Optimal Loading during Two Different Leg-Press Movements in Female Rowers

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ABSTRACT

LUND, R. J., D. G. DOLNY, and K. D. BROWDER. Optimal Loading during Two Different Leg-Press Movements in Female Rowers. Med. Sci. Sports Exerc., Vol. 36, No. 1, pp. 148–154, 2004. Purpose: The purpose of this study was to determine the optimal load for power during concentric only (CO) and stretch-shortening cycle (SSC) leg-press movements during the initial portion of the concentric phase as well as throughout the entire concentric phase in trained female rowers. Methods: Thirty female rowers (age = 19.6 ± 1.2 yr) were tested for strength (1RM), mean power (MP), peak power (PP), as well as power output at 50, 100, 150, and 200 ms (P50–P200) during both CO and SSC leg-press movements and across six different loads (30–80% 1RM) on the Omnikinetik dynamometer. Results: Split-split plot analysis indicated that MP and PP were maximized at approximately 60% 1RM in both CO and SSC movements. There were no significant differences in P50 and P100 across all loads for both CO and SSC. P200 was greatest at 30, 40, 50, and 60% 1RM for CO and SSC movements. P200 was maximized at 50, 60, and 70% 1RM during SSC. Conclusions: There was no difference in the optimal loads for MP (40, 50, and 60% 1RM) and PP (50, 60, and 70% 1RM) between CO and SSC movements. An enhancement of power during the initial 200 ms of the concentric phase of SSC movements was observed. Greater time to reach PP was the reason for the enhancement in PP output observed in CO movements. The CO training regimen associated with the sport of rowing also may have lessened the effect of the SSC. Key Words: LOWER EXTREMIT Y, FEMALE LOAD PERFORMANCE, CONCENTRIC-ONLY, STRETCH-SHORTENING CYCLE

The ability to generate power is one of the most essential functions of skeletal muscle, not only for the elite athlete but also for the performance of everyday activities. Consequently, power has received considerable attention, especially with regard to optimal loading strategies for maximum power output (2,3,6–18,24,25,27). Interestingly, a wide range of loads has been reported as optimal. Loads as low as 15% and as high as 78% of the one-repetition maximum (1RM) (23,26) have been reported to elicit maximal power production.

There may be several reasons for the observation of power optimization across such a wide range of loads. These include, but are not limited to, upper- versus lower-body movements (16), regular versus ballistic exercises (13), muscle fiber type (27), training status (12), and the definition of power (23). Due to the multifactorial nature of optimal loading, no one study may provide a complete evaluation of this condition; therefore, the control of such variables is fundamental when assessing or comparing the scientific literature.

Another factor that may affect optimal loading involves concentric-only movements (CO) versus stretch-shortening cycle movements (SSC). Elliott et al. (13) observed that the bar decelerated for a significant amount (24%) of the concentric motion during maximal “nonballistic” bench-press movements. This percentage increased to 52% when the bench press was performed with a lighter resistance. The obvious implication of this observation is that when performing repetitions with lighter resistances, a greater proportion of the concentric motion is devoted to decelerating as opposed to accelerating. This should impede the ability to express power, thus affecting the load at which peak power occurs. The problem of excessive deceleration can be overcome if the movement allows for the actual projection of the bar into free space. As mentioned, this type of movement has been described as “ballistic” (22). Ballistic training methods have been identified as most appropriate for the development of muscular power due to the greater power output associated with these methods (21). Additionally, it is well documented that the addition of the SSC also increases power output (5,7,9,23). However, in some sports, a ballistic movement incorporating the SSC may not be possible. For example, in the sport of rowing, lower-extremity movements are nonballistic in nature. Although the concentric lower-extremity action during the rowing stroke is not purely CO, the effect of the SSC is minimal at best. Additionally, it has been suggested that power training techniques may be more beneficial than classical strength training techniques for rowers (20). Nelson and Widule (20) observed that greater peak angular knee velocity during the drive phase of the rowing stroke improved the biomechanical efficiency in collegiate female oarswomen. The authors suggested that rowers should concentrate on power training.
METHODS

Approach to the problem and experimental design. The performance of nonballistic leg press movements may be beneficial to rowers due to the specificity of such movements. The sport of rowing requires that each foot remains fixed to a foot support while the rower performs a preparatory flexion of the hip and knee followed by hip and knee extension during the propulsive phase of the oar stroke. The pause between leg flexion and extension may negate any SSC response, which suggests that CO training may be an advantageous training technique. However, it has been suggested that power training techniques may be beneficial due to the greater training velocities (20). To evaluate lower-extremity power performance in collegiate rowers, a novel task of bilateral power output where the foot was fixed to a foot-pad was used. To determine any differences between CO and SSC leg-press power output, the testing conditions randomly employed a CO trial and an SSC trial. The resistance setting was varied to identify if a discreet load maximized power output and if this load varied between CO and SSC.

