RELATIONSHIP BETWEEN SPRINT TIMES AND THE STRENGTH/POWER OUTPUTS OF A MACHINE SQUAT JUMP

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ABSTRACT
Strength testing is often used with team-sport athletes, but some measures of strength may have limited prognostic/diagnostic value in terms of the physical demands of the sport. The purpose of this study was to investigate relationships between sprint ability and the kinetic and kinematic outputs of a machine squat jump. Thirty elite level rugby union and league athletes with an extensive resistance-training background performed bilateral concentric-only machine squat jumps across loads of 20% to 90% 1 repetition maximum (1RM), and sprints over 10 meters and 30 or 40 meters. The magnitudes of the relationships were interpreted using Pearson correlation coefficients, which had uncertainty (90% confidence limits) of ±0.3. Correlations of 10-meter sprint time with kinetic and kinematic variables (force, velocity, power, and impulse) were generally positive and of moderate to strong magnitude (r = 0.32–0.53). The only negative correlations observed were for work, although the magnitude was small (r = −0.18 to −0.26). The correlations for 30- or 40-meter sprint times were similar to those for 10-meter times, although the correlation with work was positive and moderate (r = 0.35–0.40). Correlations of 10-meter time with kinetic variables expressed relative to body mass were generally positive and of trivial to small magnitude (r = 0.01–0.29), with the exceptions of work (r = −0.31 to −0.34), and impulse (r = −0.34 to −0.39). Similar correlations were observed for 30- and 40-meter times with kinetic measures expressed relative to body mass. Although correlations do not imply cause and effect, the preoccupation with maximizing power output in this particular resistance exercise to improve sprint ability appears problematic. Work and impulse are potentially important strength qualities to develop in the pursuit of improved sprinting performance.

KEY WORDS impulse, force, work, velocity, kinetics, kinematics

INTRODUCTION
A variety of conditioning methods are used to improve speed, one of which is the use of resisted strength training (RST). Of particular interest to many practitioners and researchers in this area is identifying whether strength and power outputs (e.g., 1 repetition maximum [1RM], peak power, mean force) in gym-based exercises such as the squat jump are related to sprinting ability, which may provide greater insight into those exercises or variables that offer a superior training stimulus in terms of transference of gym-based gains to improving sprint ability. One approach to answering this question is to use correlational analysis, and many researchers have adopted such an approach (2,4,9,13,16,21,24,37,39,40), but the magnitude of the correlations differs markedly between studies, probably due to methodological differences.

First, many different types of dynamometry are used to assess strength and power (e.g., isometric (constant angle), isokinetic (constant velocity), and isoinertial (constant gravitational load), which is also referred to as isotonic) (1). Despite the popularity of isometric and isokinetic tests in research, the general consensus is that they lack face validity due to the large neural and mechanical differences between isometric and isokinetic tests and sprinting (1–3,8,27,35). Most isoinertial studies have used weight training movements such as the squat or power clean (5,25) or various types of jumps (21,26,27,36) and reported the correlation (r = 0.46 to −0.81) of these activities to acceleration or speed measures. Some researchers have instrumented weight training equipment (e.g., Smith machine) to examine the relationship between muscle force-time characteristics assessed under concentric and/or eccentric contractions and sprint performance (4,30,39). This type of approach has resulted in a range of correlations (r = −0.02 to −0.86), depending on methodologies used.

Second, the type of lift used influences the kinetic and kinematic outputs. In traditional weight training lifts, where the bar or load or both reach a velocity of zero at the end of the concentric phase, deceleration occurs for a considerable portion of the contraction. An alternative technique where the load (bar or oneself) is projected as in jumping and throwing
has been termed ballistic training and can result in higher force outputs (28) and would seem to offer a movement pattern that better simulates athletic performance.

