STRENGTH-POWER RELATIONSHIPS DURING TWO LOWER EXTREMITY MOVEMENTS IN FEMALE DIVISION I ROWERS

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ABSTRACT

Lund RJ, Dolny DG, Browder KD. Strength-power relationships during two lower extremity movements in female Division I rowers. JEPonline 2006;9(3):41-52. The purpose of this study was to examine the role of strength in the ability to express power during concentric-only (CO) and stretch-shortening cycle (SSC) leg press movements in a group of similarly strength-trained members of a Division I female rowing team, and to observe the effect of load on the relationship between strength and power. Subjects (n=30) performed one-repetition maximum (1RM) tests on the Omnikinetic (Omk) dynamometer as well as two series (CO vs. SSC) of explosive leg presses with loads ranging from 30-80% 1RM. Moderate to strong relationships were observed between 1RM and peak power (PP) (r = 0.436 – 0.718) for both CO and SSC except for 80% CO and 70-80% SSC. There were few significant correlations between 1RM and power output during the initial 200 ms of the concentric phase (P50-200). Additionally, subjects were placed into high-RM (n=13, 1RM>187 kg) and low-RM (n=17, 1RM<187 kg) groups and compared. The high-RM group had significantly greater PP at all loads for both CO and SSC except for 80% CO and 70-80% SSC. There were no significant differences at P50 for both CO and SSC. Stronger subjects had significantly greater P100 at 30–50% CO and at 40% SSC, greater P150 at 30–50% CO and at 40% SSC as well as greater P200 at 30-50% CO and at 50-60% SSC. It appears that strength plays a significant role in PP during both CO and SSC leg press movements in similarly trained female Division I rowers and the effect of strength diminishes at the greatest loads.

Key Words: Force, Concentric-Only, Stretch-Shortening Cycle
INTRODUCTION

The ability of skeletal muscle to express mechanical power may be its most crucial function (1). Power is a fundamental component for success in many team sports such as football (2), basketball (3), soccer (4), and volleyball (5). Additionally, power has also been observed to be important in many individual sports such as tae kwon do (6), the biathlon (7), and sprint cycling (8). Finally, power has been demonstrated to be a significant predictor of time to complete a 2000-meter rowing race (9).

Since power is the product of force and velocity, it is generally believed that strength plays an important role in regards to the expression of power, however, this relationship may depend upon the movement due to differences in type of muscle contraction and the external load involved. Schmidtbleicher (10) stated that “maximal strength is the basic quality that influences power performance.” However he postulated that in movements utilizing the stretch-shortening cycle (SSC), correlations between strength and power output would be low. Conversely, concentric-only movements (CO) rely more on strength as the load increases. This has obvious training implications however only two studies have attended to this topic specifically (11,12).

A study by Cronin, McNair and Marshall (11) explored the role of maximal strength in power production during the initial 200 ms of the concentric phase of a non-ballistic CO bench press and SSC bench press in untrained, college-aged men. The researchers separated the subjects into high-RM and low-RM groups based on one repetition maximum (1RM) performance to compare several power variables between the groups. The researchers observed that power output was significantly greater in the high-RM group for both CO and SSC bench press movements, across all loads (40, 60 and 80% 1RM) when analyzing the entire concentric phase. When analyzing the first 200 ms of the concentric phase, greater power outputs were observed in the high-RM group during the rebound (SSC) bench press movement, across all loads, however, no differences were reported during the CO bench press movement.

Stone, O’Bryant et al. (12) reported strong significant correlations between squat one-repetition maximum (1RM) and CO squat jump peak power (PP) as well as countermovement squat jump PP across a wide range of loads (10-100% 1RM). An additional analysis reported that PP was significantly greater for both CO and countermovement squat jumps at all loads in the 5 strongest subjects compared to the 5 weakest subjects.

It should be noted that the subjects used by Cronin et al. (11) had participated in no strength training for at least 6 months prior to testing. In the study by Stone, O’Bryant et al., (12) the subjects reported a wide range in resistance training experience. These subjects were purposely recruited in this manner to “magnify” any observed relationships. These two studies suggest that strength plays an important role in power production for both CO and SSC movements. This may be especially true when there is a large amount of heterogeneity within the sample. It is of interest to the authors whether or not the role of strength will be maintained in a similarly trained group that is less heterogeneous. Therefore, the purpose of this study was to examine the role of strength in the ability to express power during CO and SSC leg press movements in a group of similarly strength-trained members of a Division I female rowing team, and to observe the effect load on the relationship between strength and power. Although, we believe that strength will play a significant role in the ability to express power, we expect to see an attenuated effect due to the heterogeneity of the sample.
METHODS

Subjects
Thirty female NCAA Division I crew members participated in this study. All subjects were engaged in a resistance-training program prescribed by their strength and conditioning coach for the six months prior to testing. All procedures were reviewed and approved by the Human Assurance Committee at the University of Idaho, in accordance with the policies regarding the use of human subjects, established by the American College of Sports Medicine.

