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The Acute Effects of a Single Set of Contrast Preloading on a Loaded Countermovement Jump Training Session

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Abstract. Clark, R.A., A.L. Bryant, and P. Reaburn. The acute effects of a single set of contrast preloading on a loaded countermovement jump training session. *J. Strength Cond. Res. 20(1):162–166. 2006.*—The aim of this research was to assess the effect of a single set of contrast preloading on peak vertical displacement (PD) during a loaded countermovement jump (LCMJ) training session. Nine strength-trained males participated in 2 randomly assigned, crossover design testing sessions consisting of 5 sets of 6 repetitions of 20-kg LCMJs with 3-minute rest intervals between sets. The preloading intervention was performed 3 minutes after the first set and 4 minutes before the second set of 20-kg LCMJs. The control (CON) group performed 1 set of 20-kg LCMJs, whereas the jump squat (JS) group performed 1 set of 40-kg LCMJs. The number of repetitions performed during each preloading condition was varied to match total concentric work between the 2 sessions. A significant ($p < 0.05$) preload × set interaction for PD was observed, with the JS group jumping significantly higher during the third set performed after the preload in comparison with the CON group. Analysis of peak power output and mean power output during the concentric movement for this set revealed that as the knee flexion angle increased, the effect of the preload was augmented. These results suggest that a single set of preloading exercises enhances performance during a lower-body explosive power training session; however, the effects of a single preloading set may not peak until midway through the training session.

Key Words. postactivation potentiation, jumping, plyopower

Introduction

Preloading exercises often consist of multiple, maximal isometric voluntary contractions or heavy load (>5 repetition maximum [RM]) weight-lifting movements performed to failure. Performing these preloading exercises before movements requiring dynamic force exertion has been found to increase the explosive power of the stimulated muscle groups (2, 11, 13, 29). This increased quality of performance has been reported in terms of improved vertical and horizontal displacement during jumping movements (2, 3, 8, 13, 29), enhanced neuromuscular activation and force output during H-reflex testing (15), reduced sprint cycle times (24), and augmented power output during upper-body bench throws (4). This increase in performance abilities is due to an acute supercompensation, or postactivation potentiation, of the neuromuscular system after the preloading intervention and has been found to peak between 4 and 15 minutes after the preloading exercise (8, 15, 16, 18, 24, 29).

From a training perspective, complex training protocols recommend performing multiple sets of multiple repetitions of weight-training movements and plyometric exercise in an alternating order (7, 11, 12). Chu (7) suggests that each set of preloading exercises leads to enhanced performance during the subsequent set of plyometrics, resulting in an increased quality of the training session. This increased quality of work during each training session is suggested to result in improved longitudinal performance gains when compared with normal training methods (7, 9, 11, 12, 28), although there is a paucity of training studies in the area (11, 27). These proposed benefits of complex training do have some merit; however, the potential limitations of this method of training are important to consider. In this respect, performing multiple sets of multiple repetitions of maximal plyometric and heavy-load weight-lifting movements places a great degree of stress on the neuromuscular system and, if continued for too long, may result in overreaching or overtraining. Furthermore, previous research reporting the benefits of weight-lifting preloads has found that near-maximal (>5RM) loads performed to failure before the subsequent dynamic exercise results in enhanced performance (8, 11, 24, 29), whereas lighter loads have achieved mixed results (4, 14, 20, 22). These heavy loads, along with the potential for overreaching, considerably hinder the ability to implement complex training into an athlete's periodized training program.

Although traditional weight-lifting exercises appear to provide a preloading effect only when performed with near-maximal loads, some previous studies suggest that performance of higher-load ballistic preloading exercises can also provide these benefits. For example, recent research performed by Baker (3) suggests that the acute supercompensation effect can be achieved for the subsequent explosive exercise by performing contrast preloading exercises consisting of biomechanically similar movements with a heavier load. Specifically, the study by Baker (3) examined 40-kg loaded countermovement jumps (LCMJs) for lower-body explosive power and found a significant improvement in average power output in the set performed after a set of 60-kg LCMJs. Although the preloading exercise was performed with a heavier load, it was neither a maximal load nor performed to failure. Performing a preloading set with a submaximal load may reduce the risk of overreaching and improve the potential for increased incorporation of complex training into a periodized training program.