Third, the variety of methods used to calculate power outputs also makes comparison between studies difficult. It is thought appropriate to use system mass (inclusion of body mass) to calculate loading intensity during ballistic lower body exercises because the subjects must propel themselves and the mass associated with the bar, although there is some conjecture regarding this issue (15,30). Excluding body mass from the calculation decreases the total mass component, therefore decreasing total force and power outputs.

Fourth, there has been a preoccupation with investigating only a limited number of kinetic and kinematic variables. Maximal strength and peak power have received much attention, but other variables may be of equal if not more, importance. For example, given the impulse-momentum relationship (22), investigating the relationship between impulse and speed is of particular interest. Additionally, often only a sample of the load spectrum for the RST exercise has been examined to determine the relationship to sprint performance. Various jumps and RST exercises at body weight or light loads have been investigated, mainly owing to their perceived contraction force and velocity specificity to sprinting (4,13,39). However, kinetic variables such as power and impulse may be maximized across a broad range of the load spectrum. For example, it is generally considered that peak power during loaded squat jumps is maximized at approximately 20–65% 1RM (6,23); hence, it is worthwhile investigating a broader spectrum of loads and their relationship to sprinting performance.

Finally, the subject characteristics are also an important aspect of study design. Subjects with little or no experience in RST or from nonathletic backgrounds would appear to differ from their more well-trained and/or athletic counterparts in terms of strength and power capability, and the relationship between these outputs and speed (18). Thus, the validity of generalizing findings from 1 subject group to another, such as novice participants to athletes with experience in RST, is problematic. Additionally, difference between studies in terms of the heterogeneity of the subject group (between-subject SD) contributes to the disparity in the magnitudes of correlations between studies. Cognizant of these limitations, the purpose of this study was to investigate the relationship between sprint ability in well-trained athletes and the kinetic/kinematic outputs of a machine squat jump across a range of loads.

**METHODS**

**Experimental Approach to the Problem**

To determine the relationship between sprint ability and the kinetics and kinematics associated with squat jumps across a spectrum of loads, a correlational approach was used. Thirty well-trained subjects performed machine squat jumps across loads of 20 to 90% 1RM, and sprints over 10 and 30 or 40 meters. Thereafter, Pearson correlations were used to determine the magnitude of the relationships between variables of interest.

**Subjects**

Thirty male subjects volunteered to participate in this study. The mean (±SD) age, mass, and height of the participants were 22.3 ± 2.8 years, 100.5 ± 10.6 kg, and 181.2 ± 5.4 cm, respectively. Seventeen of the subjects were from a national-level rugby training squad, and 13 of the subjects were from a national rugby league premier squad. All subjects had an extensive resistance training background (4.2 ± 2.2 years). Subjects provided written consent for testing as part of their contractual arrangements with their respective squads and were informed that they could withdraw from the study at any time without prejudice. The Human Subject Ethics Committee of the Auckland University of Technology approved all procedures undertaken in this study.

**Equipment**

Subjects performed their assessments on a customized standing hack squat machine (Fitness Works, Auckland, NZ). The hack squat machine used a plate-loaded sled allowing vertical movement on low-friction sliders (Fig. 1). It was designed to allow subjects to perform maximal squats or explosive squat jumps, with adequate support over the shoulder girdle in a fixed plane of motion, thus reducing the risk associated with such exercises performed with free weights. The starting position of the sled was adjustable to...
the nearest 15 mm, allowing lower limb joint angles to be standardized as measured by a goniometer. A linear position transducer (P-80A, UniMeasure, Corvallis, OR) was attached to the sled and measured vertical displacement of the sled with an accuracy of 0.01 cm. Data were sampled at 500 Hz and collected by a computer-based data acquisition and analysis program (Labview 6.1. National Instruments, Austin, TX).

Sprint times over 10 and 30 or 40 meters were measured using the Kinematic Measurement System (KMS; Optimal Kinetics, Muncie, IN). The KMS timing light system was a single beam modulated visible red-light system with polarizing filters and consisted of 3 sets of gates. The start of longest on function in the KMS software was used; 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 negated the need for a double-beam system. The within-trial variability (coefficient of variation ≤1.2%) of this procedure has been reported previously (13).