Subjects. Thirty female crew members participated in this study. All subjects were engaged in a resistance-training program for the 6 months before testing. A signed informed consent letter was obtained before the subjects’ participation in the study. 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.

Procedure. Before testing, subjects attended an orientation. The purpose of the orientation was to explain the experimental procedures and to sign the informed consent form.

Anthropometric measurements included body composition, height, weight, and trochanter length. Body composition was estimated with the bioelectrical impedance method (BIA 450, Biodynamics Corporation, Seattle, WA). Bioelectrical impedance (BIA) has been shown to significantly correlate \( r = 0.621, P < 0.01 \) with the hydrostatic weighing technique in female oarswomen (24). BIA has been reported to be a valid and reliable body composition measurement in college-aged female athletes (15). Trochanter length was defined as the length from the top of the greater trochanter, as determined by palpation, to the floor while wearing a shoe. Subjects left their shoes on when measuring trochanter length because shoes were worn during testing on the Omnikinetic dynamometer (Omk). Trochanter length was required in order to estimate several lower-extremity variables for the kinetic computations (10).

Before performing 1RM, all subjects performed a warm-up consisting of 5 min of low-resistance pedaling on a cycle ergometer. Subjects then familiarized themselves with the Omk. Subjects practiced both the CO and SSC leg-press movements. Once familiarized, a 1RM double-leg press was conducted on the Omk using the National Strength and Conditioning Association (NSCA) procedure for conducting 1RM tests (1).

After a minimum of 4 d of rest, two power spectrum analyses (PSA) were performed on the Omk. One PSA 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. SSC leg press started with the legs in the extended position. The subjects then flexed and re-extended the legs. The loads used for both PSA were 30, 40, 50, 60, 70, and 80% 1RM with 3-min rest intervals between sets. Subjects were instructed to perform all repetitions as fast as possible. The order of the two PSA, as well as load assignment, was randomized to minimize an order effect.

Apparatus. 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 (Fig. 1). 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 model. In brief, the computation of the lower-extremity data is based on the assumption that the closed chain motion is confined geometrically...
as a 2 degree of freedom kinematic chain (29). The three assumptions of the model are: a) the hips are fixed throughout the movement, b) the joints are frictionless hinge joints, and c) the limb segments are rigid bodies. The Omk method has proven to be valid and reliable (11). Computations produced from the model include acceleration, velocity, position, torque, and power for the hip, knee, and ankle joints. A more complete description of the Omk has been published elsewhere (10). Mean power of the concentric phase (MP), peak power of the concentric phase (PP), as well as power at the first 50, 100, 150, and 200 ms (P_{50–200}) of the concentric phase were measured. 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 three repetitions.

**Statistical analysis.** Descriptive statistics were calculated for all variables. Six separate split-split plot statistics were used to test for movement effects (CO*SSC) and load effects (30*40*50*60*70*80% 1RM) for MP, PP, P_{50}, P_{100}, P_{150}, and P_{200}. Split-split plots were conducted as opposed to the traditional repeated measures ANOVA due to the randomization protocol of the treatments. Tukey’s HSD was used for post hoc analysis of all main and simple effects in question. The level of significance was set at (P < 0.05) for all statistical analyses. Two loads, for both CO and SSC, were randomly selected for each subject in order to calculate test-retest reliability coefficients. Test-retest reliability coefficients for MP, PP, and P_{50–200} can be found in Table 1. Results of statistical power analyses can be found in Table 2. Statistical power calculations of main effects (movement, load) and interactions (movement*load) for each of the dependent variables ranged from 0.05 to 0.999.

**RESULTS**

Descriptive statistics can be found in Table 3. Omk results are presented in Figures 2–7. For MP, there were no significant interactions as well as no significant differences due to type of movement. For both CO and SSC, MP was greater (P < 0.05) at 40, 50, and 60% 1RM compared with 30 and 70% (Fig. 2).

When comparing PP by movement, there was no significant difference at 30 and 80% 1RM. However, for loads 40, 50, 60, and 70% 1RM, PP was greater during CO versus SSC movements. For both CO and SSC, PP was greater (P < 0.05) at 50, 60, and 70% compared with 30, 40, and 80% 1RM (Fig. 3).

