Journal of Strength and Conditioning Research, 2005, 19(2), 349–357

STRENGTH AND POWER PREDICTORS OF SPORTS SPEED

JOHN B. CRONIN[1] **AND KEIR T. HANSEN**[2]

[1]New Zealand Institute of Sport and Recreation Research, Auckland University of Technology, Private Bag 92006, Auckland, New Zealand; [2]New Zealand Warriors Rugby League Club, Penrose, Auckland, New Zealand.

ABSTRACT. Cronin, J.B., and K.T. Hansen. Strength and power predictors of sports speed. *J. Strength Cond. Res. 19(2):349–357. 2005.*— For many sporting activities, initial speed rather than maximal speed would be considered of greater importance to successful performance. The purpose of this study was to identify the relationship between strength and power and measures of first-step quickness (5-m time), acceleration (10-m time), and maximal speed (30-m time). The maximal strength (3 repetition maximum [3RM]), power (30-kg jump squat, countermovement, and drop jumps), isokinetic strength measures (hamstring and quadriceps peak torques and ratios at 60°·s^{-1} and 300°·s^{-1}) and 5-m, 10-m, and 30-m sprint times of 26 part-time and full-time professional rugby league players (age 23.2 ± 3.3 years) were measured. To examine the importance of the strength and power measures on sprint performance, a correlational approach and a comparison between means of the fastest and slowest players was used. The correlations between the 3RM, drop jump, isokinetic strength measures, and the 3 measures of sport speed were nonsignificant. Correlations between the jump squat (height and relative power output) and countermovement jump height and the 3 speed measures were significant ($r = -0.43$ to $-0.66, p < 0.05$). The squat and countermovement jump heights as well as squat jump relative power output were the only variables found to be significantly greater in the fast players. It was suggested that improving the power to weight ratio as well as plyometric training involving countermovement and loaded jump-squat training may be more effective for enhancing sport speed in elite players.

KEY WORDS. isokinetic, isoinertial, hamstrings, quadriceps

INTRODUCTION

For many sporting activities, such as tennis, squash, and basketball, the athletes never attain maximum speed during sprinting, thus, the speed over the first steps (first-step quickness) and the ability to rapidly increase velocity (acceleration) would be considered of greater importance to successful performance. It has also been suggested that the acceleration phase is much shorter for these athletes as compared with top track sprinters (5). Achieving maximum speed earlier or possessing greater acceleration has obvious advantages in many sports. It has also been suggested that the running style of team-sport athletes differs from that of track athletes, the team-sport athlete running with a relatively lower center of gravity, less knee flexion during recovery, and lower knee lift (32). Thus, the predictors of sport speed could quite conceivably be different from 100-m track speed. It is also conceivable that the predictors of first-step quickness, acceleration, and maximal speed may differ.

Typically a correlational approach using isokinetic or isoinertial dynamometry has been used to elucidate the relationship between strength/power measures and sprint performance. Isokinetic assessment involves the measurement of force/torque and/or power through a range of motion with constant angular velocity. Normally, isokinetic assessment uses assessment velocities of 30–240°·s^{-1} and has been performed on college-aged subjects (3, 10) or track athletes (2, 16) and then related to 40–100-m velocities or times. Very few studies have used sports people and investigated the predictors of sprint performance over short distances (8, 11). The results of literature relating isokinetic assessment (usually at the knee or the hip) and sprint performance have been mixed and, for the most part, nonsignificant to moderate correlations ($r = -0.52$ to -0.69) have been reported (2, 3, 8, 10, 11).

The term isoinertial (constant gravitational load) describes motion involving changes in tension, length, and velocity while the load remains constant (1). In terms of isoinertial research, most correlational studies have used weight-training movements such as the squat or power clean (4–6, 19, 27) or various types of jumps (6, 14, 20–22, 26, 33) and investigated the relationship of these movements to sprint performance. The jumps have been further divided into slow and fast stretch-shorten cycle (SSC) performance, the countermovement jump a measure of slow (>250 millisecond) SSC performance and the drop jump a measure of fast (<250 millisecond) SSC performance (14, 25, 30). This type of research usually results in stronger correlations ($r = -0.60$ to -0.79) as compared with the isokinetic research previously reported. Some researchers have used instrumented Smith machines to study the relationship between movement (isometric, concentric, eccentric, and stretch-shorten cycle), measures (impulse, force in 100 milliseconds, etc.) and sprint performance (26, 33). This type of approach has resulted in the best single predictors ($r = -0.80$ to -0.86) of sprint performance.

For those strength and conditioning specialists working with sports men and women, understanding and developing sports speed would seem essential, given the importance of first-step quickness and acceleration to many sports. However, much of the research in this area has been concerned with track speed rather than sport speed and has used either students or track athletes. Most research has used an isokinetic or isoinertial approach in determining important predictors of speed. However, a combined approach may result in a better understanding of the discriminative ability of these 2 modes of contraction and their importance in assessing and/or developing sport speed. Furthermore, our understanding of the exercises that we think important for the development of sport speed is rudimentary. For example, if the squat were important to speed conditioning, then it would be expected that squat strength would be strongly related to first-step quickness, acceleration, and/or maximal speed. In addition, it might be expected that the measures of slow SSC are more important in the initial phases of sprinting, where ground-contact phases are longer and measures of fast SSC during the maximal speed phase. Such an analysis may offer greater insight into the underlying determinants of sport speed and as a result improve strength and conditioning practice in terms of assessment and exercise prescription. The purpose of this study, therefore, was to identify the relationship between certain strength and power exercises and measures of first-step quickness, acceleration, and maximal speed of professional sportsmen.