**Procedures**

The maximal strength (1RM) and concentric power-load spectrum (20–90% 1RM) were assessed for each subject. Instructions were issued to subjects to standardize pretest preparation (e.g., exercise levels, nutrition) as much as possible in the 24-hour period preceding the testing session. At each session, the subjects first performed a standardized warm-up procedure consisting of running, dynamic stretching, and ball drills. During the first session, subjects were familiarized with the equipment and procedures by performing 2 warm-up sets at a light weight (40–60 kg). Two to 3 trials were then performed to establish 1RM. In an effort to be somewhat specific to the knee angles encountered in sprinting (38), start position was standardized to 110° at the knee using a goniometer (centered at the lateral epicondyle of the knee and aligned to the lateral malleolus and greater trochanter). Adjustable mechanical brakes were used to fix the stop-start position for the machine at the 110° knee angle. Foot position was self-selected by participants but standardized to within 5 cm between all participants.

The measurement of force as described in this experiment has been verified by comparison of the linear transducer data, with data gathered simultaneously from an accelerometer and a force platform across movement types (concentric only and rebound bench press, squat, countermovement, and drop jumps), loads (40–80% 1RM), and sampling frequencies (200–1000 Hz). The data from the linear transducer were shown to be reliable (coefficient of variation = 2.1–8.4% and intraclass correlation coefficient = 0.92–0.98 for measures of mean and peak force) and valid across these conditions. The reliability of the procedures has been reported previously (12).

In the second session, after the standardized warm-up, a load of 20% of the individual’s 1RM was placed on the squat machine and the subjects completed 1 lift with maximal effort. A 1-minute rest period was then

### Table 1. Kinetic and kinematic outputs of the machine hack squat at loads of 20 and 90% 1RM.

<table>
<thead>
<tr>
<th>Load (% 1RM)</th>
<th>20% 1RM</th>
<th>90% 1RM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak force (N)</td>
<td>2940 ± 500</td>
<td>4450 ± 550</td>
</tr>
<tr>
<td>Mean force (N)</td>
<td>1530 ± 150</td>
<td>3660 ± 450</td>
</tr>
<tr>
<td>Peak velocity (m·s⁻¹)</td>
<td>1.88 ± 0.21</td>
<td>0.66 ± 0.14</td>
</tr>
<tr>
<td>Mean velocity (m·s⁻¹)</td>
<td>1.01 ± 0.10</td>
<td>0.31 ± 0.07</td>
</tr>
<tr>
<td>Peak power (W)</td>
<td>4520 ± 1070</td>
<td>2640 ± 590</td>
</tr>
<tr>
<td>Mean power (W)</td>
<td>1600 ± 230</td>
<td>1140 ± 270</td>
</tr>
<tr>
<td>Work (N·m⁻¹)</td>
<td>1260 ± 460</td>
<td>1800 ± 850</td>
</tr>
<tr>
<td>Impulse (N·s⁻¹)</td>
<td>800 ± 120</td>
<td>3410 ± 800</td>
</tr>
</tbody>
</table>

1RM, 1 repetition maximum.

### Table 2. Intercorrelation matrix for strength measures and sprint times.

<table>
<thead>
<tr>
<th></th>
<th>10-m sprint time</th>
<th>30-/40-m sprint time</th>
<th>1RM</th>
<th>Body mass</th>
<th>1RM rel</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-m sprint time</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-/40-m sprint time</td>
<td>0.87*</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1RM</td>
<td>0.20</td>
<td>-0.14</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>0.40†</td>
<td>0.64*</td>
<td>0.32†</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>1RM rel</td>
<td>-0.10</td>
<td>-0.33†</td>
<td>0.75*</td>
<td>-0.39†</td>
<td>1.00</td>
</tr>
</tbody>
</table>

1RM, machine squat 1 repetition maximum; 1RM rel, machine squat 1 repetition maximum relative to body mass.

