RELATIONSHIPS BETWEEN FORCE–TIME CHARACTERISTICS OF THE ISOMETRIC MIDTHIGH PULL AND DYNAMIC PERFORMANCE IN PROFESSIONAL RUGBY LEAGUE PLAYERS

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Abstract
West, DJ, Owen, NJ, Jones, MR, Bracken, RM, Cook, CJ, Cunningham, DJ, Shearer, DA, Finn, CV, Newton, RU, Crewther, BT, and Kilduff, LP. Relationships between force–time characteristics of the isometric midthigh pull and dynamic performance in professional rugby league players. J Strength Cond Res 25(5): 000–000, 2011—There is considerable conflict within the literature regarding the relevance of isometric testing for the assessment of neuromuscular function within dynamic sports. The aim of this study was to determine the relationship between isometric measures of force development and dynamic performance. Thirty-nine professional rugby league players participated in this study. Forty-eight hours after trial familiarization, participants performed a maximal isometric midthigh pull, with −120◦–130◦ bend at the knee, countermovement jump (CMJ), and a 10-m sprint. Force–time data were processed for peak force (PF), force at 100 milliseconds (F100ms), and peak rate of force development (PRFD). Analysis was carried out using Pearson’s product moment correlation with significance set at p < 0.05. The PF was not related to dynamic performance; however, when expressed relative to body weight, it was significantly correlated with both 10-m time and CMJ height (r = −0.37 and 0.45, respectively, p < 0.05). The F100ms was inversely related to 10-m time (r = −0.54, p < 0.01); moreover, when expressed relative to body weight, it was significantly related to both 10-m time and CMJ height (r = −0.68 and 0.43, p < 0.01). In addition, significant correlations were found between PRFD and 10-m time (r = −0.66, p < 0.01) and CMJ height (r = 0.387, p < 0.01). In conclusion, this study provides evidence that measures of maximal strength and explosiveness from isometric force–time curves are related to jump and sprint acceleration performance in professional rugby league players.

Key Words force platform, strength trained athletes, strength and power diagnosis, testing battery

Introduction
Assessment of neuromuscular function in relation to maximal strength and rate of force development (RFD) is of critical importance to a successful conditioning program in terms of monitoring and prescription of player’s development. In recent years, this assessment has been carried out using force–time curves collected during isometric contractions; however, there is considerable conflict within the literature regarding relevance of isometric testing to dynamic performance (e.g., [4,6,13,16]). For example, Stone et al. (13) identified absolute and relative peak force (PF) measured during an isometric midthigh pull (IMTP) to be highly related to multiple performance measures during sprint cycling (PF was inversely related to time over the initial 25 m, r = −0.6). In support of this, Haff et al. (4) found absolute PF (measured through IMTP) to be highly related with performance in the snatch (r = 0.9) in 6 female weightlifters. However, not all studies have reported a relationship between variables obtained during isometric tests and dynamic performance with studies by Kawamori et al. (6) McGuigan and Winchester (8) and Murphy and Wilson (10) reporting no relationship between IMTP variables and jumping performance, and Requena et al. (12) reporting no relationship between IMTP variables and 15 m sprint time.
To date, there is no uniform agreement between researchers on the role isometric tests play in sports performance diagnosis with much of the discrepancies because of methodological differences in the various studies, such as the mode of isometric collection (e.g., squat vs. midthigh pull) and the analysis of the force–time records. Additionally, the majority of the studies to date in this area have used nonelite athletes and have had relevantly small sample sizes making overall conclusions difficult.

Based on the current literature, there is a need to examine key measures derived from isometric force–time curves and the potential relationship between these variables and measures of dynamic performance (e.g., sprinting and jumping). In addition, this article aims to present a detailed explanation of the data collection and data analysis procedure of the neuromuscular variables measured in this study to allow meaningful comparison between the data presented in this study and future studies in this area.

**METHODS**

**Experimental Approach to the Problem**

Before the start of the main experimental trials, players visited the laboratory to become familiar with the testing methods of the study. Forty-eight hours after the familiarization, all participants performed 2 testing sessions each separated by a further 48-hour recovery. Players reported to the laboratory on the mornings of testing after having refrained from alcohol, caffeine, and strenuous exercise for 48 hours. On the first testing day, after the measurement of each individual’s height and weight and having completed a standardized warm-up, players were required to complete a maximum IMTP for the measurement of PF, peak rate of force development (PRFD), and force at 100 milliseconds (F100ms). On the second day of testing, players performed countermovement jump (CMJ) and 10-m sprint as measures of dynamic performance. Consumption of water (500 mL) was permitted during each test. Room temperature was maintained between 20 and 24°C. Verbal encouragement was given to maximize performance.