Procedures
Although ballistic techniques have received considerable attention in regards to training for power (13,14), the performance of non-ballistic leg press movements may be advantageous to rowers due to the specificity of such movements. Ballistic techniques involve the projection of the load into space resulting in minimal or no deceleration phase. To evaluate lower extremity power performance in collegiate rowers, a novel lower extremity dynamometer capable of measuring bilateral power output was used, where the foot was fixed to a foot-pad.

After an orientation to explain procedures and sign the informed consent, two testing sessions took place. During the first testing session anthropometric measurements (height, weight and trochanter length) were taken and a 1RM on the Omnikinetic dynamometer (Omk) was performed. Trochanter length was defined as the distance between the greater trochanter, as determined by palpation, to the floor. Trochanter length was required in order to estimate several lower extremity variables for the kinetic computations (15). Before performing 1RM, all subjects performed a warm-up consisting of 5 minutes of pedaling on a cycle ergometer with no resistance. The double leg press 1RM was conducted on the Omk using the National Strength and Conditioning Association (NSCA) procedure for conducting 1RM tests (16).

After a minimum of four days of rest the second testing session took place. This session involved two series of explosive leg presses performed on the Omk. One series consisted of CO leg press and the other involved SSC leg press. CO leg press started with the legs in the flexed position and ended with the legs in the extended position for three repetitions at each load. SSC leg press started with the legs in the extended position. The subjects then flexed and re-extended the legs for three repetitions at each load. The loads used for both series of explosive leg presses were 30, 40, 50, 60, 70 and 80% 1RM with 3-minute rest intervals between sets. A 10-minute rest interval was provided between CO and SSC sets. Subjects were instructed to perform all repetitions as fast as possible. The order of the two series of movements, as well as load assignment, was randomized to minimize an order effect. A flow figure has been provided for clarification (Figure 1).

Instrumentation
The Omk (Interactive Performance Monitoring, Pullman, WA) is a seated, closed chain, bilateral lower extremity dynamometer that allows the user to move in either a unilateral or bilateral stepping movement pattern. Resistance is provided pneumatically in order to minimize the effect of inertia. The motion is concentric extension-eccentric flexion and reflects the muscle actions encountered.
during rowing, and therefore this represents a suitable assessment tool for this investigation. The instrument is designed to measure crank position, pedal position, seat position as well as normal and tensile forces about the crank. The modeling of the lower extremity kinematics and kinetics is based on a modified Hanavan anthropometric mode (17). The Omk method has proven to be valid and reliable and a more complete description has been published elsewhere (15). Peak power of the concentric phase (PP), as well as power at the first 50, 100, 150 and 200 ms (P₅₀₋₂₀₀) of the concentric phase was recorded. Time-to-peak power (TPP) was defined as the time (ms) between the beginning of the concentric phase and peak power output. All variables were recorded as the mean of the right and left legs averaged over the three repetitions.

**Statistical Analyses**

Descriptive statistics were calculated for all variables. Pearson product moment correlation tests were conducted to determine the strength of the relationships between 1RM and all power variables across all loads for both CO and SSC. Subjects were also sorted into two groups by 1RM. The subjects with 1RM values greater than 187 kg (n=13) were placed in the high-RM group and subjects with 1RM values less than 187 kg (n=17) were placed in the low-RM group. This cut off value was chosen because it resulted in no tie scores between the low and high-RM groups. Independent t-tests were used to compare the means of all power variables between the high-RM and low-RM groups across all loads for both CO and SSC. The alpha level was preset (p<0.05) for all statistical analyses. Assuming a desired power of 80% and a standard deviation of 100 W for PP (based on previous work in our lab), it was calculated that 22 participants would be required to detect a significant difference of 100 W. Our actual sample would detect a difference of approximately 115 W. Intraclass correlations of all power variables can be found in Table 1.