*Clear, strong correlation.
†Clear, moderate correlation.
allowed before the load was increased to 30% of the individual’s 1RM. This process was repeated for loads 30, 40, 50, 60, 70, 80, and 90%, of the individual’s 1RM. Subjects were given instructions to move every load with maximal effort and jump if the load permitted. All lifts were commenced from the standardized starting position; thus, concentric force was measured with no eccentric counter-movement.

Timing lights were placed at the start and at 10 and 30 or 40 meters in order to collect sprint times over the 2 distances. Thirteen athletes were assessed over 10 and 30 meters, and 17 athletes were assessed over 10 and 40 meters, depending on the normal speed-testing protocol of the respective sporting organizations. All athletes performed a thorough warm-up as part of their training routine. This included jogging, ball skill drills, dynamic stretching, and submaximal sprints. The starting position was standardized for all subjects. Athletes started in a 2-point crouched position with the left toe 30 cm back from the starting line and the right toe approximately in line with the heel of the left foot. All assessments were performed on an indoor court surface, and subjects wore rubber-soled track shoes.

**Results**

The kinetic and kinematic outputs of the machine hack squat at loads of 20 and 90% 1RM are shown in Table 1. Mean sprint times were 1.82 ± 0.07, 4.19 ± 0.16, and 5.54 ± 0.21 seconds for 10-, 30-, and 40-meter distances, respectively. Mean maximal strength (1RM) was 305 ± 46.6 kg, and relative strength (1RM per kilogram of body mass) 3.07 ± 0.48 kg per kilogram of body mass.

The intercorrelation matrix for strength measures and sprint times are detailed in Table 2. Body mass was moderately correlated with 10-meter sprint time and strongly
correlated with 30- and 40-meter sprint time. Strength, as described by a subject’s 1RM, was only slightly correlated with sprint times at either distance, but 1RM expressed relative to body mass (1RM rel) was moderately negatively correlated with 10-meter sprint time. Sprint times for 10 and 30 or 40 meters were correlated nearly perfectly.

The relationship between kinetic and kinematic measures across a spectrum of loads expressed relative to body mass and sprint times are shown in Figure 3. Peak and mean velocities are not reported as it is not valid to express velocity relative to body mass. Values were generally positive and of trivial to low magnitude \((r = 0.01–0.29)\), for example, mean power per kilogram \((r = -0.06 \text{ to } 0.30)\) and peak force per kilogram \((r = -0.03 \text{ to } 0.28)\). Work per kilogram and impulse per kilogram were of clear moderate negative correlation with 10-meter sprint time \((r = -0.2 \text{ to } -0.39)\) across most loads. Mean force per kilogram \((r = -0.32 \text{ to } -0.40)\) and impulse per kilogram body mass \((r = -0.31 \text{ to } -0.47)\) were of clear moderate negative magnitude to 30- or 40-meter sprint time.

**DISCUSSION**

The sprint times observed in the present study were similar to those of other studies using well-trained rugby and rugby league athletes (4,13,27). Maximal strength was considerably higher than reported in other similar research, probably attributable to the higher starting position (110° knee angle) of the squat used in this study, enabling a more forceful movement due to an advantageous length-tension relationship in the knee and hip extensors (20). Clearly, the participants in the present study were a well-trained sample and as fast and strong as other similar athletes. Of interest, therefore, acknowledging the training status of the athletes used in this study and the methodological limitations cited previously, was establishing whether any of the kinematic and/or kinetic variables assessed using a machine squat jump across a spectrum of loads were clearly correlated with sprint ability.