METHODS

Approach to the Problem and Experimental Design

To determine the relationship between strength and power and the measures of speed, various isoinertial and isokinetic strength and power measures were assessed. These included maximal strength (3 repetition max [3RM]), power (30-kg jump squat, countermovement, and drop jumps), and isokinetic strength measures (hamstring and quadriceps peak torques and ratios at $60°\cdot s^{-1}$ and $300°\cdot s^{-1}$). Correlations and a comparison of these variables between the fastest and slowest players were used to examine the relationship between these strength/power variables and measures of first-step quickness, acceleration, and maximal speed.

Subjects

Twenty-six males volunteered to participate in this research. The subjects' mean (± *SD*) age, mass, and height were 23.2 ± 3.3 years, 97.8 ± 11.8 kg, 183.1 ± 5.9 cm, respectively. All of the subjects were either part-time or full-time professional rugby-league players. Subjects provided written consent for testing as part of their contractual arrangements with the New Zealand Warriors. Subjects were informed that they could withdraw from the study at any time without prejudice.

Equipment

Isoinertial Strength and Power. Subjects performed their 3RM squat and loaded countermovement jump assessments using a plate-loaded Olympic Barbell (Elieko, Sweden). The countermovement jumps and drop jumps were performed using the Kinematic Measurement System (KMS; Optimal Kinetics, Muncie, IN). The KMS consisted of a portable contact mat connected to a laptop computer via a 4-way data cable. The system calculated jump height (cm), flight time (millisecond), ground-contact time (milliseconds), and absolute power output using customized software.

Isokinetic Strength. A Biodex System II Isokinetic Dynamometer (Biodex Medical Systems Inc, New York) was used to assess the hamstring and quadriceps strength of the subjects. Prior to the start of each testing session, the dynamometer was statically calibrated with a 36.1-N weight at terminal extension (horizontal) in accordance with the manufacturer's recommendations. This system was used to measure the hamstring and quadriceps torque at 2 different velocities (60 and $300°\cdot s^{-1}$).

Sprint Equipment. Sprint times over 5, 10, and 30 m were also measured using the KMS. The KMS timing light system was a single-beam modulated visible red-light system with polarizing filters and consisted of 4 sets of gates. The "start of longest on function" in the KMS software was utilized, therefore, the timing of the sprint was initiated at the longest break of the infrared beam. This controlled for the beam being broken more than once by the athlete at the beginning of the sprint and therefore negated the need for a double-beam system.

Procedures

The assessment procedures outlined below occurred over the course of 5 days, in a testing week at the end of off-season training prior to the start of the regular season. All subjects had undertaken a 12-week periodized strength-training program involving upper and lower limb lifting, 3–4 times per week, prior to testing. The sprint followed by the isoinertial assessments were performed on day 1, the isokinetic assessment on days 3–5.

Isoinertial Strength Assessment. Procedures for 3RM testing were similar to those described by Baker and Nance (5). The athlete performed a general warm-up followed by static stretching. They then performed 4–5 submaximal sets of 3–5 repetitions, gradually building toward an estimated 3RM load. They then attempted 3 repetitions at the estimated load. Following each successful 3RM attempt, the load was increased in 5-kg increments until the maximum lift was achieved. The 3RM parallel squat was used as a measure of maximum strength. The high bar position was used for all 3RM squat testing. Squat depth was visually assessed by the same investigator for all testing, with the athlete being required to descend to a depth where a line between the lateral epicondyle of the femur and the greater trochanter was approximately parallel to the floor. The athlete was given an oral signal once they had reached the appropriate depth.

Isoinertial Power Assessment. Jump Squat (JS). The bar, loaded with 30 kg, was also placed in the high bar position during jump-squat testing. The jumper started with both feet on the contact mat with their hands holding the bar in position just wider than shoulder width. Each athlete was instructed to sink (approximately 120° knee angle) as quickly as possible and then jump as high as possible in the ensuing concentric phase. To improve the reliability of the data, it was recommended that, at take off, the subject leave the mat with the knees and ankles extended and land in a similarly extended position (28).

Countermovement Jump (CMJ). The jumpers started with both feet on the contact mat with their palms on their hips. They were instructed to sink (approximately 120° knee angle) as quickly as possible and then jump as high as possible in the ensuing concentric phase. It was also recommended that, at take off, the subject leave the mat with the knees and ankles extended and land in a similarly extended position (28).

Drop Jump (DJ). The participant stepped from a 40-cm box and, immediately upon landing on the contact mat, jumped as high as possible. Instructions were to jump for maximum height and to minimize the contact times. Feedback to the athlete as to their height and contact time was given after each jump (28, 29). Three trials were performed for all the jumps and the best 2 were averaged and used for analysis.

Isokinetic Assessment

The back of the Biodex chair was slightly reclined so that the subject was sitting with a hip angle of 110°. The axis of rotation of the power head was aligned with the lateral femoral condyle and the lower limb was secured so that the bottom of the lever arm pad was immediately superior to the medial malleolus. All subject position variables were recorded so that they could be held constant for the other limb. Each subject was secured to the apparatus in accordance with the Biodex operation manual via a strap about the waist, 2 straps across the shoulders (crossing at the chest), and 1 across the thigh. These restraints were tightened so that they were firm but not uncomfortable. During the test, the subject was instructed to hold the chest straps and not the handles.

Once secured in the chair, the computer set-up procedure was commenced. The range of motion was set at 90° with terminal extension being 0°. To correct for gravity, the subject's limb was weighed in a relaxed state at terminal extension (0°). The torque exerted on the dynamometer in this position was used to correct for gravity by adding the angle-equivalent torque to knee extension and subtracting it from knee flexion. The cushion was set to hard to reduce the effects of limb deceleration at the ends of the range of motion and sensitivity was set to C (medium) in accordance with manufacturer's recommendations for knee flexion and knee extension (Biodex Medical Systems Inc.).