Although this method of preloading is promising, it may be further enhanced from a training perspective if just a single set of preloading exercises is found to be beneficial over multiple sets of multiple repetitions of plyometric exercises. This may markedly reduce the stress placed on the neuromuscular system by performing multiple sets of preloading exercises and further improve the potential for inclusion of preloading into a periodized training program. In a previous study using maximal voluntary contractions as the preloading exercise, Gullich and Schmidtbleicher (15) found that the acute supercompensation effect of a single set of maximal voluntary contractions continued over not only a single set of multiple repetitions, but also multiple sets of a single repetition of isometric plantar flexion performed with 2 minutes of rest between sets. Jones and Lees (19) examined the effect of a single preloading exercise on multiple sets with multiple repetitions; however, only 1 of these sets was performed during the acute supercompensation time period of between approximately 4 and 15 minutes after preloading (8, 15, 16, 18, 24, 29). Whether the acute supercompensation effect of a single preloading exercise results in improved performance over multiple sets of multiple repetitions of an explosive power movement during this timeframe is unknown.

Therefore, the purpose of the current study was to determine whether 1 set of a biomechanically similar preloading exercise is sufficient to improve vertical jump height performance over multiple sets of multiple repetitions of LCMJs. Power output during distinct phases of the concentric range of motion of the jumping exercise was also analyzed. This was performed to determine the effect, if any, that a preloading intervention had on the jumping movement.

METHODS

Experimental Approach to the Problem

This study attempted to determine whether a single preloading set consisting of a higher-load ballistic exercise would result in improved performance throughout an explosive power training session. The training session implemented in this study consisted of 5 sets of 6 repetitions of maximal-intensity LCMJs performed with an absolute load of 20 kg and 3 minutes of rest between sets. The explosive power training session was performed twice in a randomly assigned crossover design. One session incorporated a preloading set of 40-kg LCMJs performed between the first and second set of 20-kg LCMJs (experimental protocol), whereas the other session consisted of a control preloading set of 20-kg LCMJs between the first and second sets (control protocol). These absolute loads were chosen because of the velocity-specific nature of the exercises and also because of limitations of the braking mechanism used at the time. The braking system would allow for only full vertical braking of 40 kg. Because of the young age of the subjects and the need to standardize the eccentric component of the movement, the braking mechanism was set so that for each load the bar would be held stationary by the brake but could be lowered vertically by applying minimal force. The brake settings were recorded and held constant throughout the testing sessions. Analysis of vertical displacement was performed to assess performance. The initial, median, and takeoff phases of the concentric movement of the LCMJs were also assessed to determine what effects, if any, the preloading protocol had on the jumping movement.

Subjects

Nine male, strength-trained subjects (age: 17.3 ± 2.2 years; height: 177.9 ± 3.3 cm; body mass: 83.2 ± 8.7 kg, 4RM parallel squat: 108.8 ± 19.6 kg) volunteered to participate in the present study, which was approved by the Central Queensland University Ethical Review Board. Subjects were adolescent, high school boarding students who were participating in a regular in-season strength and conditioning program for rugby union and were required to have at least 1 year of resistance-training experience. These subjects were chosen because they were among the strongest participants in their rugby union teams' strength-training programs—an important factor contributing to performance augmentation after a preload (1, 8, 15, 29). All subjects must have completed at least 3 days of strength training per week for 4 weeks before the commencement of this study. A minimum of 48 hours and a maximum of 96 hours was mandated between the final training session of their strength-training program and the initial familiarization session in this study. Subjects were instructed to refrain from intense exercise and standardize their caffeine or creatine intake for 72 hours before each testing session.