P_{50} was greater (P < 0.05) in SSC versus CO across all loads. P_{50} during CO did not significantly differ by load. For SSC movements, P_{50} was greater (P < 0.05) at 40, 50, and 60% 1RM compared with 30, 70, and 80% 1RM (Fig. 4).

P_{100} was greater (P < 0.05) in SSC versus CO across all loads. CO P_{100} did not significantly differ by load. For SSC,
P<sub>100</sub> was greater (P < 0.05) at 30, 40, 50, and 60% 1RM compared with 70 and 80% 1RM (Fig. 5).

P<sub>150</sub> was greater (P < 0.05) in SSC versus CO across all loads. P<sub>150</sub> during CO was greater (P < 0.05) at 30, 40, and 50% 1RM compared with 60, 70, and 80% 1RM. For SSC, P<sub>150</sub> at 40, 50, and 60% 1RM were greater (P < 0.05) than 30, 70, and 80% 1RM (Fig. 6).

P<sub>200</sub> was greater (P < 0.05) in SSC versus CO at loads of 50, 60, 70, and 80% 1RM. However, at loads of 30 and 40% 1RM, P<sub>200</sub> was greater (P < 0.05) in CO versus SSC. P<sub>200</sub> during CO was greater (P < 0.05) at 30, 40, and 50% 1RM compared with 60, 70, and 80% 1RM. For SSC, P<sub>200</sub> was greater (P < 0.05) at 50 and 60% 1RM compared with 30, 40, 60, and 70% 1RM (Fig. 7).

Significant movement*load interactions were observed for all power variables except MP.

**DISCUSSION**

MP was the only power variable that did not have significant interactions. For both movements, MP tended to plateau and was greater at 40, 50, and 60% 1RM (P < 0.05) compared with the other loads. These results suggest that MP is maximized at moderate loads, during the leg-press exercise. Similar results have been reported for MP during leg-press and squat exercises (16,26) as well as for the bench press (9). Although MP peaked at 60% 1RM, there was no significant difference between 40, 50, and 60% 1RM.
1RM, indicating that MP is maximized across a range of loads. Although there may be an identifiable load at which MP or PP "peaks," this load may not be statistically different than loads that are moderately lighter or heavier. This has been identified in previous studies (3,26). It should be noted that MP and PP were maximized at loads greater than 30% 1RM, which refutes earlier work in this area (17).

These studies used single-joint, unilateral movements. However, the results of this study are in agreement with more recent work that used multi-joint, bilateral movements (3).

In regard to PP, the optimal load during CO movements did not differ significantly between loads of 50, 60, and 70% 1RM. The optimal load during SSC movements occurred at loads of 60 and 70% 1RM, demonstrating that power output is maximized across a range of loads as opposed to a single discrete load. Similar to MP, the SSC had no meaningful effect on the load at which PP was maximized. Again, it appears that PP occurs at loads greater than originally proposed (17) and demonstrates more of a plateau than a definite peak (3,9,19).

Interestingly, there was no movement effect for MP. This finding was unexpected due to previous literature observing increased power output in movements that incorporate the SSC (5,7,9,23). MP may be similar for CO and SSC yet attained through different strategies. This is demonstrated by analyzing power*time curves (Fig. 8). For instance, during CO movements, subjects generally achieved a higher PP but had a much lower rate of increase in power production. For SSC movements, subjects generally achieved a lower PP but had a greater rate of increase in power production. SSC appeared to generate power at a greater rate, whereas CO required more time with similar MP outputs as the result of each movement. The advantage of the SSC during the early phase of movement maybe due to increased myoelectrical potentiation and restoration of elastic energy (4). Additionally, competitive rowers served as subjects in this study. Rowing incorporates a predominantly CO movement of the legs and is similar to the CO conditions in the present study. Specificity of CO movement training may have negated the expected enhancement of SSC to MP and provided an advantage to PP during CO.

PP was significantly greater during CO movements across all loads except 30 and 80%. This finding was unexpected due to the power enhancement typically associated with SSC activities. The addition of SSC decreased the duration of the concentric phase and also decreased the duration of the deceleration phase. For example, at 60% 1RM (Fig. 9), the mean duration of the CO concentric phase was 82% longer than the SSC concentric phase with the same load. The mean time for the deceleration phase made up a smaller proportion of the entire CO concentric phase (38%) compared with SSC (48%). More time to generate torque could also lead to greater power output during CO. This can be seen in the differences in time to PP (TPP). TPP
was greater for CO due to the lower observed velocity early in the movement (Fig. 10), resulting in more time to generate any appreciable torque.