To familiarize the subjects with the device and the testing velocities, subjects performed 5–10 graded submaximal knee flexion and extension repetitions followed by 2–3 maximal repetitions. After a short rest period, 5 maximal knee flexion and extension (9) reciprocal movements at an angular velocity of $60° \cdot s^{-1}$ were performed. The subject was instructed to push as hard and fast as possible and move through as much of the preset range of motion as they could. During the test, the subject was given standardized verbal encouragement from the tester and was able to see the computer screen (the movement trace) for visual feedback.

The subject remained in the chair but the straps were loosened as the subject rested for 3 minutes. The movement velocity was increased to $300° \cdot s^{-1}$ and subjects were given a chance to familiarize to the new speed, after which they completed 10 test repetitions. Subjects were released from the restraints and permitted to walk around for 5 minutes prior to the other leg being tested. The opposite leg was tested using an identical protocol. The order that the legs were tested in was randomized. The data were windowed at 95%. This means that any data not obtained at the preset isokinetic speed or at 95% of that speed was not reported.

Sprint Assessment

Timing lights were placed at the start, 5 m (first-step quickness), 10 m (acceleration), and 30 m (speed) in order to collect sprint times over the 3 distances. All athletes performed a thorough warm-up as part of their training routine. This included jogging, ball-skill drills, static stretching, and submaximal sprints. The starting position was standardized for all subjects. Athletes started in a 2-point crouched position with the left toe approximately 30 cm back from the starting line and the right toe approximately in line with the heel of the left foot. All subjects wore rubber-soled track shoes.

Data Analysis

The load that each subject could lift for a maximum of 3 repetitions was used as an indication of maximal strength. CMJ height was determined by the flight time from the contact mat according to the formula of Young (28),

$$\text{jump height (cm)} = g \times t^2/8,$$

where g = acceleration due to gravity ($9.81\ ms^{-2}$) and t = flight time of the jump (seconds).

The mean power output for the jump squat was predicted according to the equation of Harman (12). In order to calculate power output during the loaded jump squat, the following modification was made to the same formula,

$$\begin{aligned}\text{average power (W)} = {} & 21.1 \times \text{jump weight (cm)} \times 23.0 \\ & \times [\text{body weight (kg)} + 30\ \text{kg}] \\ & - 1{,}393.\end{aligned}$$

The reactivity coefficient was determined according to the formula of Komi (17),

$$\begin{aligned}\text{reactivity coefficient} = {} & \text{drop-jump height (cm)} \\ & \div \text{contact time (seconds)}.\end{aligned}$$

Statistical Analyses

Pearson correlation coefficients were used to determine the interrelationships among strength, power, and sprint variables. The variables for inclusion were the isoinertial maximal strength (3RM), isoinertial power (loaded jump squat, countermovement, and drop jumps), isokinetic measures (hamstring and quadriceps peak torques $60° \cdot s^{-1}$ and $300° \cdot s^{-1}$), and sprint measures (5-, 10-, and 30-m times). To examine the importance of the strength and power measures on sprint performance, the 13 subjects with the fastest 5-m times (0.906 ± 0.024 seconds) and 13 subjects with the slowest 5-m times (0.984 ± 0.037) were compared using independent sample t-tests. A 0.05 level of significance was adopted for all statistical models.

RESULTS

The interrelationship between strength variables can be observed in Table 1. Maximal squat strength (3RM) was not significantly related to any of the jump measures, but a relationship can be observed between squat strength and the hamstring torques at both speeds (r = 0.64–0.71) and quadriceps torque at $300° \cdot s^{-1}$ (r = 0.69). When squat strength was expressed relative to each subject's mass, the relative strength was not significantly related to any power or speed variable. In terms of the relationship between the 3 jumps, the jump squat, countermovement, and drop-jump heights, and reactivity coefficients, appear significantly interrelated (r = 0.69 to 0.73). However, from the coefficients of determination (R^2 = 47.6–53.2%), it appears that there is a great deal of unexplained variance between the tests. The only isoinertial power measure to be significantly related to the isokinetic measures was jump-squat power. This measure was not significantly related to any other isoinertial strength or power measure. With regards to the interrelationship between

TABLE 1. Intercorrelation matrix between strength, power, and speed measures.*

	3RM	SJHt	SJPo	CMJ	DRC	Q60	H60	Q300	H300	SJRel	Sp5	Sp10	Sp30
3RM	1.00												
SJHt	0.16	1.00											
SJPo	0.42	0.07	1.00										
CMJ	0.14	0.73†	0.01	1.00									
DRC	−0.18	0.69†	−0.35	0.71†	1.00								
Q60	0.12	0.19	0.48†	0.25	−0.05	1.00							
H60	0.71†	0.05	0.64†	0.11	−0.07	0.73†	1.00						
Q300	0.69†	0.13	0.66†	0.16	−0.27	0.73†	0.73†	1.00					
H300	0.64†	0.00	0.35	−0.21	−0.29	0.58†	0.73†	0.64†	1.00				
SJRel	0.15	0.91†	0.16	0.66†	0.66†	0.29	0.22	0.21	0.07	1.00			
SP5	−0.05	−0.64†	−0.13	−0.60†	−0.35	−0.34	−0.19	−0.04	−0.13	−0.55†	1.00		
Sp10	−0.01	−0.66†	−0.11	−0.62†	−0.38	−0.31	−0.15	−0.00	−0.09	−0.54†	0.92†	1.00	
Sp30	−0.29	−0.56†	0.15	−0.56†	−0.34	−0.17	−0.07	−0.07	0.05	−0.43†	0.73†	0.78†	1.00

* 3RM = maximal strength of squat; SJHt = height from 30-kg jump squat; SJPo = average power output from 30-kg jump squat; CMJ = countermovement jump height; DRC = drop jump reactivity coefficient; Q60 = quadricep peak torque at $60 \cdot \text{deg} \cdot \text{s}^{-1}$; H60 = hamstring peak torque at $60 \cdot \text{deg} \cdot \text{s}^{-1}$; R60 = hamstring/quadricep ratio at $60 \cdot \text{deg} \cdot \text{s}^{-1}$; Q300 = quadricep peak torque at $300 \cdot \text{deg} \cdot \text{s}^{-1}$; H300 = hamstring peak torque at $300 \cdot \text{deg} \cdot \text{s}^{-1}$; R300 = hamstring/quadricep ratio at $300 \cdot \text{deg} \cdot \text{s}^{-1}$; SJRel = average power output from 30-kg jump squat/body mass.