Testing Procedure

Preliminary Tests. The subjects involved in this study performed 3 testing sessions over a 2-week period to minimize any training effects. The first session involved a 5-minute warm-up followed by testing for the concentric work performed per repetition for each subject during 20-kg and 40-kg LCMJs, allowing for equal concentric work matching during preloading in the subsequent 2 testing sessions. This ensured that any changes in performance that were noted in the sets performed after the preload were because of the load implemented and not because of an increase in the amount of work performed during the preloading exercise. The number of repetitions performed during the control (CON) and jump squat (JS) groups' preloading protocols during the subsequent testing sessions was calculated by equalizing concentric work during these sets with the work performed during a 4RM squat test. Loaded countermovement jump preload work was equated with 4RM squat work because this would allow for a similar amount of total concentric work to be performed during the LCMJ preloads when compared with previous studies that have used heavy squats as the preloading exercise.

The warm-up consisted of 5 minutes of light-intensity ladder and hurdle drills. This warm-up was replicated before the 2 subsequent testing sessions to standardize the level of neuromuscular arousal during each training intervention.

The concentric work testing consisted of the subjects performing 2 sets of 6 repetitions of 20-kg LCMJs followed by 2 sets of 6 repetitions of 40-kg LCMJs with a minimum 3-minute rest interval between sets. Knee flexion angle for each subject was standardized during LCMJs to 80° by an adjustable laser monitoring system. This was set up so that once the bar passed through the laser beam a loud audio signal occurred, prompting the subject to perform the countermovement and jump vertically for maximum height. Each subject's concentric work per repetition was also measured during a 4RM squat test, which was performed after the 4 sets of

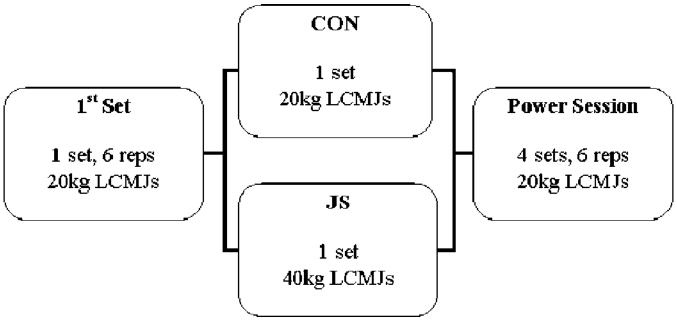

FIGURE 1. Flowchart of experimental protocol. CON = control group; LCMJ = loaded countermovement jump; JS = jump squat.

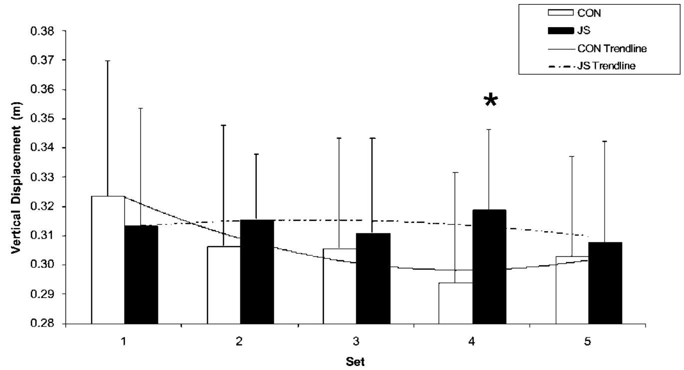

FIGURE 2. Vertical jump height (in meters) during each set of explosive loaded countermovement jumps. *Jump squat (JS) group significantly different compared with control (CON) group, $p < 0.05$.

