The role of maximal strength and load on initial power production

JOHN B. CRONIN, PETER J. MCNAIR, and ROBERT N. MARSHALL

Sport Performance Centre, and Neuromuscular Research Unit, School of Physiotherapy, Auckland University of Technology, Auckland, NEW ZEALAND; and Department of Sport and Exercise Science, The University of Auckland, Auckland, NEW ZEALAND

ABSTRACT

CRONIN, J. B., P. J. MCNAIR, and R. N. MARSHALL. The role of maximal strength and load on initial power production. Med. Sci. Sports Exerc., Vol. 32, No. 10, pp. 1763–1769, 2000. Purpose: The influence of maximal strength, as measured by the maximal load lifted for one repetition (1RM), on power production in the initial 200 ms of the concentric phase for both rebound and nonrebound movements was investigated. We also investigated the effect of external load upon this relationship. Methods: Twenty-seven male subjects (21.9 ± 3.1 yr, 89.0 ± 12.5 kg) were separated by previously determined bench press 1RM into high (100.88 ± 7.24 kg) and low (72 ± 6.61 kg) RM groups. Concentric only bench presses and rebound bench presses were compared between and within groups to note the effect of RM across external loads of 40%, 60%, and 80% 1RM, on instantaneous, mean, and peak power output. Results: The results of this study clearly indicated the enhancement of concentric motion by prior eccentric muscle action (336 – 1332% enhancement in the first 20 ms). Possessing a high RM augmented power production in the initial 200 ms of stretch-shorten cycle activity, across all the external resistances tested (P < 0.05). The temporal characteristics of this enhancement, however, differed across loads. That is, 80% 1RM loading showed a later time to peak enhancement (80 ms vs 20 ms). Interestingly, the influence of RM on concentric only motion in the initial 200 ms across the external resistances tested was found to be nonsignificant. Conclusions: The results suggest that the role of maximal strength during initial power production between concentric and stretch-shorten cycle activity differs, which has important implications for the training of athletes. Key Words: MUSCLE POWER, BENCH PRESS, ENHANCEMENT

There is much debate as to the mechanisms underlying the enhancement associated with concentric motion preceded by eccentric muscle action. A recent article by van Ingen Schenau and colleagues (32) and subsequent dialogue between scientists has fuelled this debate to new levels. As a result, the contradictory data in this area make any clear position as to the explanations of this enhancement very difficult. Most of the literature, however, attributes the enhancement to one or more of a combination of four factors: the recovery of elastic strain energy, a higher active muscle state before the beginning of the concentric muscle action, myoelectrical potentiation, and chemomechanical potentiation (4–6,8,9,15). When calculating this enhancement, researchers typically use the ratio between the rebound and nonrebound values for a chosen variable and evaluate this enhancement in terms of the benefits gained at the end of the concentric phase. It is recognized, however, that the augmentation due to prior eccentric muscle action in stretch-shortening cycle (SSC) activity primarily enhances the initial period of the concentric phase (6,29,34). Dependent on the movement time of specific athletic activities, the measurement of power augmentation in the initial concentric phase as compared with the entire concentric phase may be a better predictor of success and/or better differentiate training methods that may facilitate success.

For the purposes of this article, maximal strength will be defined as the maximal voluntary force a muscle or group of muscles can exert as measured by the greatest load that can be moved through the concentric phase of motion (27). In terms of the relationship between maximal strength and SSC ability, most research has compared SSC ability and maximal isometric strength, and/or related maximum strength with SSC performance as measured by release velocity or height jumped/thrown at the completion of the concentric phase (13,14,24). The role of maximal strength in the initial concentric phase of SSC performance is not well documented. Schmidtbleicher (27,28) explained the effects of maximal strength on isometric, concentric, and SSC performance. He suggested that maximal strength is the basic quality that affects power performance, the extent being dependent on the magnitude of the external load. For power production during concentric contractions, the influence of maximal strength diminishes with decreasing external loads and other strength qualities become more important. These qualities have been described by various practitioners (27,30) as starting strength or initial rate of force development and explosive strength or maximum rate of force.
development. These strength qualities are typically measured from an isometric force-time curve.