† Denotes significance at $p < 0.05$.

isokinetic measures, all measures were moderately correlated with each other ($r = 0.58$–0.73). However, the coefficients of determination indicate, once more, a great deal of unexplained variance (46.8–66.4%) between the different measures.

The relationship between speed measures can also be observed from Table 1. The strongest relationship ($r = 0.92$) was between the measures of first-step quickness and acceleration. The relationship between first-step quickness and maximal speed is weaker. That is, first-step quickness (5-m time) accounts for less than 53% of the explained variance associated with maximal speed (30-m time).

The strength and power measures significantly related to 5-, 10-, and 30-m sprint performance are also detailed in Table 1. For all 3 distances, the same 3 variables were significant predictors of sprint performance. Jump-squat and countermovement jump heights were the best correlates ($r = -0.56$ to -0.66) of sprint performance over the 3 distances. However, these measures only accounted for 30.8–43.9% of the common variance associated with sprint performance. No isokinetic measure was significantly related to 5-m time ($r = -0.04$ to -0.34), 10-m time ($r = -0.00$ to -0.31), and 30-m time ($r = -0.05$ to -0.17).

The values for each of the variables for the fast and slow groups can be observed in Table 2. A similar procedure was used to determine if the results differed if ranked according to 10-m and 30-m times. All results were similar to the 5-m rankings, with any change in ranking having no effect on the outcome statistic. Only 3 variables were significantly different between the fast and slow groups, the loaded squat-jump and countermovement-jump heights and the relative power output from the loaded jump squat. The other variables could not discriminate between fast and slow sprinters.

DISCUSSION

The measure of maximal leg strength (squat 3RM) was only significantly related to the isokinetic measures and not any other isoinertial power (jumps) or speed measure. It might be assumed, because the movement patterns are similar between the squat and the jumps, that a significant relationship may exist between the measures. This was not the case, the 2 tests having very little common variance and, for the most part, assessing different strength qualities. This supports the contention that strength and power indices are not the same (1) and should be measured separately.

The relationship between 3RM strength and the 3 speed measures was also found to be nonsignificant ($r = -0.01$ to -0.29). Baker and Nance (5) found no significant

TABLE 2. Differences between the fastest and slowest players based on 5-m rankings.

Variable	Fast	Slow	T-test	p-value
Speed 5 m (s)	0.906	0.984	−6.28	0.000
Speed 10 m (s)	1.600	1.696	−4.86	0.000
Speed 30 m (s)	3.859	4.126	−3.55	0.002
Squat 3RM (kg)	190	169	1.64	0.117
Countermovement jump height (cm)	46.5	36.9	4.75	0.000
Squat jump height (cm)	31.2	25.6	3.10	0.006
Squat jump power output (Watts)	2227	2144	0.93	0.362
Squat jump relative power output (Watts/kg)	22.4	21.4	2.08	0.050
Drop jump reactivity co-efficient	180	158	1.37	0.183
Quadriceps 60 $\text{deg} \cdot \text{s}^{-1}$ ($\text{N} \cdot \text{m}^{-1}$)	324	294	1.44	0.172
Hamstrings 60 $\text{deg} \cdot \text{s}^{-1}$ ($\text{N} \cdot \text{m}^{-1}$)	172	166	0.77	0.454
Quadriceps 300 $\text{deg} \cdot \text{s}^{-1}$ ($\text{N} \cdot \text{m}^{-1}$)	180	168	1.15	0.268
Hamstrings 300 $\text{deg} \cdot \text{s}^{-1}$ ($\text{N} \cdot \text{m}^{-1}$)	127	126	0.08	0.937

relationships between a 3RM squat and 10-m ($r = -0.06$) and 40-m ($r = -0.19$) sprint performance of professional rugby-league players. This is also similar to the findings of Costill et al. (6), who studied the relationship of various strength power measures to 40-yard dash performance using college football players. Squat strength was among the lowest ($r = 0.20$) correlations reported in this study. A nonsignificant ($r = 0.3$) relationship between squat (1RM) and 40-m sprint performance was also reported by Wilson et al. (27).

Baker and Nance (5) found that none of their absolute strength and power measures were correlated significantly to 10-m and 40-m sprint performances for professional rugby-league players. However, when the measures were expressed relative to body mass, the squat, power clean, and jump-squat measures were found to correlate ($r = -0.66$ to -0.76) to sprint performance. Similarly, the relative squat strength (1RM/body mass) for 20 female track athletes and 10 recreationally trained females was found to correlate highly ($r = -0.88$) with 100-m sprint times (19). When squat strength was expressed relative to each subject's mass in this study, the relative strength was not significantly related to any power or speed variable. It would seem that the 3RM as a strength measure has very little to offer in terms of explaining the variance associated with sprint performance of this sample. This could be due in part to traditional (nonprojection) exercises such as the 3RM squat having different velocity/acceleration profiles from sprint-type motion. In terms of movement pattern specificity, assessment that is ballistic in nature and allows projection of oneself or a bar (e.g., drop jumps, jump squats, etc.) have acceleration/deceleration profiles that more closely simulate the movement profiles of athletic activity (23). This would explain the stronger relationships between power assessment of this type and sprint performance (see Table 1).