**Subjects**

Thirty-nine professional rugby league players (Table 1) provided written informed consent to participate in this study, which was approved by the university ethics committee. Participants were recruited on the basis that they had been engaged in a structured weight-training program for at least 2 years and were able to complete an IMTP with correct technique as assessed by a qualified strength and conditioning coach. At the time of inclusion into the study, players had just completed their preseason training before the start of the season, the season before the testing the team finished in the play-off positions in the Super League (Great Britain).

**Isometric Midthigh Pull Testing**

The IMTP testing was carried out with players standing on a portable force platform (type 92866AA, Kistler Instruments Ltd., Farnborough, United Kingdom), which was positioned on the floor centered under the bar of a power rack. Players were positioned so that they assumed a body position similar to that of athletes competing the second pull of a power clean with a flat trunk position and their shoulders in line with the bar. This position allowed athletes to maintain a knee angle of approximately 120–130° (which was checked using a goniometer, Smith & Nephew, Hull, United Kingdom) as previously used (4,13). The bar height could be fixed at various heights above the force platform, to accommodate different sized subjects, and the rack was anchored to the floor. Once the bar height was established, the players stood on the force platform, and their hands were strapped to the bar in accordance with previously established methods (4,13). The portable force platform with built-in charge amplifier was used to measure the vertical component of the ground reaction force (GRF) of the subjects during performance of a maximal effort IMTP. A sample rate of 1,000 Hz and a vertical force range of 20 kN were used for all trials. The force–time data were recorded on a portable computer using a 16-bit analog to digital converter. A sample length of 10 seconds was used for all trials, consisting of a pretrigger phase of 2 seconds, and a posttrigger phase of 8 seconds. The pretrigger phase was a record of the force–time history immediately before the trigger switch being operated, and the posttrigger phase, which included the IMTP, was a record of the force–time history immediately after the trigger switch had been operated. The trigger switch simultaneously initiated a signal lamp used to inform the subject to perform an IMTP. Thus, the 2 seconds of pretrigger data represented a quiet standing phase with the IMTP being initiated some time during the beginning of the 8 seconds posttrigger phase and lasting for approximately 5 seconds. The platform’s calibration was checked before and after

**Table 1. Physical characteristics of subjects at baseline (n = 12).**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>97.0 ± 8.2</td>
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<tr>
<td>Height (cm)</td>
<td>180.0 ± 6.1</td>
</tr>
<tr>
<td>Age (dec y)</td>
<td>24.0 ± 4.6</td>
</tr>
<tr>
<td>3RM bench press (kg)</td>
<td>135 ± 16</td>
</tr>
<tr>
<td>3RM back squat (kg)</td>
<td>157 ± 21</td>
</tr>
<tr>
<td>Skinfold thickness (mm) †</td>
<td>36.5 ± 14.8</td>
</tr>
<tr>
<td>Phosphate decrement test total time (s)‡</td>
<td>59.8 ± 2.1</td>
</tr>
</tbody>
</table>

*Rm = repetition maximum.
†Data are sum of 4 skinfold sites (biceps, triceps, subscapular, and suprailiac).
‡Test comprises 10 × 40-m sprints with a rolling 30-second recovery between each sprint.
each testing session. During each trial, subjects were instructed to pull as hard and as fast as possible for a period of approximately 3 seconds. These commands were based on previous research indicating that the use of these instructions produces optimal results for PF and PRFD (3).

**Countermovement Jump and Sprint Acceleration Testing**

**Countermovement Jump.** For the measurement of lower body power, subjects completed CMJ on the portable force platform. To isolate the lower limbs, subjects stood with arms akimbo (2,5). After an initial stationary phase of at least 2 seconds in the upright position for the determination of body weight, the subjects performed a CMJ, dipping to a self-selected depth and then accelerating upward in an attempt to gain maximum height. Subjects landed back on the force platform, and their arms were kept akimbo throughout the movement.

Sprint Acceleration Testing. The time taken to cover a distance of 10 m from a stationary start was used as the measure of sprint speed performance. After their usual warm-up routine supervised by a qualified strength and conditioning coach, athletes performed 3 trials of maximum effort over the 10-m distance on an indoor track. Athletes started in a 2-point crouched position with their preferred foot forward on a mark 30 cm behind the start gate. Light gates (Brower Timing System, Salt Lake City, UT, USA) were set up at the start (0 m) and at 10 m. The subjects were instructed to run as fast as possible during the test and to make sure to run all the way through the finishing gate and the fastest time of the 3 trials was used for data analysis.