**RESULTS**

Descriptive statistics (mean±SD) of anthropometric variables and 1RM for the high-RM and low-RM groups are presented in Table 2. Descriptive statistics of TPP are displayed in Table 3.

Correlation matrices of all variables of interest are in Tables 4-6. Moderate to strong relationships were observed between 1RM and PP (r = 0.436 – 0.718) for both CO and SSC except for 80% CO and 70-80% SSC (Table 4). All of the 1RM-P₅₀ and 1RM-P₁₀₀ relationships (Table 5) were insignificant except for 40% SSC (r = 0.369, r = 0.544). Moderate relationships were observed between 1RM and P₁₅₀ (r = 0.432 – 0.672) at 30% and 40% 1RM for both CO and SSC (Table 6). Moderate 1RM-P₂₀₀ relationships (r = 0.483 – 0.639) were observed at 30 and 40% CO and at 50 and 60% SSC (Table 6).

### Table 1. Intraclass correlations of all power variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>R</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td></td>
<td>0.918</td>
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</tr>
<tr>
<td>PP</td>
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<td>0.758</td>
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</tr>
<tr>
<td>P₅₀</td>
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<td>0.702</td>
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</tr>
<tr>
<td>P₁₀₀</td>
<td>53</td>
<td>0.894</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>P₁₅₀</td>
<td>53</td>
<td>0.927</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>P₂₀₀</td>
<td>53</td>
<td>0.918</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>SSC</td>
<td>53</td>
<td>0.734</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>PP</td>
<td>51</td>
<td>0.659</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>P₅₀</td>
<td>51</td>
<td>0.738</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>P₁₀₀</td>
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<td>0.687</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>P₁₅₀</td>
<td>51</td>
<td>0.648</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>P₂₀₀</td>
<td>51</td>
<td>0.648</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

### Table 2. Descriptive statistics of subjects by high-RM and low-RM groups

<table>
<thead>
<tr>
<th>Variable</th>
<th>High-RM (n=13)</th>
<th>Low-RM (n=17)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>19.8 ± 1.0</td>
<td>19.5 ± 0.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>176.9 ± 4.7</td>
<td>176.3 ± 4.9</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>80.2 ± 5.8</td>
<td>76.1 ± 5.5</td>
</tr>
<tr>
<td>1RM (kg)</td>
<td>202.7 ± 9.9</td>
<td>178.3 ± 9.8</td>
</tr>
</tbody>
</table>
Results of the independent t-tests have been displayed graphically (Figures 2-8). High-RM subjects had significantly greater PP at all loads for both CO and SSC (Figures 2,3).

There were no significant differences between high-RM and low-RM groups in regards to $P_{50}$ for both CO (Figure 5) and SSC (Figure 7). High-RM subjects had significantly greater $P_{100}$ at 30–50% CO (Figure 5) and at 40% SSC (Figure 7). High-RM subjects had significantly greater $P_{150}$ at 30–50% CO (Figure 6) and at 40% SSC (Figure 7). High-RM subjects had significantly greater $P_{200}$ at 30-50% CO (Figure 6) and at 50 and 60% SSC (Figure 9).

DISCUSSION

The Effect of Strength on Peak Power (PP)

Concentric-Only Movements

It has been established that strength plays an important role in the ability to express power during CO and SSC movements when the sample is heterogenous. The purpose of this study was to investigate the role of strength in a homogenous group of similarly strength-trained athletes. The results of this study suggest that strength plays a significant role in this type of group, although the relationships are not as strong. Power output depends on multiple factors. Variability in power output cannot be completely accounted for by differences in strength alone, especially in a group of similarly trained athletes. In addition to inherent lack of variability due to sample homogeneity, weaker relationships may be attributed to the training status of the subjects. It has been observed that lower level rugby players displayed greater strength-power relationships than professional rugby players (18). Additionally, the professional rugby players exhibited significant power-velocity relationships whereas the lower level rugby players did not. The author suggested that as training status increases, athletes may increase their reliance on speed (as opposed to force) when attempting express maximal power.

Another reason for weaker relationships may be that the 1RM as a strength measurement may not provide enough precision for a correlation statistic. The researchers encountered a large number of identical performances in regards to the 1RM variable. The lack of variability in this dependent variable would lower the strength of the correlations. In such cases, a more effective method of analyzing the data may be to separate the subjects into high-RM and low-RM groups and perform t-tests. The results of the t-tests (Figure 2) clearly indicate an advantage to being stronger. Another method for strength assessment is to measure isometric peak force with a force plate (19). Although the 1RM has greater external validity, the use of a force plate may be a more appropriate for correlation analysis. Finally, it has been suggested that certain measurements are more or less likely to correlate with one another independent of the movement pattern (20). That is, weaker correlations may be due to the type of test being used.