It is thought that the countermovement jump is a measure of slow (>250 millisecond) stretch-shorten cycle (SSC) performance and the drop jump a measure of fast (<250 millisecond) SSC performance (14, 25, 30). In terms of the interrelationship between jump measures ($r = 0.69–0.73$) and the associated coefficients of determination ($R^2 = 47.6–53.2\%$), there appears a great deal of unexplained variance between the tests, suggesting that the different jumps to some degree measure different explosive leg-power qualities, such as slow and fast SSC performance.

Interestingly, it was the measures of slow SSC performance (countermovement and loaded jump squats) that resulted in the highest correlations ($r = -0.43$ to -0.64) with sprint performance (see Table 1). Costill et al. (6) found the vertical jump to have the highest correlations ($r = -0.63$) with 40-yard sprint performance. Similar correlation coefficients between squat jump ($r = -0.68$), countermovement jump ($r = -0.65$), and 30-m maximal running velocity of 25 male sprinters have been reported previously (21). Furthermore, countermovement jumps ($r = -0.60$ to -0.64) were significantly related to the 30- and 100-m times of 17 female college sprinters (14). Young et al. (31) found the countermovement jump of 18 football players to be significantly related ($r = -0.66$) to their 20-m sprint times. The magnitude of the correlations in all these studies, including the present investigation, is surprisingly similar despite the variation in the population sampled and the distance of the sprint tests.

The jump height (28.6 ± 1.8 cm) associated with 30-kg jump squats for the players of this study was greater than those reported by McBride et al. (18) for power lifters (15.6 ± 1.4 cm), Olympic lifters (18.9 ± 1.7 cm), sprinters (23.9 ± 1.6 cm), and controls (18.7 ± 1.4 cm). This difference may be attributed to subject experience with the jump-squat movement and/or subject characteristics, the rugby-league players of this study were on average heavier and taller than the subjects of McBride et al. (18). Comparison of power outputs between research is problematic as McBride et al. (18) used peak power outputs for analysis and Baker and Nance (5) used different absolute loads from that of this study.

The relationship between the 30-kg jump squats and other strength/power measures is interesting. Jump-squat height was significantly related to countermovement jump ($r = 0.73$) and drop-jump performance ($r = 0.69$) and the power outputs associated with this movement significantly related to 3 of the 4 isokinetic strength measures (see Table 1). That is, the calculated power output associated with the jump squat has greater common variance with the isokinetic peak-torque measures than the jump height associated with the same movement. It would seem that similar measures/constructs (e.g., jump heights, kinetic measures—peak torque, power output, etc.) are more likely to significantly correlate to each other independent of the movement. This has important implications for correlational research in that nonsignificant relationships between movements may be reported, when actually it is the measure and not the movement that are unrelated. Careful choice of measures as well as movements are needed if assessment and training protocols are to be advanced through the use of correlational research.

The relationships between jump-squat height and power output and the 3 measures of sprint performance were found to be significant ($r = -0.43$ to -0.63). Baker and Nance (5) found no significant relationships between 10- and 40-m sprint performance and jump-squat power output at absolute loads of 40, 60, 80, and 100 kg for professional rugby-league players. Baker and Nance (5) reported a mean power output of 1,626 ± 238 W for a jump squat of 40 kg, whereas the mean power output for a 30-kg jump squat was 2,182 ± 202 W for the players participating in this study. When Baker and Nance (5) expressed the jump-squat power outputs relative to body mass, however, they reported significant correlations between all power outputs and 10- and 40-m sprint performance ($r = -0.52$ to -0.75). Significant relationships were found between jump-squat relative power output and 5-m ($r = -0.55$, $p = 0.01$), 10-m ($r = -0.54$, $p = 0.01$), and 30-m times ($r = -0.43$, $p = 0.04$) in this study.

There are a number of apparent differences between the current study and that of Baker and Nance (5), which may explain the different findings. First, this study used a lighter absolute load (30 kg), the subjects were heavier (4.4 kg) and taller (1.2 cm), and, hence, system mass and resultant power outputs were greater. The jumps were also performed using a plate-loaded Olympic weightlifting bar, as opposed to the Smith machine used by Baker and Nance (5). The Smith machine allows only vertical displacement of the bar, whereas the use of the Olympic bar resulted in both horizontal and vertical displacement of the load and is likely to have allowed greater trunk extension during the concentric phase of the jump. The current study also used a regression equation based on jump height and flight time (13) to calculate mean power output as opposed to power values being differentiated from displacement data.

The absence of a statistically significant relationship between drop-jump performance and sprint performance is difficult to explain. Intuitively, drop-jump performance may be less important in explaining the variance associated with the 5- and 10-m times, as the stance phase associated with these distances would be longer and hence the countermovement jump may assume greater significance. However, as distance and velocity increase, drop-jump performance may be expected to assume greater significance due to the faster SSC contribution to locomotion. This is evident in other research as significant correlations between best drop-jump performance (50 cm, $r = 0.72$) and the 30-m maximal running velocity of 25 male sprinters have been reported (21). The sprint ability (30-m, 100-m, and 300-m times) of 17 female high school sprinters was correlated with the ground-contact time for a drop jump and drop-jump index (height/contact time) (14). The drop-jump index was significantly related ($r = -0.70$ to -0.79) to 30- and 100-m times while the ground-contact time did not achieve statistical significance. The reactivity coefficients of 15 sportsmen were also found to be significantly related to shorter sprint performance (8 m) for both bilateral (30 cm, $r = -0.55$) and unilateral (15 cm, $r = -0.61$) drop-jump performance (32). However, the absence of a relationship between drop-jump performance and sprint performance is not peculiar to this study. None of the reactivity coefficients from heights of 30, 45, 60, and 75 cm were significantly correlated to starting or maximum speed performance of elite track and field athletes (33). Young et al. (25) also reported a nonsignificant relationship between 30-cm drop-jump reactivity coefficient and 20-m sprint times in football players.