Schmidtbleicher (28) also stated that for power performance in a SSC activity the correlation between maximal strength and power output is fairly low. This appears somewhat contradictory to earlier comments. Hartmann and Tunneman (1989) cited in King (16) stated that greater loads influenced the effects associated with the SSC. At high loads, the contribution of a SSC to power output was decreased and the contribution of maximal strength greater. Conversely, for lighter loads, the contribution of maximal strength to power output is less. The contribution of the SSC for such loads is greater due to shorter coupling and concentric contraction times, and faster rates of eccentric muscle action (1,3,6,16). Alternatively, due to the shorter movement times associated with light-load explosive movement, the greater the importance of the eccentric phase as it enables a higher active muscle state. This will improve the ability of the neuromuscular system to develop high force and power during rapid muscle shortening.

This study aims to investigate the influence of an individual’s maximal strength on power production in the initial concentric phase (200 ms) for both rebound and nonrebound movement and to note the effect of external load upon this relationship. Such an investigation should provide information as to the conditions of loading and movement type, which are optimal for the production of maximal power by the neuromuscular system. The application of this information should benefit activities characterized by applications of force for very brief periods of time.

METHODS
Subjects

Twenty-seven men volunteered to participate in this research. The subject mean (± SD) age, weight, and maximal bench press strength (1RM) as measured by a rebound bench press, were 21.9 ± 3.1 yr, 89.0 ± 12.5 kg, and 86.3 ± 13.7 kg. All of the subjects were of an athletic background; however, none reported using strength training in the previous 6 months. The Human Subject Ethics Committee of the University of Auckland approved all the procedures undertaken and all subjects signed an informed consent form.

Testing Procedures

The testing procedures utilized in this research were similar to those outlined by Newton and his coworkers (22). Testing was performed over two sessions, the first of which determined the maximal bench press load as measured by a rebound bench press that each subject could lift for one repetition (1RM). At the completion of the RM testing, subjects performed a number of bench presses to familiarize themselves with the power movements. These were a nonrebound or concentric bench press (CBP), in which a mechanical brake was positioned so that the bar rested approximately 5 cm above each subject’s chest, parallel to the nipples. The bar was then projected from rest as fast as possible and was held at the end of the movement. For the rebound bench press (RBP), subjects were instructed to begin with the weighted barbell at arm’s length and then lower the bar as quickly as possible, to just above the nipples and then immediately push the bar upward, the bar again held at the end of the movement.

The second session began with a generalized warm-up of arm/shoulder mobilization exercises, two sets of 10 bench presses at 40% 1RM, followed by 5 min of pectoral and triceps brachii static stretches. Each subject was strapped across the upper chest to the bench and was instructed to move the bar as “fast” as possible for all loads and movement types. Strapping of the upper body was necessary as it was noted during piloting that if the upper torso came away from the bench or remained fixed affected the kinematics of the lift markedly. Two movements were performed for three training loads (40, 60, and 80% 1RM). One trial was completed per movement type and load, and rest periods of 1 min between each explosive movement and 2 min between change of loads were provided. Reliability was established in pilot testing. Table 1 indicates the intraclass correlation coefficients across trials and days for mean power and peak power. Due to the high correlation’s between one and three trials and the high test-retest reliability of one trial over 7 d, the performance and analysis of one trial was thought to give similar information as to the mean of three trials. For this reason and to minimize fatigue and maximize motivation the use of the testing procedures outlined above were thought appropriate. For the rebound movements, no pause was allowed between the eccentric and concentric phases and the trial was rejected if the bar touched the chest, or the eccentric phase was terminated greater than 5 cm from the chest. Before testing, starting loads and movement types were randomized between subjects to reduce the possible confounding effects of order and fatigue.

