of the explained variance was attributed to body mass rather than height (4). Comparing the effects of two predictor variables (vastus lateralis fiber composition, body mass) on performance (maximal power production, maintenance of power) measured during cycle ergometry were studied in 18 untrained but physically active men (14). Unlike the current investigation, muscle fiber percentage was determined with biopsies rather than an exercise test estimating FT percentage. No significant correlations were found for FT percentage or relative fiber area for the 2 performance measures; however, body mass was significantly correlated to maximal power production ( $r = 0.54$ ) and power maintenance at 55 ( $r = -0.47$ ) and 73% ( $r = -0.49$ ) of maximal power output (14). Results showed anaerobic KE performance to

be more dependent on body mass rather than muscle fiber characteristics, in agreement with current study results (14).

Prior work claims muscle fiber percentage explains a small amount of the variance associated with performance (3, 14). Muscle fibers are normally recruited at speed and load conditions that allow maximal power development (2). Type IIb vastus lateralis fiber percentage is both strongly correlated to isometric KE strength ( $r = 0.72$ ) and inversely related to citrate synthetase activity ( $r = -0.78$ ) resulting from an anaerobic running protocol (8, 9). Examining peak torque at  $3.14 \text{ rad}\cdot\text{s}^{-1}$ , strong correlations in absolute type II (a + b) fiber area ( $r = 0.91$ ) and IIa fiber area corrected for cross-sectional area ( $r = 0.66$ ) occurred in 5 male sprinters and marathon runners (6). Conversely, examining KE peak torque at  $4.86 \text{ rad}\cdot\text{s}^{-1}$  in 12 men and 18 women showed no significant relationships for either the percentage or relative area of FT fibers (3). Similarly, maximal power production and power maintenance with cycle ergometry in 18 men was also poorly related to both the percentage and relative area of FT fibers (14). Results suggest FT fibers may explain more of the variance associated with strength rather than power test outcomes (3, 6, 8, 14). In addition, training experience may also explain differences in study results because the Johansson study used highly trained male athletes (6).

Six weeks of Wingate (30-second) training failed to change vastus lateralis fiber type percentages (1). Following training, 11 subjects receiving the exercise treatment showed no changes in muscle fiber distribution or aerobic and anaerobic KE performance vs. 6 control subjects. Though the exercise protocol did not change fiber percentages, the vastus lateralis incurred significant IIa increases and IIb decreases in myosin heavy chain content (1). In contrast, after 6–8 weeks of strength training, significant IIb  $\rightarrow$  IIa shifts occurred to the vastus lateralis, but detraining reversed this shift (17, 18). Differences in changes to vastus lateralis FT fiber results between the two studies may have resulted from the greater training volume and mechanical loading done while strength training (17, 18). Increased training volume and mechanical loading with cycle ergometry may have led to similar FT fiber changes observed with strength training as well as KE performance gains (1, 17, 18). Though the current investigation estimated KE FT percentages through an exercise test rather than a muscle biopsy, it explained a small amount of the variance associated with anaerobic KE performance, in agreement with prior studies (1, 3, 14).

Isokinetic tests, like that used in the current study, have assessed KE performance. A 60-second isokinetic KE protocol correlated significantly with a 30-second Wingate cycle ergometer test (13). Using 15 male subjects and comparing peak and mean values for power

and torque between the 2 tests showed significant ( $r = 0.52\text{--}0.76$ ) correlations. It was concluded the isokinetic protocol represents a valid laboratory test for evaluating intense anaerobic KE performance (13). Examining factors related to maximal and maintenance of KE power output, an isokinetic KE protocol like that used in the current study elicited peak and mean power outputs of  $458 \pm 102$  and  $295 \pm 51$  W, respectively, in 18 untrained men (14). Using maximal power as a performance measure, nonsignificant relationships were seen with both percentage of FT fibers and area; however, combining body mass and FT fiber percentage in a multivariate analysis resulted in a significant ( $r = 0.55$ ) correlation (14). Such results are similar to the current study, in which the variance of 2 KE performance tests could be explained by examining body mass and FT fiber percentage, with body mass addressing more of the variance for each criterion variable.

Analysis of current study vertical jump data resulted in separate significant prediction equations by gender. Other studies have shown gender differences for performance factors used in anaerobic KE power tests. Examining anaerobic arm and leg peak and mean power values in adolescent male and female athletes showed greater male power outputs even after normalizing for mass and cross-sectional area differences (12). Results suggest factors aside from anthropometry contribute to gender differences in power production in adolescent athletes (12). Such results are in contrast with other studies comparing factors leading to power production in males and females (10, 11). Differences between studies may result from the subjects sampled because the latter investigations examined untrained subjects (10–12). Current study results appear more like those of Mayhew and Salm (10) and Murphy et al. (11) because both used untrained subjects and suggest body mass is a greater predictor of anaerobic KE power performance.

Unlike the vertical jump, analysis of seated leg press peak angular velocity using the 2 independent variables did not result in significant prediction equations for each gender. Prior work examining KE performance shows no differences in perceived exertion or median frequency by gender during seated isokinetic exercise (15, 16). Non-weight-bearing exercise, such as the seated leg press in the current study and the aforementioned investigation (15, 16), may contribute to nonsignificant gender differences. In contrast, current study vertical jump data, which involved a heterogeneous body mass sample ( $n = 52$ , range 143.33–45.91 kg) likely contributed to significant prediction equations by gender. Pooling male and female seated leg press data likely led to a significant prediction equation through increased sample size. The leg press multiple  $R^2$  value (0.5444) suggests other independent variables contributed to the variance of this

criterion measure. Future investigations should examine the contribution of fiber area and anthropometric variables such as leg length toward predicting inertial seated leg press performance. Beta values for the 2 independent variables were comparable in the leg press prediction equation, suggesting during non-weight-bearing KE performance, body mass explained a smaller amount of the variance vs. the vertical jump. Male vertical jump data show larger beta and  $R^2$  vertical values. Factors such as torso length and/or KE fiber cross-sectional area could thus address the greater relative unexplained variance in female vertical jump performance (4). In summary, in comparing the relative contributions of two independent variables towards predicting anaerobic KE performance in untrained healthy college-age subjects, body mass, an anthropometric variable, explained a greater portion of the variance during an exercise performance test designed to estimate KE FT percentage.

### Practical Applications

Body mass is an anthropometric measure that explains a large amount of the variance associated with intense anaerobic KE performance. Although muscle fiber percentage may help explain KE performance in elite athletes (6), current study results in an untrained sample seem to indicate otherwise. The isokinetic test requires subjects to provide maximal effort throughout the 50-repetition test to offer the most accurate estimate of KE FT fiber percentage. The test takes approximately 100 seconds to complete. Providing maximal effort for this duration in untrained subjects is likely why this test yielded the lowest intraclass correlation value (0.68) of the 3 tests examined. A weakness to the isokinetic test is that it provides no indication of KE fiber area, which could address more of the unexplained variance in the current investigation. Future work combining estimated KE FT fiber percentage and body mass data in motivated athletes may explain more of the variance associated with anaerobic KE performance.

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