As compared with the isoinertial measures, the relationship between the isokinetic measures and sprint performance were weaker. In terms of specificity, there is little wonder that the relationship between isokinetic strength measures and sprinting performance were moderate. Contraction mode specificity would suggest that isokinetic assessment bears little resemblance to the accelerative/decelerative motion implicit in limb movement during sprint performance. Furthermore, the absence of SSC-type motion during this type of assessment further detracts from the validity of such an approach. In terms of velocity specificity, a great deal of research has used assessment velocities that are disparate to the actual movement velocities of sprinting (2, 24). Posture specificity is another factor that compromises findings. Isokinetic assessment is predominantly performed using seated leg flexion/extension or press-type movements. Furthermore, assessment tends to be uniarticular (at hip or knee or ankle) and open chain in nature. Finally, joint range of motion during assessment typically differs significantly from those found during sprint running. Realizing that sprinting is a closed chain, multiarticular task, the rationale for utilizing such assessments seems problematic and the nonsignificant correlations of this study would appear to support such a contention.

In terms of the interrelationship between isokinetic measures, all measures were moderately correlated with each other. However, it can be observed from the coefficients of determination that there is a great deal of unexplained variance (46.8–66.4%) between the different measures. This would be expected between different muscle groups. It is also evident that assessments at slow ($60°\cdot s^{-1}$) and fast ($300°\cdot s^{-1}$) velocities are, for the most part, measuring different force-velocity qualities of the same muscle group.

In the present study, isokinetic measures of peak torque during knee extension and flexion at 2 velocities were found to be statistically unrelated to sprint performance, with no correlation greater than $r = -0.31$ and most correlations less than $r = -0.08$. Farrar and Thorland (10) investigated the relationship between sprint times (40 and 100 yards) and isokinetic peak torques (60 and $300°\cdot s^{-1}$) of hip and knee flexors/extensors of 52 college-aged males. None of their strength measures significantly correlated to sprint performance, with no correlation greater than $r = -0.22$ and most correlations lower than $r = -0.08$. However, other research has reported moderate correlations between isokinetic measures and sprint performance. Nesser et al. (22) investigated the relationship between the peak torque measured at the hip, knee, and ankle at 3 different speeds (60, 180, and $450°\cdot s^{-1}$) and the 40-m sprint performance of 20 sportsmen. Of the 17 isokinetic measures reported, only 5 measures were significantly related ($r = -0.537$ to -0.613) to sprint performance, the highest correlation measured during knee flexion at $450°\cdot s^{-1}$. Using a regression approach, Alexander (2) studied the relationship between isokinetic hip, knee, and ankle peak torques at 30, 150, 180 and $230°\cdot s^{-1}$ and the 100-m times of 23 elite male and female sprinters. The best single predictor for both male ($R^2 = 0.55$) and female athletes ($R^2 = 0.41$) was concentric knee extension peak torque ($230°\cdot s^{-1}$) normalized to body mass. Thereafter, the predictor models differed considerably. The best predictor ($r = -0.57$) of the 40-yard-dash times for 39 male college athletes was the peak concentric hamstring force measured at $60°\cdot s^{-1}$ (3). Guskiewicz et al. (11) found correlations of a similar magnitude when studying the predictors of sprint performance in 41 collegiate baseball and football players. Of the 2 velocities used for assessment (60 and $240°\cdot s^{-1}$), peak hip flexion ($r = -0.57$) and extension ($r = -0.56$) relative to body mass, as measured at $60°\cdot s^{-1}$, was found to be the best predictor of 40-yard-sprint performance. Dowson and colleagues (8) measuring the sprint times of elite sprinters and rugby players over shorter sprint distance (0–15, 30–35 m) found significant but weak correlations for most knee-flexion and extension measures. They found the strongest relationship between sprint performances at the speeds tested (60, 120, 150, 180, and $240°\cdot s^{-1}$) was peak torque during concentric knee extension at the highest velocity ($240°\cdot s^{-1}$). These researchers reported correlations for 0–15-m times ($r = -0.52$) and 30–35-m times ($r = -0.69$). Mixed results were found when peak torque measures were expressed relative to body mass (6). No significant relationships were found between the sprint and isokinetic measures when the isokinetic measures of this study were expressed relative to body mass. It is difficult to make any conclusions from these studies as to the relationship between isokinetic strength measures and sprint performance.

It is difficult to compare the speed of the subjects of this study to other studies due to the many different distances assessed, starting techniques, gender, age, the lack of clarity regarding testing procedures and, in many instances, the absence of any reported means and standard deviations. Those studies that have reported sprint times over similar distances to this study can be observed in Table 3. It appears that the subjects of this study were as fast if not faster than the subjects used in other studies over similar distances. It may also be surmised that the professional rugby-league players achieve speed earlier than the track athletes, supporting the contention that sport speed may differ from track speed in terms of the need to achieve maximal speed as early as possible. However, this cannot be concluded definitively from this table, as the results of Dowson et al. (6) attest and the different start procedures, age, and type of athlete used for this analysis makes such conclusions problematic. Further research that compares elite sports persons and elite track athletes over shorter distances is needed before any conclusions as to the acceleration-speed profiles of these athletes can be made.

With regard to the relationship between first-step quickness (0–5 m), acceleration (0–10 m), and maximal speed (0–30 m), it is obvious from Table 1 that the 2 measures of short-distance quickness (5 and 10 m) for the most part measure similar sprint qualities (84%). However, there is less common variance (52.9–60.8%) between these measures and the maximal speed measure, indicating the need to assess and develop these 2 qualities independently. Similar results have been reported by Baker and Nance (1), who found a shared variance of 52% between 10-m and 40-m times and concluded that factors contributing to performance over these 2 distances may be quite different. When the players were divided into slowest and fastest sprinters (based on 5-m rankings), no significant between-group differences was found for any of the 3 distances. This indicates that those players who were fast over 5 m were also the fastest over 30 m, signifying the need for a good start and rapid acceleration for better sprint performance.