Equipment

Modified Smith Press. Subjects performed bench presses on a modified Smith Press machine. A linear transducer (Unimeasure, Corvallis, OR) was attached to the bar and measured vertical bar displacement relative to the ground with an accuracy of 0.01 cm. These data were sampled at 200 Hz by a computer based data acquisition and analysis program.
RESULTS

Figure 1 shows the percentage improvement (RBP/CBP × 100) achieved using rebound at a load of 40% 1RM, between groups with differing maximal strength. For both the high and low RM groups, the mean initial power output (0–200 ms) in the concentric phase across all loads was enhanced when the concentric muscle action was preceded by eccentric muscle action. The greatest SSC augmentation was found at the inception of the concentric phase (20 ms). The mean percentage improvement across 40, 80, 120, 160, and 200 ms was statistically analyzed. The two curves differed significantly until 200 ms ($F = 4.674, df = 16, P = 0.052$). Greater SSC augmentation was found in the high RM group.

Utilizing a loading intensity of 60% 1RM resulted in similar results to that of 40% 1RM in terms of percentage and duration of improvement between groups with differing maximal strength. For 80% 1RM, however, the percentage improvement was less and the difference between high and low strength groups nonsignificant throughout the initial 200 ms.

Table 2 compares the differences between high and low RM groups on a number of variables for concentric only and rebound bench press motion. The high and low RM groups differed by 28% in terms of their maximal bench press strength. This difference was reflected in the differences between mean power outputs shown within the table. Utilizing rebound reportedly reduces the duration of the ensuing concentric phase as compared with concentric only motion (22). This phenomenon was observed across all loads; however, it was only found to be significant at the lighter loading intensity of 40% 1RM. Similar findings were observed for time to peak power. That is, for the lighter loading intensity of 40% 1RM, the time to peak power was achieved earlier in the rebound condition, whereas no significant differences were found between conditions and groups for other loads. As load increased, so too did the time taken to achieve peak power. It appears, for light loads at least, that the effect of rebound is to shift the power-time curve to the left as evidenced by shorter time to peak power, shorter concentric contraction times, and similar peak power outputs.

Mean power output was enhanced by 8.0–15.8% across loads for the bench press motion that used rebound. However, there was no significant difference in peak power output between rebound and concentric only conditions across 40, 60, and 80% 1RM. The high RM group produced statistically higher mean and peak power output across most loads for both rebound and nonrebound motion. The highest mean power output was found at 60% 1RM, whereas the highest peak power output was found at the lighter loading intensity of 40% 1RM.

Figures 2 and 3 compare the high RM and low RM group for concentric and rebound motion across light (40% 1RM) and heavy (80% 1RM) loading. The comparison of CBP curves from Figure 2 shows that both the high RM and low RM group produce similar power-time curves for light loads (40% 1RM). Initial power output was greater, however, in those subjects that possessed greater RM for muscle actions that required rebound. Loading the muscle at 60% 1RM produced similar curves to Figure 2 and therefore was not reported.

Data Analysis

The displacement-time data were filtered using a low-pass filter with a cutoff frequency of 10 Hz. The filtered data were then differentiated using a finite differences algorithm to determine velocity and acceleration data. The following variables were determined for the bar from its kinematic and mass characteristics during the concentric phase: average velocity, peak velocity, peak acceleration, mean force, peak force, mean power, and peak power. For the sake of clarity and presentation, temporal analysis of the power variable involved calculating instantaneous power output from the power-time signal every 20 ms for the initial 200 ms of the concentric action. The changes within 20 ms were found to be representative of the signals collected using the 5-ms data collection frequency. The duration of 200 ms was selected so as results and findings could be applied to activities involving application of force for very brief periods. Furthermore, this time was consistent with the methods and finite times used in previous research (34). The augmentation effect of the prior eccentric contraction was calculated by comparing the RBP–CBP mean power values and expressing the difference as a percentage per unit time (20 ms).