LCMJs. This testing commenced with each subject performing 4 repetitions of the parallel squat with a load equal to his bodyweight. The weight was then increased subjectively until the subject could not perform a complete set of 4 repetitions. The last successful set was deemed the subject's 4RM, and the results for concentric work per repetition were derived from this set. Concentric work (in joules) per repetition was measured with a cable-extension potentiometer (IDM Instruments, Victoria, Australia) and the Plyopower Ballistic Measurement System (Fitness Technologies, Adelaide, Australia). The mean of the concentric work performed during the 3 repetitions with the highest work scores during each set was deemed the mean concentric work per repetition for that set. This was then averaged across the 2 sets for each condition to give the mean concentric work per repetition for each LCMJ load.

Testing Sessions. This study consisted of a randomly assigned, crossover design with subjects performing both the CON and the heavier-load JS preloading conditions. Both sessions consisted of the previously described 5-minute standardized warm-up followed by 1 set of 6 repetitions of 20-kg LCMJs, the preloading set, and then another 4 sets of 6 repetitions of 20-kg LCMJs. Three minutes of rest between sets was imposed to allow for sufficient recuperation; however, a 4-minute rest interval was enforced between the preloading set and the first set performed after the preloading set. This was allocated to ensure that every set after the preload was performed during the previously determined timeframe of supercompensation. The only difference between the 2 sessions was the preloading set, during which the CON group performed 20-kg LCMJs and the JS group performed 40-kg LCMJs. A flowchart of the testing procedure is shown in Figure 1. These 2 preloading protocols were matched for concentric work by varying the number of repetitions for each condition, resulting in equal concentric work to that performed during a 4RM squat. After analysis of the concentric work per repetition data, the CON and JS groups were asked to perform an average of 4.7 ± 0.4 and 4.2 ± 0.5 repetitions, respectively, rounded off to the nearest full repetition, as the preloading intervention. Vertical displacement (in meters) was measured during each repetition of LCMJs in the sets performed pre- and postintervention. The mean of the 3 highest jumps during each set was termed the peak vertical displacement (PD) for that set. Peak vertical displacement was chosen as the primary performance measure because it gives a measurement of lower-body ballistic performance. Before this investigation, it was deemed that should there be any significant differences in PD between the groups, an analysis of mean power output (MPO) and peak power output (PPO) of the 3 repetitions for each condition during that set would be undertaken. This would consist of analyzing MPO and PPO during 3 distinct phases of the concentric movement, the initial 50 milliseconds after the eccentric to concentric changeover, the median 50 milliseconds of the concentric movement, and the final 50 milliseconds of the concentric movement before leaving the ground. These phases of the movement were chosen because they represent 3 distinct ranges of movement in which potential changes to performance may have occurred. These sections were determined for each subject by analysis of the power and displacement graph. Only statistically significant sets were analyzed for PPO and MPO to reduce the risk of committing a type I error.

Statistical Analyses

Repeated-measures analysis of variance was performed to assess PD. In the event of a significant effect or interaction, Fisher LSD post hoc analysis was carried out. If this post hoc analysis revealed differences between the 2 groups during specific sets, dependent-samples t-tests were performed comparing the 3 different phases of the concentric movement between the groups for that set. Only sets in which a significant effect or interaction was found were assessed for PPO and MPO to maintain data integrity and reduce the risk of committing a type I error. The confidence level was set at $p \leq 0.05$ for all statistical analysis.

RESULTS

Analysis of PD for the set performed before the preloading intervention (PD for each set shown in Figure 2) revealed no significant difference between the 2 groups. A significant ($p < 0.05$) main effect for preloading group was found, with the JS group outperforming the CON group in the sets performed after the preloading intervention. A significant ($p < 0.05$) preload × set interaction for PD was recorded in the LCMJs performed after the preloading intervention. Post hoc contrasts revealed that the JS group jumped significantly ($p < 0.05$) higher (8.6%) during the third set performed after the 40-kg preloading intervention in comparison with the CON group. Analysis of PPO and MPO during the 3 phases of the