Sprint ability over short distances (<10 meters) and longer distances (>30 meters) are considered by many researchers and practitioners to require separate and specific strength qualities and therefore training techniques (14,38). It is generally considered that shorter sprints require greater contributions of concentric muscle contractions and knee extensor activity versus longer sprints that are characterized by greater stretch-shortening cycle (SSC) and hip extensor activity. However, reported correlations between sprint times over different distances (4,13,27,39) are typically very strong \((r = 0.72–0.99)\). The correlations between 10- and 30- or 40-meter sprint times in the present study were similar to those cited in previous studies \((r = 0.87)\). It would appear that the indices of acceleration and maximal speed for this sample share a great deal of common variance (>75%) and the preoccupation of researchers and practitioners to treat and train these variables as separate qualities possibly overemphasized (38).

Maximal strength is perceived to be an underpinning neuromuscular quality for athletic performance (29,31);
however, considerable investigation into the relationship between maximal strength and sprinting ability provides the antithesis of such a contention. For example, Baker and Nance (4) found trivial to small nonsignificant relationships between 3RM squat strength and 10-meter ($r = -0.06$) or 40-meter ($r = -0.19$) sprint times of professional rugby league players. Several other studies (11,13,19) have reported very low correlations between maximal strength and sprint measures ($r = -0.01$ to 0.30), which are supported by the results of the present study. Strength, as assessed by IRM, was only trivially correlated to sprint times at either distance ($r = 0.20$ and $r = -0.14$ for 10- and 30- or 40-meter sprint times, respectively). It is reasonable to assume that larger athletes would be stronger, but also sprint slower due to the inertia associated with greater body mass, particularly in the early stages of the sprint. The clear moderate correlation between body mass and 10-meter sprint time ($r = 0.40$) supports this assertion. However, conjecture remains as other researchers (37) have reported a near-perfect correlation between body mass and 10-meter sprint time ($r = -0.62$) and maximum force ($r = -0.72$). The best predictors of maximum sprinting speed included F100/wt ($r = -0.80$) and maximum force ($r = -0.79$). Using a similar methodology, Wilson et al. (34) found the force at 30 milliseconds in a concentric squat jump was significantly correlated to sprint performance ($r = -0.62$) and able to effectively discriminate between good and poor performers. The results of Wilson et al. (34) and Young et al. (39) support the concept that because sprinting involves efforts of short duration, strength qualities such as the rate of force development or force applied at 100 milliseconds may be more important than maximal strength.

Mechanical power output has attracted a great deal of attention in the research and conditioning fraternity in an attempt to clarify its relationship to functional performance (4,5,24,25,30,32,39,40). However, disentangling the findings is challenging due to discrepancies in research design, terminologies, and methods for calculation of power. We observed a clear, strong, positive correlation between mean and peak power and sprint times at both distances, most probably explained by the fact that the larger athletes produced greater force outputs, but were also slower due to greater body mass. Of particular interest is that no clear negative correlations were found between mean or peak power at either of the sprint distance times, even when power was expressed relative to body mass. Indeed, correlations were mostly positive across the entire load spectrum. These findings are in direct contrast to those of Sleivert and Taingahue (30) who investigated the relationship between 5-meter sprint times and power variables in trained athletes from rugby, rugby league, and basketball with an average of 2.4 years of RST experience. Average power and peak power were assessed over 30–70% 1RM of concentric-only traditional squats and split squats performed in a ballistic manner. Notably, both average power and peak power relative to body mass were strongly negatively correlated with 5-meter sprint time ($r = -0.64$ to $-0.68$). The authors chose not to incorporate body mass (so-called system mass) into the equation for force, asserting that it is not strictly mechanically correct to do so. Sleivert and Taingahue (30) noted that not using system mass has the effect of markedly reducing power outputs and altering the point on the power-
load spectrum where maximal power outputs occur. It is conceivable that excluding system mass may also influence correlational analysis between power variables and sprint times; however, it seems unlikely that it would exclusively account for the difference in the magnitude of the correlations between the present study and that of Sleivert and Taingahue (30). Similarly, Baker and Nance (4) also found strong relationships between relative average power outputs of loaded (40–100 kg) countermovement jump squats and sprint times over 10 meters \((r = -0.52\) to \(-0.61)\) and 40 meters \((r = -0.52\) to \(-0.76)\). It is not clear from their methodology whether system mass was used.