Statistical Analysis

Only the power-time data from the CBP and RBP will be reported here. To examine the importance of maximal strength to the performance of dynamic SSC actions, the nine subjects with highest RM (100.88 ± 7.24 kg) and nine subjects with the lowest RM (72 ± 6.61 kg) were compared. As there were two levels of between subjects factor (high and low RM), two levels of within subjects factor mode (concentric and rebound action) and three levels of the within subject factor (load), a $2 \times 2 \times 3$ mixed factor analysis of variance with post hoc contrasts was used to distinguish the effects. The alpha level was set at 0.05.
For the heaviest loading intensity (80% 1RM), the influence of maximal strength on power output in concentric only motion was nonsignificant throughout the initial 200 ms (see Fig. 3). For the RBP condition, however, the group possessing greater maximal strength produced greater instantaneous power throughout the initial 200 ms.

For all three loads, greater initial instantaneous power output in motion that utilized rebound was shown. Concentric only motion was typified by a gradual increase in power output initially with a greater rise in power output later in the initial 200 ms. Figure 3 shows the slower rise in instantaneous power output for both concentric (significant at 60 ms) and rebound motion (significant at 20 ms) utilizing heavier loads as compared to the lighter loading intensity shown by Figure 2.

The contribution of RM to initial concentric power output was nonsignificant. It appears that for power performance utilizing concentric only motion other “strength qualities” may be important. To delineate this effect on concentric and rebound motion and its relationship to maximal strength, subjects were sorted into two groups of nine based on their peak power in the first 40 ms of the CBP (PP40ms). Figure 4 shows the importance of fast PP40ms for initial power output for concentric only motion at 80% 1RM. The effect of PP40ms on rebound motion was nonsignificant. These findings were similar across all loading intensities thus the representation of only the one graph (Fig. 4). Moreover, the difference between maximal strength, mean power and peak power output in the slow and fast PP40ms groups was found to be nonsignificant. The only significant difference was a within group effect between RBP and CBP mean power.

### DISCUSSION

**Initial SSC Enhancement and the Effect of Maximal Strength**

SSC enhancement as measured by release velocity or jump height has been shown to improve performance by approximately 12–18% when calculated over the entire concentric phase (1,8,18). Similar values for enhancement were found in this research, the use of rebound improving bench press mean power output by 8–15.8% across the loads tested. The present results for the initial concentric action, however, indicated that the average prestretch augmented

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**TABLE 2.** The low and high RM groups compared between similar movements and loads for duration of concentric contraction, mean power output, peak power output, and time to peak power.

<table>
<thead>
<tr>
<th>Movement</th>
<th>RM</th>
<th>Duration of Contraction (ms) (±SD)</th>
<th>Mean Power Output (Watts) (±SD)</th>
<th>% Diff. Low-High Strength (%)</th>
<th>Peak Power Output (Watts) (±SD)</th>
<th>% Diff. Low-High Strength (%)</th>
<th>Time to Peak Power (s) (±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBP 40% Low RM</td>
<td>.689 (.134)</td>
<td>201.08 (28.28)</td>
<td>30.7*</td>
<td>445.13 (61.14)</td>
<td>27.5*</td>
<td>.434 (.123)</td>
<td></td>
</tr>
<tr>
<td>CBP 40% High RM</td>
<td>.688 (.122)</td>
<td>290.80 (56.60)</td>
<td>0.001</td>
<td>613.62 (149.61)</td>
<td>0.006</td>
<td>.452 (.112)</td>
<td></td>
</tr>
<tr>
<td>RBP 40% Low RM</td>
<td>.607 (.088)</td>
<td>232.85 (25.49)</td>
<td>27.5*</td>
<td>444.85 (51.89)</td>
<td>28.2*</td>
<td>.381 (.033)</td>
<td></td>
</tr>
<tr>
<td>RBP 40% High RM</td>
<td>.617 (.098)*</td>
<td>321.16 (60.40)</td>
<td>0.001</td>
<td>619.22 (161.07)</td>
<td>0.007</td>
<td>.343 (.038)*</td>
<td></td>
</tr>
<tr>
<td>CBP 60% Low RM</td>
<td>.834 (.065)</td>
<td>314.63 (61.98)</td>
<td>24.5*</td>
<td>501.79 (35.27)</td>
<td>12.4</td>
<td>.595 (.064)</td>
<td></td>
</tr>
<tr>
<td>CBP 60% High RM</td>
<td>.822 (.066)</td>
<td>243.77 (52.07)</td>
<td>0.004</td>
<td>572.65 (79.76)</td>
<td>0.076</td>
<td>.595 (.064)</td>
<td></td>
</tr>
<tr>
<td>RBP 60% Low RM</td>
<td>.786 (.070)</td>
<td>353.09 (66.25)</td>
<td>0.002</td>
<td>556.02 (80.94)</td>
<td>0.008</td>
<td>.549 (.073)</td>
<td></td>
</tr>
<tr>
<td>RBP 60% High RM</td>
<td>1.171 (.071)</td>
<td>207.83 (40.79)</td>
<td>21.9*</td>
<td>440.32 (73.42)</td>
<td>14.6</td>
<td>.717 (.366)</td>
<td></td>
</tr>
<tr>
<td>CBP 80% Low RM</td>
<td>1.233 (.162)</td>
<td>232.23 (56.08)</td>
<td>0.004</td>
<td>515.05 (157.88)</td>
<td>0.222</td>
<td>.784 (476)</td>
<td></td>
</tr>
<tr>
<td>RBP 80% Low RM</td>
<td>1.164 (.178)</td>
<td>212.64 (33.04)</td>
<td>25.8*</td>
<td>408.88 (77.35)</td>
<td>18.1</td>
<td>.698 (309)</td>
<td></td>
</tr>
<tr>
<td>RBP 80% High RM</td>
<td>1.224 (.253)</td>
<td>286.50 (79.92)</td>
<td>0.005</td>
<td>498.66 (167.88)</td>
<td>0.164</td>
<td>.705 (.321)</td>
<td></td>
</tr>
</tbody>
</table>