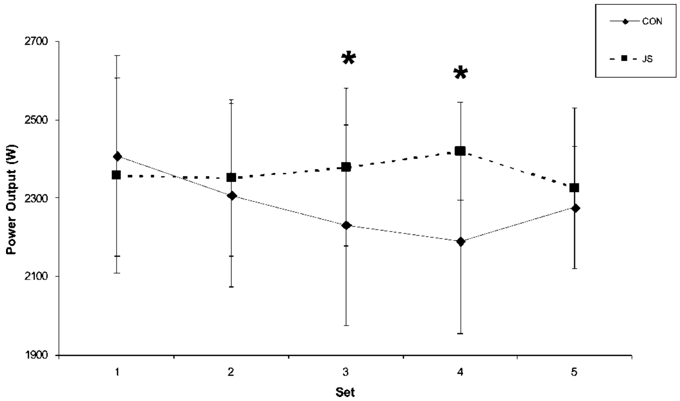

FIGURE 3. Peak power output during the final 50-millisecond phase of the concentric movement during each set of explosive loaded countermovement jumps. *Jump squat (JS) group significantly different compared with control (CON) group, $p < 0.05$.

concentric movement during this set revealed no significant difference between the groups for the initial and median 50-millisecond phases of the concentric movement. However, a significant preload × set interaction for PPO ($p < 0.05$) and nonsignificant trend for MPO during the final 50-millisecond interval of the concentric movement, which corresponded to the takeoff phase of the LCMJ, was recorded. Post hoc contrasts for PPO revealed that the JS group produced significantly ($p < 0.05$) higher PPO results than did the CON group during the second and third sets performed after the preloading intervention. The significant result for PPO during the final 50-millisecond phase of the concentric movement is displayed in Figure 3.

DISCUSSION

Previous research has shown that performing a preloading exercise before a single set of an explosive power exercise can increase subsequent performance (2–4, 8, 13, 15, 24, 29). The present study attempted to reveal whether a single set of preloading would enhance explosive power performance throughout an entire ballistic power training session. The significant ($p < 0.05$) main effect for preload suggests that the JS group outperformed the CON group throughout the entire training session performed after the preloading intervention. However, the post hoc contrasts for the significant preload × set interaction showed that the only significant ($p < 0.05$) difference was during the third set performed after the preload. Although the only statistically significant ($p < 0.05$) difference between the groups for jump height was observed during the third set performed after the preload, all the sets performed after the JS preload resulted in higher PD scores than those performed after the CON preloading intervention. For example, the first set performed after the preload showed a 3.0% increase in performance for the JS group in comparison with the CON group, a similar performance increase to those noted in a number of previous studies (4, 8, 14, 29). In the present study, the post hoc contrasts results for the significant preload × set interaction for individual sets may have reached significance if a greater number of subjects were involved, which would have enhanced statistical power. This is suggested by the fact that PPO for the final 50-millisecond phase of the concentric movement was significantly higher in both the second and third sets performed after the preload for the JS group in comparison with the CON group. This result shows that the effect of a preload is evident not only for 1 set performed after a preloading intervention, but also for multiple sets.

An interesting finding of this study was that the increase in performance peaked during the third set performed after the preload, which was approximately 10 minutes after the preloading intervention. This supports the evidence proposed by Gullich and Schmidtbleicher (15), who found that acute supercompensation peaked 8.7 ± 3.6 minutes after a maximal voluntary contraction preloading intervention. This timeframe for optimal supercompensation is much longer than the 1.5- to 3-minute rest interval between preloading and plyometric exercise recommended by Chu (7).