SSC retained an advantage over CO in power development, during the first 200 ms. $P_{50-200}$ was greater in SSC versus CO with few exceptions. Walshe et al. (28) reported similar results for the squat exercise in 40 trained male subjects. They reported that the benefit of the SSC was clearly evident during the first 100 ms. The benefit decreased from 100 to 200 ms, and there was no observable benefit thereafter. Possible explanations for the enhanced power output during the initial phase of SSC included the state of muscle activation, the restoration of elastic energy, tendon recoil, and potentiation of the contractile element.

Cronin et al. (9) observed similar results. Untrained males exhibited greater mean PP values during the first 200 ms of CO versus SSC bench press at 60 and 80% 1RM, but it is not clear whether those differences were significant. Although the authors did not address this issue, there was less available time to achieve PP during the SSC bench press, resulting in lower PP output compared with CO bench press.

The opposite effect was observed during “ballistic activities,” such as rebound jumps (RJ) and nonrebound jumps (NRJ). Although increased potentiation due to the activation of muscle spindles and the reutilization of stored potential energy in the series elastic component were partially responsible for the increased work performed during RJ, Bosco and associates (6) observed that the time to perform work was also a factor. During RJ, there was less time available to perform positive work when compared with NRJ. Additionally, time to perform positive work was negatively correlated with efficiency. During the initial portion of the concentric phase of RJ, the muscles are in an active state and the series elastic component is taut. This allows the muscle to perform a larger amount of work in a shorter period of time, when compared with NRJ. Due to the “ballistic” nature of the jumping activity, there was no need to decelerate. This resulted in a greater amount of work performed in less time, resulting in greater power output in the SSC activity.

Differences in the testing equipment must also be considered. For example, several studies have reported enhanced power during the vertical jump with countermovement (CMJ) (6,14). Both of these studies used force platforms to measure power output. Comparison of force platforms and the Omk reveals a major difference. Inertial forces are a factor with the force platform but not with the Omk. In the Omk, the force responsible for the eccentric action is fluid pressure, which is constant, unlike inertia. Considering the effects of inertia during a CMJ, increased power output would be expected compared with a CO squat jump (SJ). Further analysis of these studies indicated that two of the studies compared power output during the concentric phase, thereby removing the effect of inertia. Greater power output during the CMJ compared with the SJ was reported in both studies (5,6). The main purpose of using the Omk in the present study was that it provides a protocol for lower-extremity moment with the foot in contact with a foot-pad, similar to the conditions of rowing. Throughout the eccentric flexion and subsequent concentric extension of Omk exercise, one could evaluate lower-extremity power with and without the benefit of SSC, even if this contribution is less than with ballistic-type activities. Providing lower-extremity power curves in a movement that simulates the leg action of rowing may allow one to tailor lower-extremity training programs to best suit the needs of the rower.

It appears that female rowers may benefit by training with both CO and SSC techniques. Absolute power output was greater during CO; however, the enhancement of power output during the initial 200 ms during SSC should also be taken into consideration. The combination of both methods may provide a more broad training effect, improving power output throughout the entire drive phase. It should be noted that training solely with CO techniques has demonstrated increased vulnerability to dysfunction and injury associated with eccentric movements (26). Furthermore, greater performance in peak torque, vertical jump height and strength (3RM) has been reported after training both eccentrically and concentrically compared with CO training (8). The incorporation of a “mixed methods” strategy has been discussed previously (21) and may apply in the case of training rowers.

In summary, there was no difference in the optimal loads for MP (40, 50, and 60% 1RM) and PP (50, 60, and 70% 1RM) between CO and SSC movements. Surprisingly, PP was greater during CO movements across all loads except 30 and 80% 1RM. The absence of a difference in MP between movements was also unexpected. Increased time to reach PP during CO movements was the reason for the enhancement in PP output. The absence of a difference in MP between movements was also related to the difference in time to achieve PP between movements. The CO training regimen associated with the sport of rowing also may have lessened the effect of the SSC. Initially, there appeared to be no SSC effect on power. Further analysis of power output during the first 200 ms indicated otherwise. That is, during the first 200 ms of the concentric phase, power output was greater in SSC movements across all loads. The only ex-
ception to this was $P_{200}$ during repetitions at 30, 40, and 50% 1RM. This discrepancy was attributed to temporal factors. The use of CO, nonballistic leg press maybe potentially beneficial in training rowers, due to greater MP and PP output as well as greater specificity. However, the benefit of the SSC during the initial 200 ms of the concentric phase was obvious and deserves considerable attention in regards to training this population.

Further research should compare CO and SSC concentric phase performance during “ballistic” activities. The efficacy of CO versus SSC training techniques on CO concentric phase performance should also be explored.

REFERENCES