* Significant at an alpha level of 0.05.

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Figure 2—Mean instantaneous power during the initial 200 ms of the ascent phase for the CBP and RBP at 40% 1RM between groups of differing RM: †, CBP low RM; ‡, CBP high RM; †, RBP low RM; Δ, RBP high RM. * Denotes there are significant differences from 60 ms (P <0.05).

Figure 3—Mean instantaneous power during the initial 200 ms of the ascent phase for the CBP and RBP at 80% 1RM between groups of differing RM: †, CBP low RM; ‡, CBP high RM; †, RBP low RM; Δ, RBP high RM. * Denotes there are significant differences from 20 ms (P <0.05).
power production was between 330-1330% in the initial 100 ms for all loads. Furthermore, increases of 140–510% in power output were recorded in the following 100 ms. Comparisons between the power curves revealed that during the initial 200 ms, the RBP involved a greater rate of doing work as compared to the CBP across all loads (see Figs. 2 and 3). However, the decay in this benefit was quite rapid at the lighter loading intensities (40–60% 1RM) with most of the potentiation dissipated by 200 ms (see Fig. 1). These results are in agreement to other research that reported similar forces, velocities, and power outputs between rebound and concentric only activities 250 ms into the concentric phase and any prestretch augmentation no longer apparent after 0.37s (6,34).

It is clear from the Figures 2 and 3 that the group possessing greater maximal strength produced significantly greater power output during the initial concentric phase of the RBP motion. The higher initial power outputs recorded for the RBP technique for the high RM group are probably due to the ability of a stronger muscle to generate a higher level of active state at the inception of the concentric phase. Figure 1 also revealed that for the lighter loads, the percentage improvement in initial power output afforded by rebound is greatest among subjects possessing greater maximal strength. This suggests that a stronger muscle may utilize the mechanisms associated with concentric augmentation to greater effect compared with a weaker muscle. This in part may explain the nonsignificant differences between high and low strength groups at 80% 1RM. That is, associated with heavier loading intensities are decreases in stretch velocity and increases in coupling time and the duration of the eccentric-concentric phases. Some researchers have suggested that optimal use of elastic strain energy occurs when the natural frequency of the musculotendinous unit is equal to the movement frequency of the SSC activity, allowing the system to operate in resonance (2,7,33). In essence, the concept of resonance suggests that elastic systems have a preferred rate of stretch in which elastic energy is stored and subsequently used in the ensuing power production phase. It may be speculated that the differences in stretch velocity, coupling times, and eccentric-concentric phase durations as imposed by the external loading of 80% 1RM affected the resonance of the musculotendinous system.