In terms of the measure of first-step quickness (5-m time), very little research has investigated the relationship between strength and power and quickness over this distance, which is puzzling considering the importance of this quality in many court sports such as tennis, badminton, netball, etc. Young et al. (17) have investigated the relationship between strength qualities and sprint performance over 2.5 and 5 m. However, the subjects were track athletes and the times were measured from a block start, making comparisons and any assessment and/or training recommendations difficult. For this distance, other qualities, such as leg length and flexibility, may have an important influence on the prediction of performance (7), and hence research that uses variables in addition to strength/power qualities may result in models that are of greater benefit and value for strength and conditioning practitioners.

Of the measures used to predict sport speed, 3 measures consistently predicted sprint performance over the 3 distances, these measures associated with jump performance (see Table 1). However, it can be observed from the coefficients of determination (18.8–43.9%) that there remains a great degree of unexplained variance indicating there may be better measures (e.g., tests of horizontal leg power) that predict sport speed. More likely is that 1 strength measure cannot adequately express or provide insight into all the mechanisms responsible for the per-

TABLE 3. Reported sprint times (mean ± *SD*) for 5-, 10-, and 30-m distances.

Author	Subjects	Start	5 m	10 m	30 m
Baker (4)	9 National rugby league backs	Standing		1.71 ± 0.006	
	10 National rugby league forwards	Standing		1.75 ± 0.09	
	9 City based rugby league backs	Standing		1.74 ± 0.05	
	10 City based rugby league forwards	Standing		1.75 ± 0.08	
Cronin and Hansen	26 Professional Rugby League players	Standing 0.5 m behind timing light	0.95 ± 0.05	1.65 ± 0.06	3.99 ± 0.23
Dowson et al. (8)	8 Rugby players	Standing 1.0 m behind timing light	1.00 ± 0.06		
	8 Track sprinters	Standing 1.0 m behind timing light	0.97 ± 0.09		
	8 Sportsmen	Standing 1.0 m behind timing light	1.03 ± 0.06		
Nesser et al. (22)	20 Sportsmen	Standing		2.09 ± 0.13	
Young et al. (33)	20 Elite junior track and field athletes	Block starts	1.44 ± 0.07	2.19 ± 0.11	4.58 ± 0.28

formance of a task. Future research should use a regression approach to determine predictor models for first-step quickness, acceleration, and maximal speed.

PRACTICAL IMPLICATIONS

It should be noted that correlations can only give insights into associations and not into cause and effect; therefore, the practical applications described herewith need to be interpreted with this in mind. In summary, the absence of any relationship between the isokinetic measures and sprint performance were not unexpected, considering the limited specificity using this type of assessment. Isokinetic research in this area may benefit from an investigation of the relationship between eccentric contraction velocities and assessment that is multiarticular in nature. Assessing at velocities indicative of sprint performance is also needed. Also, the preoccupation of research to report peak torques warrants further investigation. Total work (area under the torque curve) or average power (work/second) may give more information about the relationship of muscular performance to sprint performance than a single point on the curve. In terms of isoinertial assessment and any assessment for that matter, the strength and conditioning practitioner or scientist must be careful in describing relationships between variables. As observed in this study, the relationship between isokinetic strength and different countermovement jump measures was found to differ according to whether the outcome variable was recorded as a power output or as a height. This has important implications for correlational research in that nonsignificant relationships between movements may be reported, when actually it is the measure and not the movement that are unrelated. Furthermore, as stated previously, the great majority of research uses acyclic vertical-type movements (e.g., squat, vertical jumps) to predict an activity that is cyclic and horizontal in nature. Further research may benefit from investigating movements that require greater horizontal force production.

It was concluded that the preoccupation of correlational studies to find the best strength predictors of functional performance is problematic. First, 1 strength measure cannot adequately express or provide insight into all the mechanisms responsible for performance of a task. Based on the results, it is suggested that the sports trainer, sport scientist, or clinician should not rely solely on a single strength measurement to predict performance or readiness to return to activity after injury. Rather, research needs to determine the influence of other factors on functional performance. It may be that several different strength measures or several factors in combination with strength measures will provide the best predictive capabilities of functional performance. The challenge for research, therefore, is to develop assessment batteries that have been based on a multifactorial analysis (e.g., anthropometric, mechanical, physiological, etc.) of a task. Such an approach would no doubt improve strength-conditioning practice, especially in terms of the assessment and development of athletes.