**Statistical Analyses**

**Determination of the Initiation of the Midthigh Pull.** A reliable start time or initiation of the IMTP was needed as a reference point for calculation of subsequent variables. The force–time history was not suitable to define a start time because it lacked stability because of the subject holding onto the bar of the rack thus causing a, sometimes considerable, variation in the force being transmitted through the force platform during the pretrigger quiet standing phase. However, the rate of change of force with respect to time (WRT), that is, RFD did show stability during this period, and therefore, this variable was suitable to determine a quiet standing baseline value and threshold, beyond which the IMTP could be defined as having started. The instantaneous rate of change of force WRT was calculated from the first derivative of the vertical component of the GRF–time history. The GRF–time history was first filtered using a dual-pass Butterworth filter (low pass, 20-Hz cut-off) and then numerically differentiated using the central difference method. Filter settings were determined from a pilot study based on Fourier analysis and inspection. The first second of the first derivative–time history was then discarded to avoid the edge effects associated with digital filtering, and a mean and SD were calculated for the remaining 1 second of quiet standing immediately before the trigger point. The start time (T) of the IMTP was then defined as the instant, after the trigger point, that the first derivative exceeded the mean value plus 5 SDs.

The PF was determined from the vertical component of the GRF–time history and was defined as the peak produced during the IMTP minus the subject’s body weight. The F100ms was defined as the absolute value of the vertical component of the GRF minus the subject’s body weight 100 milliseconds after T. The PRFD was taken as the maximum value of the first derivative of the vertical component of the GRF–time history after T.

**Countermovement Jump.** The vertical component of the GRF as the subject performed the CMJ was used in conjunction with the subject’s body weight to determine the instantaneous velocity and displacement of the subject’s center of gravity (CG) (5). Instantaneous power was determined using the following standard relationship:

\[
\text{Power} (W) = \text{vertical GRF (N)} \times \text{vertical velocity of CG (m s}^{-1} \text{)}.
\]

To determine the velocity of the subject’s CG, numerical integration was performed using Simpson’s rule with intervals equal to the sample width. Before the calculation of the strip area, the subject’s body weight (as measured in the stationary phase) was subtracted from the GRF values. The area of the strip, of width equal to the sample rate, then represented the impulse for that time interval. Using the relationship that impulse equals change in momentum, the strip area was then divided by the subject’s mass to produce a value for the change in velocity for the CG. This change in velocity was then added to the CG’s previous velocity to produce a new velocity at a time equal to that particular interval end time. This process was continued throughout the jump. Because this method can only determine the change in velocity, it was necessary to know the CG velocity at some point in time. For this purpose, the velocity of the CG was taken to be zero at the point identified as the start of the jump. The start of the jump was defined as the time when the subject’s GRF exceeded the mean ± 5 SDs from the values obtained in the second (of the stationary body weight measuring phase) immediately before the command to jump, in a fashion similar to Vanrenterghem et al. (14). Integration started from this point.

Vertical displacement was determined by a second integration. The instantaneous velocity time history was numerically integrated (in the same way as described above) from the start point of the jump. The height (vertical displacement) of the CG at the start point of the jump was defined as zero. Jump height was then defined as the difference in the vertical displacement of the CG, between take off (toes leave the force plate) and maximum vertical displacement achieved.

Instantaneous RFD was calculated from the first derivative of the vertical GRF. Before numerical differentiation, the vertical GRF was filtered using a dual-pass Butterworth filter...
Filter settings were determined from a pilot study and based on Fourier analysis and inspection. The PRFD was taken as the highest RFD during the concentric or eccentric phase of the jump. The concentric phase was defined as succeeding the point that the instantaneous velocity of the CG equaled zero after the initiation of the jump.

Test–retest reliabilities (intra-class correlation coefficient [ICC]) for PF, PRFD, and maximum jump height were 0.979, 0.890, and 0.976, respectively. Following a test for the normality of distribution, data were expressed as the mean ± SD. Pearson’s product–moment correlation coefficients was used to assess the relationship between the IMTP variables and measures of dynamic performance.

**RESULTS**

**Peak Force and Peak Rate of Force Development**

Results from Pearson’s product–moment correlation revealed absolute isometric PF (2,529.4 ± 397.8 N) was not a significant predictor of 10-m time (1.7 ± 0.1 seconds) or CMJ height (36.5 ± 4.6 cm); however, PF was significantly correlated to concentric power (5,025.0 ± 528.2 W) (Table 2).

In contrast, there was a significant negative correlation between relative PF and 10-m time and a significant positive correlation between relative PF and CMJ height (Table 2). In addition, PRFD (2,365.4 ± 7,423.9 N s⁻¹) was significantly related to 10-m time and CMJ height (Table 2).