**Maximal Strength and Enhancement to Mean and Peak Power Output**

Loads of 30–50% 1RM are proposed as the loads that best optimize power output (10,20,23). Higher peak powers were found at 40% 1RM, whereas higher mean power outputs were found at 60% 1RM. It could be that loading of 40% 1RM leads to higher peak power values by optimizing the velocity contribution to power output. Conversely, the heavier loading of 60% 1RM may offer superior mean power values by optimizing the force production contribution to power output. It has been suggested that during more traditional lifts, such as the bench press, power outputs may be maximized at loads of 60% 1RM or greater (21). In terms of training, the importance of mean and/or peak power for an activity may need to be determined and the training loads prescribed accordingly.

The use of rebound led to reduced concentric times at the lighter load of 40% 1RM only. A reduced concentric phase across loads has been reported by other research (22). The apparent difference in our findings across the heavier loads may be explained, as smaller differences in SSC enhancement have been found with heavier loads due to longer stretching phases and increased coupling times. The benefits gained from the mechanisms involved in enhancement may therefore be compromised (4). Comparing high-low RM groups revealed those subjects in the high RM groups produced greater mean and peak power outputs, irrespective of whether they were performing rebound or nonrebound motion. Possessing greater maximal strength can be concluded to be an important factor in producing mean and peak power output for both concentric and eccentric-concentric motion. Coupled with the finding that there was no significant difference in peak power between CBP and RBP motion when groups of similar RM were compared would suggest that an individual’s maximal strength is a fundamental quality for powerful concentric and SSC motion. The relative importance of possessing a greater RM, however, would seem a function of the duration of the concentric phase and the type of muscle action.

Interestingly, peak power across the total concentric phase was not affected by rebound action. It would seem that the effect of a rebound movement is to cause a phase shift of the power-time signal to the left, the peak power remaining unaffected other than in temporal terms. Producing greater peak power would seem a function of maximal strength rather than an individual’s ability to utilize the SSC. This is indicated by peak power occurring after most of the SSC enhancement has decayed as shown by the instantaneous power signals depicted in Figure 1 and kinematic/kinetic data presented in Table 1.
Load, Maximal Strength, and SSC Power Production

Comparison of the power outputs for the RBP between high and low RM groups revealed that for all external resistances the low RM group’s power was less than their high RM counterparts (see Figs. 2, 3 and Table 2). This has been attributed to a higher active muscle state due to the eccentric phase. Alternatively, it may be that the stronger subjects can produce greater power output during the early concentric phase for the same relative load due to the force-velocity-power characteristics of muscle. Irrespective of the reason, the ability to maximize power output through use of the SSC over the external resistances used in this research would seem to be influenced by an individual’s maximal strength. In fact, as resistance increases the role of a greater RM became more marked.

Schmidtbleicher’s (27,28) position that the correlation between maximal strength and power output from a SSC is fairly low is not apparent from our findings. Our findings suggest that maximal strength is an important influence on instantaneous, mean, and peak SSC power output across all the loads tested in this study. It may be speculated that having greater maximal strength may influence SSC enhancement in many ways. First, greater strength is associated with greater muscle cross section and therefore a greater number of myosin crossbridges in parallel that can interact with the actin filaments to generate force (11). If the crucial contribution of eccentric muscle action is to allow the muscle to build up a high level of active state then having a greater number of crossbridges and therefore potential for a greater fraction of attached crossbridges at the beginning of the concentric phase would explain the SSC enhancement associated with the high RM group. Alteration to tendon architecture has also been attributed to strength training, greater strength being associated with enhanced collagen synthesis and increases in collagen content resulting in increased tendon thickness, weight, strength, and stiffness (31,35). Grimby (12) also reported that strength training increased the collagen content of the muscle, which indicated an increase in strength of the epimysium, perimysium, and endomysium. This suggests that stronger muscles may have improved connective tissue maximum tensile strength and elastic energy storage and utilization capabilities.