REFERENCES

1. ABERNETHY, P., G. WILSON, AND P. LOGAN. Strength and power assessment: Issues, controversies and challenges. *Sports Med.* 19:41–417. 1995.
2. ALEXANDER, M.J.L. The relationship between muscle strength and sprint kinematics in elite sprinters. *Can. J. Sport Sci.* 14: 148–157. 1989.
3. ANDERSON, M.A., J.H. GIECK, D. PERRIN, A. WELTMAN, R. RUTT, AND C. DENEGAR. The relationship among isometric, isotonic and isokinetic concentric and eccentric quadriceps and hamstring force and three components of athletic performance. *J. Orthop. Sports Phys. Ther.* 14:114–120. 1991.
4. BAKER, D. A comparison of running speed and quickness between elite professional and young rugby league players. *Stength Cond. Coach.* 7:3–7. 1999.
5. BAKER, D., AND S. NANCE. The relation between running speed and measures of strength and power in professional rugby league players. *J. Strength Cond. Res.* 13:230–235. 1999.
6. COSTILL, D.L., S.J. MILLER, W.C. MYERS, F.M. KEHOE, AND W.M. HOFFMAN. Relationship among selected tests of explosive leg strength and power. *Res. Quart. Amer. Ass. Health Physical Ed. Rec.* 39:785–787. 1968.
7. CRONIN, J.B., P.J. MCNAIR, AND R.N. MARSHALL. Relationship between strength qualities and motor skills associated with court performance. *J. Hum. Movt. Stud.* 40:207–224. 2001.
8. DOWSON, M.N., M.E. NEVILL, H.K. LAKOMY, A.M. NEVILL, AND R.J. HAZELDINE. Modelling the relationship between isokinetic muscle strength and sprint running performance. *J. Sports Sci.* 16:257–265. 1998.
9. ELLENBECKER, T.S., AND E.P. ROETERT. Concentric isokinetic quadricep and hamstring strength in elite junior tennis players. *Isok. Exerc. Sci.* 5:3–6. 1995.
10. FARRAR, M., AND W. THORLAND. Relationship between isokinetic strength and sprint times in college-age men. *J. Sports Med.* 27:368–372. 1987.
11. GUSKIEWICZ, K., S. LEPHART, AND R. BURKHOLDER. The relationship between sprint speed and hip flexion/extension strength in collegiate athletes. *Isok. Exerc. Sci.* 3:111–116. 1993.
12. HARMAN, E. Estimation of human power output from vertical jump. *J. Appl. Sport Sci. Res.* 5:116–120. 1991.
13. HARMAN, E.A. The measurement of human mechanical power. In: *Physiological Assessment of Human Fitness.* P.J. Maud and C. Foster, eds. Champaign, IL: Human Kinetics, 1995. pp. 87–113.
14. HENNESSY, L., AND J. KILTY. Relationship of the stretch-shortening cycle to sprint performance in trained female athletes. *J. Strength Cond. Res.* 15:326–331. 2001.
15. HOLM, I., P. LUDVIGSEN, AND H. STEEN. Isokinetic hamstring/quadricep ratios: Normal values and reproducibility in sport students. *Isok. Exerc. Sci.* 4:141–145. 1994.
16. HOUSH, T.J., W.G. THORLAND, G.D. THARP, G.O. JOHNSON, AND C.J. CISAR. Isokinetic leg flexion and extension strength of elite adolescent female track and field athletes. *Res. Quart. Exerc. Sport.* 55:347–350. 1984.
17. KOMI, P.V. Physiological and biochemical correlates of muscle function: Effects of muscle structure and stretch- shortening cycle on force and speed. *Exerc. Sport Sci. Rev.* 12:81–121. 1984.
18. MCBRIDE, J.M., T. TRIPLETT-MCBRIDE, A. DAVIE, AND R.U. NEWTON. A comparison of strength and power characteristics between power lifters, olympic lifters and sprinters. *J. Strength Cond. Res.* 13:58–66. 1999.
19. MECKEL, Y., H. ATTERBOM, A. GRODJINOVSKY, D. BEN-SIRA, AND A. ROTSTEIN. Physiological characteristics of female 100 metre sprinters of different performance levels. *J. Sports Med. Phys. Fit.* 35:169–175. 1995.
20. MERO, A., AND P.V. KOMI. Force-, EMG-, and elasticity-velocity relationships at submaximal, maximal and supramaximal running speeds in sprinters. *Eur. J. Appl. Physiol.* 55:553–561. 1986.
21. MERO, A., P. LUHTANEN, J.T. VIITASALO, AND P.V. KOMI. Relationships between the maximal running velocity, muscle fiber characteristics, force production and force relaxation of sprinters. *Scand. J. Sports Sci.* 3:16–22. 1981.

22. NESSER, T.W., R.W. LATIN, K. BERG, AND E. PRENTICE. Physiological determinants of 40-meter sprint performance in young male athletes. *J. Strength Cond. Res.* 10:263–267. 1996.
23. NEWTON, R., AND W. KRAEMER. Developing explosive muscular power: Implications for a mixed methods training strategy. *Strength Cond.* 6:36–41. 1994.
24. SALE, D. Testing strength and power. In: *Physiological Testing of the High Performance Athlete.* J.D. MacDougall, H.A. Wenger, and H.J. Green, eds. Champaign, IL: Human Kinetics, 1991. pp. 21–106.
25. SCHMIDTBLEICHER, D. Training for power events. In: *Strength and Power in Sport.* P.V. Komi, ed. Boston: Blackwell Scientific Publications, 1992. pp. 381–395.
26. WILSON, G.J., A.D. LYTTLE, K.J. OSTROWSKI, AND A.J. MURPHY. Assessing dynamic performance: A comparison of rate of force development tests. *J. Strength Cond. Res.* 9:176–181. 1995.
27. WILSON, G.J., A.J. MURPHY, AND A. WALSHE. The specificity of strength training: The effect of posture. *J. Appl. Physiol.* 73: 346–352. 1996.
28. YOUNG, W. A simple method for evaluating the strength qualities of the leg extensor muscles and jumping abilities. *Strength Cond. Coach.* 2:5–8. 1995.
29. YOUNG, W. Strength qualities: What they are and what they mean to the coach. *Strength Cond. Coach.* 3:13–16. 1994.
30. YOUNG, W., AND S. ELLIOTT. Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. *Res. Quart. Exerc. Sport.* 72:273–279. 2001.
31. YOUNG, W., M. HAWKEN, AND L. MCDONALD. Relationship between speed, agility and strength qualities in Australian Rules football. *Strength Cond. Coach.* 4:3–6. 1996.
32. YOUNG, W.B., R. JAMES, AND I. MONTGOMERY. Is muscle power related to running speed with changes of direction? *J. Sports Med. Phys. Fit.* 42:282–288. 2002.
33. YOUNG, W., B. MCLEAN, AND J. ARDAGNA. Relationship between strength qualities and sprinting performance. *J. Sports Med. Phys. Fit.* 35:13–19. 1995.

Address correspondence to John Cronin,
john.cronin@aut.ac.nz.