The effect of load on the strength-power relationship is consistent with previous work (11,12) but is in disagreement with Schmidtbleicher (10). In the case of CO, strength did not play a greater role in
power production as loads increased as hypothesized by Schmidtbleicher. In fact, the only load that did not demonstrate a significant 1-RM relationship was the heaviest. One potential explanation is that Schmidtbleicher was referring to absolute loads as opposed to the relative loads used in this study. Although greater strength is desirable when overcoming inertia of an absolute load, the advantage of greater strength may be negated to a certain degree when comparing subjects with relative loads. That is, the stronger subjects have to overcome a greater inertial force based on the proportion of their 1RM. In contrast, based on the same argument, strength would play a greater role in power production when comparing subjects with absolute loads.

To confirm this argument, a supplemental analysis was performed on eight of the subjects in this study. Three subjects had a 1RM of 160 kg and five subjects had a 1RM of 205 kg. Examination of their relative loads revealed that three of the loads were within approximately 5 kg of each other. More specifically, absolute loads of approximately 64, 81, 98 and 125 kg were performed by each of the eight subjects. In the case of CO movements (Figure 4) the high-RM group displayed greater power output than the low-RM group as the absolute loads become heavier. Additionally, the low-RM group displayed a greater decrease in power output between 98 and 125 kg. At some point, power would begin to decrease as the absolute loads became too heavy to generate any appreciable velocity in both high-RM and low-RM subjects however this point will occur earlier in low-RM subjects. This concept may be particularly important when developing training methodologies for the sport of rowing where athletes compete against one another in absolute terms.

**Stretch-Shortening Cycle Movements**

Like the CO movements, the strength-power relationships were moderate but significant and the relationship weakened as loads increased (Table 4). Additionally, the results of the t-tests also demonstrate clearly, the advantage of stronger subjects at all loads (Figure 3). It was previously hypothesized that there was little relationship between strength and power output during SSC movements (10). The 1RM-PP relationships and high and low-RM comparisons suggest otherwise and are in agreement with previous work (11,12). Cronin et al. (11) provided three speculations for their observation of a strength effect during SSC movements. First, greater strength is associated with greater cross-sectional area therefore is associated with a greater number of crossbridges in parallel. This would allow for a potentially higher active state of the muscle following the eccentric stretch. Second, strength training results in enhanced tendon architecture as well as increased collagen content of muscle. This would result in greater connective tissue tensile strength and an improved capacity for elastic energy storage, thus improving the ability to perform SSC movements.
Third, strength training may improve muscle stiffness. The stiffer muscle will resist deformation during SSC actions resulting in greater storage of elastic energy in the series-elastic component and greater mechanical efficiency.

Based on these results, it appears that strength plays a significant role in the PP during both CO and SSC leg press movements in this sample. This was demonstrated for both relative and absolute loads. The concept of the “mixed methods” strategy has been previously discussed (21) and based on the results of this study, it seems that this strategy would be appropriate with female rowers. It should also be noted that training exclusively with CO techniques has been associated with an increased risk of dysfunction and injury (22) as well as an inferior training effect when compared to training both concentrically and eccentrically (23).

**The Effect of Strength on $P_{50-200}$**

Concentric-Only Movements

The role of strength in power output during the first 200 ms of CO movements is less clear. The correlations between 1RM and $P_{50-200}$ were generally weak and insignificant with a few exceptions; however the comparisons between high-RM and low-RM subjects were more interpretable (Figures 5,6). Cronin et al. (11) reported an obvious strength effect during SSC bench press across all loads with little observed effect during CO bench press during the first 200 ms. Although there was no effect during the first 50 ms, the data collected from 100-200 ms of this study suggests the opposite.
Aside from sampling differences (gender and training status) the most obvious explanation of this discrepancy may be due to the exercise mode (leg press vs. bench press). There simply may not be enough time for any meaningful differences to manifest themselves during the leg press as compared to the bench press. Time to peak power (TPP), which may be considered to be the acceleratory phase of the movement, may offer some insight to this argument. Theoretically, the greatest observed difference between high and low-RM subjects in regards to power output should occur at TPP. This is demonstrated when the difference between high and low-RM subjects is analyzed with increasing loads. The largest observed difference between high and low-RM subjects for \( P_{200} \) occurred at 30% 1RM because the power output at 200 ms occurred essentially at TPP (217 ms, Table 3). With increasing loads the difference between 200 ms and TPP increases resulting in a diminished strength effect.