A key finding in the present study was that impulse expressed relative to body mass was clearly correlated with 30- and 40-meter sprint times across all loads and to 10-meter sprint time at 20 and 30% 1RM \((r = -0.31\) to \(-0.47)\). Given the impulse-momentum relationship, impulse is theoretically an important determinant of sprint ability as indicated by biomechanists reporting the determinants of speed via qualitative models (20). This variable therefore should be of greater interest to the strength and conditioning fraternity; however, impulse has received little attention in the research on predictors of speed. Wilson et al. (34) investigated the relationship between impulse developed in the first 100 milliseconds of a concentric Smith squat jump (unloaded) from \(110^\circ\) (imp110) and \(150^\circ\) (imp150) knee angles, and sprinting ability over 30 meters. Although reported as non-significant, they reported a moderate correlation \((r = -0.49)\) between imp150 and sprint ability. Interestingly, the relationship between imp110 and sprint ability was trivial \((r = 0.06)\). Young et al. (39) also investigated the relationship between impulse at 100 milliseconds in a squat jump and sprint times, but the correlation was not reported. Another little-reported variable of interest is total work done. We observed negative correlations between work and 10-meter sprint time \((r = -0.18\) to \(-0.34)\), and when expressed relative to body mass, 30- and 40-meter sprint times \((r = -0.01\) to \(-0.28)\). Perhaps impulse and work are important strength qualities to develop in the pursuit of enhanced sprint performance. Further research is needed on the relationship of these strength measures to functional performance.

**Practical Applications**

The reader needs to be cognizant of the following limitations when interpreting the results of this study. First, the resistance exercise (machine hack squat) used a purely bilateral, acyclical, vertical expression of force. Although it is common conditioning practice to use squat jumps and derivatives, it has been postulated that a more specific training method for speed would use horizontal force production in unilateral movements, such as loaded sled towing (41). Indeed, biomechanical similarity of assessment dynamometry to the functional performance task is a fundamental tenet of a correlational relationship. However, given the propensity of conditioning practitioners to use squats and derivatives as a key exercise in resistance training programs, investigation of this exercise would appear logical. Second, the strength and power variables were assessed over the concentric phase of the movement only. Thus, no measures of eccentric force contribution or SSC activity were assessed. Also, the kinetic and kinematic variables were assessed over the entire contraction, whereas force production during sprinting occurs in a very short duration (33). Finally, only single repetitions were performed at each load. Typically, training involves multiple repeated repetitions; kinetic and kinematic outputs may differ between multiple and single repetitions (18). It is, however, worthwhile investigating single repetitions, allowing for the methodological issues discussed previously. It should be noted that correlations can only give insights into associations and not into cause and effect; therefore, longitudinal training studies are needed to provide valid information regarding possible superior training stimuli. Additionally, the homogeneity of our subject group may account for some of the disparity between our correlations and those of other researchers. The practical applications described herewith need to be interpreted with this in mind.

The purpose of this study was to establish whether any kinetic or kinematic variables were related to sprint ability over 10 and 30 or 40 meters. If a clear, strong relationship was found, it may provide greater insight into better variables to monitor and develop for improved sprint ability. The fact that neither mean power nor peak power was negatively correlated with sprint times suggests that the preoccupation with maximizing power output in machine squat jumps to improve sprint ability is misplaced. Variables such as impulse and work are potentially more useful. However, it is most likely that the bilateral, vertical, acyclical resistance exercise used in this study lacked biomechanical specificity to sprinting performance. Research needs to monitor the changes in kinematics and kinetics of an exercise, and sprint times over a training intervention to better understand those variables and exercises that may improve sprint ability.

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**References**

Squat-Jump Power and Sprint Ability