**Force at 100 milliseconds**

There was a significant positive and negative correlation between F100ms and 10-m time and concentric

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**Table 2.** Relationships between various force measures, obtained during the IMTP and dynamic performance.*

<table>
<thead>
<tr>
<th></th>
<th>Peak force (N)</th>
<th>Relative peak force (N·kg⁻¹)</th>
<th>Peak rate of force development (N·s⁻¹)</th>
<th>Force 100 ms (N)</th>
<th>Relative force 100 ms (N·kg⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-m time (s)</td>
<td>−0.23</td>
<td>−0.37†</td>
<td>−0.66‡</td>
<td>−0.54‡</td>
<td>−0.68‡</td>
</tr>
<tr>
<td>CMJ height (cm)</td>
<td>0.31</td>
<td>0.45‡</td>
<td>0.39†</td>
<td>0.30</td>
<td>0.43‡</td>
</tr>
<tr>
<td>Concentric power (W)</td>
<td>0.52‡</td>
<td>0.18</td>
<td>0.28</td>
<td>0.55‡</td>
<td>0.38†</td>
</tr>
</tbody>
</table>

*IMTP = isometric midthigh pull; CMJ = countermovement jump.
†Significant at p < 0.05.
‡Significant at p < 0.01.

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**Figure 1.** Relationship of relative force at 100 milliseconds with countermovement jump (CMJ) height (A) and 10-m time (B).
power, respectively (Table 2). Relative F100ms was highly correlated to 10-m time and CMJ height (Table 2, Figure 1A, B).

**Discussion**

The aim of this study was to examine the relationship between a number of maximum strength and RFD measures of neuromuscular functioning collected during an IMTP and dynamic performance in professional rugby league players. This study demonstrated that dynamic performance in the form of sprint acceleration and countermovement jumping is significantly related to maximum strength and PRFD measures obtained during an IMTP.

In this study, absolute PF was not related to either measure of dynamic performance which is a finding that agrees with some previous research (6,9) but in contrast to the findings of Haff et al. (4) and Stone et al. (13). However, this discrepancy may be explained by the differences in the dynamic activity examined in each study. Where a significant relationship between absolute isometric PF and dynamic performance was found, activities used involved little or no stretch-shorten cycle suggested by the authors as a possible explanation (cycling [3], snatch [4]). The PF expressed relative to body weight, similar to the findings of Khamouï et al. (7), was significantly related with dynamic performance. Performance in the CMJ and 10-m time relied heavily on the acceleration of body mass, as opposed to overcoming inertia and air resistance during sprint cycling (13) or rapid acceleration of an Olympic bar during the snatch (4), and therefore, the absolute measures of PF are secondary in importance to the ability of the athlete to produce high levels of force per kilogram of body mass. Although this does not explain differences in the stretch-shorten cycle activity between the 2 measures, research has identified the IMTP PF to be related to lower body strength (8,9,11) and lower body strength to be related to CMJ and 15-m sprint performance (12); therefore, it is likely that those athletes with the greatest relative lower body strength also performed best for the CMJ and 10-m sprint, potentially explaining the existing relationships found in this study.

The F100ms was significantly negatively related to 10-m time; moreover, when scaled relative to body mass, it showed highly significant relationships with both 10-m time and CMJ height. During sprinting, ground contact time ranges between 50 and 250 milliseconds (1); therefore, those athletes able to produce greater amounts of force during this time are likely to elicit the quickest 10-m times. This has been confirmed by Weyand et al. (15) who found that it was the ability of the athlete to apply greater force in the short ground contact time and not the ability to reposition their limbs more quickly, which was fundamental to speed performance.

Although isometric strength testing has been criticized as to its usefulness in characterizing dynamic performance in the past (6,8,16), this study supports its potential usefulness in relation to dynamic sports. The majority of previous researchers have based their conclusions on a limited sample size, and some studies reported findings from nonelite populations. In this study, we had a sample size of 39 elite rugby league players, which adds additional validity and application to the current findings. In addition, this article presents a detailed explanation of the data collection and data analysis procedure of the neuromuscular variables measured in this study to allow meaningful comparison between the data presented in this study and future studies in this area.

In conclusion, this study has identified that isometric measures of relative PF, PRFD, absolute and relative F100ms are significantly related to measures of dynamic performance in professional rugby league players.

**Practical Applications**

This study demonstrates significant relationships between IMTP variables (relative PF and relative force at 100 milliseconds) and dynamic performance. Because both the training and competition load placed on professional rugby league players, using traditional methods to perform a strength diagnosis by measuring strength, speed, and power separately is not always practical. Therefore, conditioning coaches may seek to use the IMTP as an alternative method to monitor their athlete’s overall strength and power progression.

**References**