During the CO leg press, TPP at 40, 60 and 80% 1RM were 245, 311 and 468 ms respectively (Table 3). By contrast, TPP at 40, 60 and 80% of CO bench press in untrained males were 443, 580 and 751 ms respectively (11). TPP occurred much nearer to 200 ms in the leg press than in the bench press. By measuring a relatively short initial period of the bench press, the lack of an observable strength effect may be expected. Perhaps if Cronin et al. had collected data for longer than 200 ms, greater separation between the high and low-RM subjects may have been observed.

**Stretch-Shortening Cycle Movements**

In regards to SSC movements, Cronin et al. reported that strong subjects demonstrated higher power output than weaker subjects during the first 200 ms of CO bench press. With the exception of \( P_{100} \) and \( P_{150} \) at 40% 1RM and \( P_{200} \) at 50 and 60% 1RM, strength did not play a significant role in power output during...
the first 200 ms of the concentric phase in SSC movements (Figures 7-9). Again, aside from gender and training status, TPP and exercise mode may at least partially explain the discrepancy.

Due to the high movement velocities during SSC, TPP was often attained within 200 ms (Table 5). That is, the $P_{50-200}$ data was near PP. An obvious strength effect was observed for PP during SSC so it would be expected that this effect would also be observed during the first 200 ms if in fact PP occurred near TPP. TPP for SSC at 40% 1RM was 158.3 ms and the only significant comparison made for $P_{150}$ was at 40% 1RM. TPP for SSC at 50 and 60% 1RM was 188.6 and 215.5 ms respectively and significant differences between high and low-RM for $P_{200}$ was observed only at 50 and 60% 1RM. The final observed significant difference was observed for $P_{100}$ at 40% 1RM however TPP was not able to explain this difference.

SSC mechanisms should also be considered as a potential mechanism for the diminished strength effect observed during the first 200 ms of SSC movements. It has been reported that the observed increase in initial power output during SSC movements is related to the activity of the muscle spindles and the reutilization of energy by the series elastic component of the muscle (24,25). Furthermore, reliance on the muscle spindles and series elastic component increases as the duration of the concentric phase decreases. This suggests that during SSC actions, as the duration of the concentric phase increases, initial power output relies more on strength and less on the SSC mechanism. In this study, TPP at 40, 60 and 80% of 1RM during SSC leg press were 158, 215 and 339 ms respectively (Table 7). During SSC bench press, Cronin reported values of 362, 566 and 702 ms for the same loads. Due to the higher absolute velocity of the SSC leg press, there was very little coupling time which maybe at least partially responsible for the lack of a strength

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**Figure 6.** $P_{150}$ and $P_{200}$ by high-RM and low-RM subjects across all loads during CO leg press. * indicates a significant difference ($p < 0.05$) between groups.

**Figure 7.** $P_{50}$ and $P_{100}$ by high-RM and low-RM subjects across all loads during SSC leg press.
effect and a potentially greater reliance on the SSC mechanism (less reliance on strength). It should also be noted that the subjects were rowers. As such, the subjects utilize a predominantly CO movement of the legs, which is similar to the CO conditions used during the testing. This specificity could have had an effect on the relationships. However if this were the case, one would expect to see less reliance on the SSC mechanism and more reliance on strength for initial power output.

The results of this study suggest that strength plays a significant role in $P_{100-200}$ when the observed time period occurs near TPP. For CO movements this occurred with the lighter loads (30-50% 1RM, Figures 5,6). For SSC movements it occurred with the more moderate loads (40-60% 1RM, Figures 7-9). As such, it may be argued that $P_{50-200}$ provides no more information than PP alone in this case.

**CONCLUSIONS**

In summary, this study suggests that increasing leg press strength may improve the ability of female rowers to generate PP during both CO and SSC non-ballistic leg press. TPP was responsible for any strength effect observed during CO and SSC movements for $P_{100-P_{200}}$. Although power production is a function of multiple variables, the role of strength should remain a consideration when developing training methodologies of female rowers.

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