Analysis of PPO and MPO during the 3 phases of the concentric movement for the third set performed after the preload showed that the majority of the improvement in performance was due to increases in power output during the final phase of the movement. This final phase of the movement during the third set performed after the preload recorded significantly higher PPO (11.9%) and a trend toward increased MPO (9.9%) for the JS group in comparison with the CON group. The median phase of the movement also recorded notably higher MPO (5.1%) and PPO (5.6%) for the JS group in comparison with the CON group, although this failed to reach significance. The JS group recorded slightly higher MPO (1.6%) and PPO (1.5%) scores for the initial interval in comparison with the CON group; however, this result was negligible. This pattern suggests that as the knee flexion angle is increased during the concentric jumping movement, the athlete is able to produce increasingly greater power output in comparison with a nonpreloaded athlete. Potentially, this may be because of increased incorporation and contribution of additional aroused musculature, such as the triceps surae, toward the end of the concentric movement (5). An increase in the contribution of these aroused muscles toward the final phase of the jumping movement may increase the effect of the supercompensation mechanism, given that an increase in the sum of the stimulated muscle groups working together at a specific point would lead to further increases in performance.

Another potential mechanism responsible for the increase in power production toward the end range of the movement may be an acute effect of the preloading set on proprioceptors such as the muscle spindles. Previous research suggests that the muscle spindles play a role in regulating musculotendinous stiffness (6) and also cocontraction of opposing muscle groups (25) and are susceptible to postcontraction potentiation (17). It has been previously suggested (7) that these muscle spindles may be acutely stimulated by a preloading exercise, leading to increased performance potential. This may result in changes to the cocontraction patterns of the involved musculature or acute alterations in the level of musculotendinous stiffness and neuromuscular excitability of the preloaded muscle groups, comparable with responses evident during fatigue (21, 23). Performance of preloading exercises may increase the level of neuromuscular activation during subsequent performance, which is similar to the effects of fatigue (21, 23) but in contrast not resulting in considerable changes to multijoint coordination and efficiency of the countermovement. This may result in an enhanced ability to perform explosive exercise after a preload.

For any of these previously mentioned mechanisms to be responsible for enhanced performance, there would have to be alterations in neuromuscular activation after a preload. However, the few studies that have analyzed electromyography during complex training have produced mixed results (10, 15, 19, 26). Further research in the area is necessary to determine the mechanisms of supercompensation after preloading exercises.

PRACTICAL APPLICATIONS

A single set of contrast preloading may enhance performance during subsequent sets of low-load plyometric exercises. This acute performance enhancement, if performed throughout a training cycle, may result in greater long-term adaptations in comparison with nonpreload training. However, further research on preload training and its long-term benefits are essential before any definitive conclusions can be made.