It is also well documented that strength and power training can improve muscle stiffness (17,25). Komi (17) proposed that the facilitatory stretch reflex from the muscle spindles can be enhanced and the inhibitory feedback from the Golgi tendon organs can be simultaneously decreased through strength training. Increases in reflex potentiation after strength training have been reported (19,26). This increased strength would allow greater stiffness, which in turn allows greater, stretch-load tolerance, storage of elastic energy, and improved power and mechanical efficiency. Research from Wilson et al. (33) supports this contention with the stiffest subjects producing superior average force and rate of force development to their more compliant counterparts. Any number if not all of these factors could explain the significant contribution that a greater RM has to power output in SSC activity. Such speculation as to the benefits of greater maximal strength, however, certainly need investigation and provides direction for future research.

Maximal Strength and Initial Concentric Power Production

The contribution of maximal strength to concentric only power output is interesting and warrants discussion. As indicated by Figures 2 and 3, the contribution of greater maximal strength to concentric power output in the first 200 ms for all loading intensities was nonsignificant. In an effort to elucidate the contribution of maximal strength to power output the subjects were sorted by initial power output (PP40ms). As expected Figure 4 shows that having high PP40ms produced vastly superior power output for the first 200 ms of the concentric only condition. The effect of PP40ms for the rebound condition, however, was nonsignificant. Analysis of the RBP data revealed no significant differences between the 1RM, mean and peak power of the fast PP40ms and slow PP40ms groups. That is, the ability of the neuromuscular system to generate power quickly appears unimportant in motion using the SSC. Conversely, it would appear that being stronger is not important in concentric only performance of less than 200 ms, across a variety of external loads as shown by the graphs. These results seem to indicate that the neuromuscular basis of PP40ms differs to maximal strength and strength qualities such as starting strength (initial rate of force development) and explosive strength (maximum rate of force development) have greater importance for rapid concentric power output. As such, rate of onset of muscle activation, increased firing frequencies, selective recruitment of fast motor units, synchronization, preferential recruitment of fast muscles, depressed inhibitory and/or improved facilitatory reflexes, myosin light chain composition, and type of troponin and tropomyosin isoforms are all factors that may affect rate of force development and therefore initial power output (11,13,17,25,26).

CONCLUSION

The results of this study indicate the importance of possessing greater maximal strength when producing power in the initial 200 ms of SSC activity, across the external resistances tested. Motion that used rebound produced higher power at the inception of the concentric phase, which resulted in greater initial instantaneous and mean power outputs for both low and high RM groups. This potentiation is probably due to a combination of several factors including contraction dynamics, restitution of elastic strain energy, and greater myoelectrical potentiation. The subjects that possessed greater RM using rebound motion produced greater power output to the lower RM group. It has been suggested that the ability of stronger muscles to generate a higher active state at the inception of the concentric phase is the underlying mechanism responsible for this phenomenon. This difference can be attributed to a number of factors that affect the force production capability of the contractile,
series elastic, and parallel elastic components of the musculotendinous unit. The augmentation to power production was found across all external loads tested though the temporal characteristics of this potentiation differed across loads. For SSC activity of short duration, greater maximal strength will result in greater instantaneous power production; maximal strength training methods should therefore be an integral training strategy for such activity.

The present findings also reinforce the importance of PP_{0ms} in producing power in the initial 200 ms of concentric only motion. The influence of possessing a high RM in this type of motion across a variety of external resistances is secondary to the ability of the neuromuscular system to produce the greatest amount of power per unit time. For concentric only motion that requires high rates of initial power production, maximal strength training is not recommended. Instead, methods that improve the rate of power development would appear better training options for the development of motor performance of short duration (<200 ms), even when the external resistance is high.

Address for correspondence: John Cronin, Sport Performance Centre, Auckland University of Technology, Private Bag 92006, Auckland 1020, New Zealand; E-mail: john.cronin@aut.ac.nz.

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