REFERENCES

1. ANDERSON, O. Contrast training enhances power workout quality—But only if you're already quite strong. *Peak Perf.* 178:1–4. 2003.
2. BAKER, D. Specific strength/power training for elite divers: Case studies from the Australian Institute of Sport. *Strength Cond. Coach* 2:20–27. 1994.
3. BAKER, D. A series of studies on the training of high-intensity muscle power in rugby league football players. *J. Strength Cond. Res.* 15:198–209. 2001.
4. BAKER, D. Acute effect of alternating heavy and light resistances on power output during upper-body complex power training. *J. Strength Cond. Res.* 17:493–497. 2003.
5. BOBBERT, M.F., AND G.J. VAN INGEN Schenau. Co-ordination in vertical jumping. *J. Biomech.* 21:249–262. 1988.
6. BROWN, M.C., G.M. GOODWIN, AND P.B.C. MATTHEW. The persistence of stable bonds between actin and myosin filaments of intrafusal muscle fibres following their activation. *J. Phys.* 210: 9–10. 1970.
7. CHU, D.A. *Explosive Power and Strength: Complex Training for Maximum Results.* Champaign, IL: Human Kinetics, 1996.
8. DUTHIE, G.M., W.B. YOUNG, AND D.A. AITKEN. The acute effects of heavy loads on jump squat performance: An evaluation of the complex and contrast methods of power development. *J. Strength Cond. Res.* 16:530–538. 2002.
9. EBBEN, W.P., AND D.O. BLACKARD. Complex training with combined explosive weight training and plyometric exercises. *Olympic Coach* 7:11–12. 1997.
10. EBBEN, W.P., R.L. JENSEN, AND D.O. BLACKARD. Electromyographic and kinetic analysis of complex training variables. *J. Strength Cond. Res.* 14:451–456. 2000.
11. EBBEN, W.P., AND P.B. WATTS. A review of combined weight training and plyometric training modes: Complex training. *Strength Cond. J.* 20:18–27. 1998.
12. FORAN, B. *High Performance Sports Conditioning.* Champaign, IL: Human Kinetics, 2001.
13. FRENCH, D.N., W.J. KRAEMER, AND C.B. COOKE. Changes in dynamic exercise performance following a sequence of preconditioning isometric muscle actions. *J. Strength Cond. Res.* 17: 678–685. 2003.
14. GOURGOULIS, V., N. AGGELOUSSIS, P. KASIMATIS, G. MAVROMATIS, AND A. GARAS. Effect of a submaximal half-squats warm-up program on vertical jumping ability. *J. Strength Cond. Res.* 17:342–344. 2003.
15. GULLICH, A., AND D. SCHMIDTBLEICHER. MVC-induced short-term potentiation of explosive force. *New Stud. Athl.* 11(4):67–81. 1996.
16. HAMADA, T., D.G. SALE, AND J.D. MACDOUGALL. Postactivation potentiation in endurance-trained male athletes. *Med. Sci. Sports Exerc.* 32:403–411. 2000.
17. HUTTON, R.S., AND S.W. ATWATER. Acute and chronic adaptations of muscle proprioceptors in response to increased use. *Sports Med.* 14:406–421. 1992.
18. JENSEN, R.L., AND W.P. EBBEN. Kinetic analysis of complex training rest interval effect on vertical jump performance. *J. Strength Cond. Res.* 17:345–349. 2003.
19. JONES, P., AND A. LEES. A biomechanical analysis of the acute effects of complex training using lower limb exercises. *J. Strength Cond. Res.* 17:694–700. 2003.
20. KOCH, A.J., H.S. O'BRYANT, M.E. STONE, K. SANBORN, C. PROULX, J. HRUBY, E. SHANNONHOUSE, R. BOROS, AND M.H. STONE. Effect of warm-up on the standing broad jump in trained and untrained men and women. *J. Strength Cond. Res.* 17:710–714. 2003.
21. PSEK, J.A., AND E. CAFARELLI. Behaviour of coactive muscles during fatigue. *J. Appl. Physiol.* 74:170–175. 1993.
22. RADCLIFFE, J.C., AND J.L. RADCLIFFE. Effects of different warm-up protocols on peak power output during a single response jump task [Abstract]. *Med. Sci. Sports Exerc.* 28:S189. 1996.
23. RODACKI, F., A.L. FOWLER, N.E. BENNETT, AND J. SIMON. Multi-segment coordination: Fatigue effects. *Med. Sci. Sports Exerc.* 33:1157–1167. 2001.
24. SMITH, C.J., A.C. FRY, L.W. WEISS, Y. LI, AND S.J. KINZEY. The effects of high-intensity exercise on a 10-second sprint cycle test. *J. Strength Cond. Res.* 15:344–348. 2001.
25. SOLOMONOW, M., R. BARATTA, AND R. D'AMBRSOSIA. The role of the hamstrings in the rehabilitation of the anterior cruciate ligament-deficient knee in athletes. *Sports Med.* 7:42–48. 1989.
26. TRIMBLE, M.H., AND S.S. HARP. Postexercise potentiation of the H-reflex in humans. *Med. Sci. Sports Exerc.* 30:933–941. 1998.
27. VERKHOSHANSKY, Y. Speed-strength preparation and development of strength endurance of athletes in various specializations. *Sov. Sports Rev.* 21:120–124. 1986.
28. YOUNG, W. Neural activation and performance in power events. *Mod. Athl. Coach* 30:29–31. 1992.
29. YOUNG, W.B., A. JENNER, AND K. GRIFFITHS. Acute enhancement of power performance from heavy load squats. *J. Strength Cond. Res.* 12:82–84. 1998.

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