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Acute Effects of Plyometric Exercise on Maximum Squat Performance in Male Athletes

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ABSTRACT

This study examines the acute effects of plyometric exercise on 1 repetition maximum (RM) squat performance in trained male athletes. Twelve men (mean age ± *SD*: 20.5 ± 1.4 years) volunteered to participate in 3 testing sessions separated by at least 6 days of rest. During each testing session the 1RM was assessed on back squat exercise. Before all 3 trials subjects warmed up on a stationary cycle for 5 minutes and performed static stretching. Subjects then performed 5 submaximal sets of 1–8 repetitions before attempting a 1RM lift. Subjects rested for at least 4 minutes between 1RM trials. During the first testing session (T1) subjects performed a series of sets with increasing load until their 1RM was determined. During the second and third testing sessions subjects performed in counterbalanced order either 3 double-leg tuck jumps (TJ) or 2 depth jumps (DJ) 30 seconds before each 1RM attempt. The average 1RM lifts after T1 and testing sessions with TJ or DJ were 139.6 ± 29.3 kg, 140.5 ± 25.6 kg, and 144.5 ± 30.2 kg, respectively (T1 < DJ; $p < 0.05$). These data suggest that DJ performed before 1RM testing may enhance squat performance in trained male athletes.

Key Words: strength testing, repetition maximum, power, complex training

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Introduction

Coaches and trainers often use maximal strength testing to assess muscular fitness, track progress, provide motivation, and develop individualized programs. If there is qualified supervision and if appropriate testing guidelines are followed, maximal strength testing can be a safe, effective, and reliable method of evaluating muscular fitness in athletes and nonathletes (2, 16). Although isokinetic and isometric tests are often used in the clinical setting, 1 repetition maximum (RM) tests using free weights (i.e., barbells) are typically used to assess the strength of athletes. The 1RM is the maximal amount of weight that can be lifted only once for a specific exercise, using a proper exercise technique.

Athletes are often instructed to engage in some type of physical activity or warm-up before any type of strength testing. It is widely conjectured that increasing flexibility (increasing range of motion in the joints) will reduce the risk of injury and enhance performance. Several minutes of low- to moderate-intensity aerobic exercise followed by various stretching techniques has been traditionally recommended by coaches and trainers to aid the athlete in preparing for an upcoming event. The ergogenic benefits of this type of warm-up have been studied since the 1950s (17), and since that time researchers have focused on determining the best type of warm-up for improving exercise performance. Recently, however, the value of pre-event static stretching has been questioned (12), and increased attention has centered on performance of high-intensity contractions during the warm-up period (11). Although further study is required, high-intensity contractions during the pre-event warm-up may potentially create an optimal environment for subsequent training or testing (or both) (5, 11).

Although the influence of different stretching protocols on jumping ability and maximal strength continues to be researched (19, 23), the idea of performing high-intensity contractions (e.g., high-load strength-training exercises) before the performance of exercises that require explosive power (e.g., plyometrics) is gaining some degree of popularity among researchers and practitioners (1, 4, 6, 9, 24). Even though the parameters associated with high-intensity contractions and muscle performance have not been fully examined, it is possible that positive effects may occur if high-load strength-training exercises are performed before plyometric exercises. To our knowledge, the effects of performing quick, powerful movements before performance of 1RM strength tests have not been examined. More specific information regarding the effect of plyometric exercise on 1RM strength would be useful to coaches, trainers, and athletes. Therefore, the purpose of this study was to examine the acute effects of plyometric exercise on maximal squat performance in trained athletes.

Methods

Experimental Approach to the Problem

In this study we wanted to examine the effects of 3 different testing protocols on 1RM squat performance. A group of male athletes were tested on the squat exercise on 3 different occasions at least 6 days apart. During the first testing session, subjects performed a traditional warm-up protocol before 1RM testing. During the second and third testing sessions, the subjects performed either tuck jumps (TJ) or depth jumps (DJ) before attempting a 1RM lift. This approach allowed us to individually assess 1RM performance on each testing occasion and to carefully monitor the response of each subject to the testing protocol.

Subjects

Twelve male athletes ([mean ± *SD*] age: 20.5 ± 1.4 years, weight 87.4 ± 11.6 kg, height 179.1 ± 11.1 cm) volunteered to participate in this study. Subjects were informed about the nature of this study, and they signed an informed consent form approved by the Internal Review Board for use of human subjects at the university. Subjects were screened for any medical or orthopedic concern that would limit participation. All subjects had previous experience in strength training (mean 5.2 years) and at least 1 year of experience performing plyometric exercises to encourage consistent jumping performances. Eleven of the 12 subjects (92%) played collegiate baseball and participated regularly in baseball practice, which included agility drills and speed training. No subject performed strength-training or plyometric exercises for the lower body during the study period. The mean vertical jump of the subjects was 59.9 ± 13.9 cm.

Testing Procedures

All testing sessions took place during a 3-week period. Each session consisted of a general warm-up of low-intensity aerobic exercise (5 minutes of stationary cycling at a ''comfortable'' pace) followed by 6 lower-body static stretches (each stretch was held for 20 seconds and performed twice). After the general warm-up procedures, the 1RM was assessed on the free-weight back squat exercise as described previously (2). Briefly, the plate-loaded barbell (York Barbell Company, York, PA) was placed above the posterior deltoids at the base of the neck, and the downward movement phase continued until the thighs were parallel to the floor. Before attempting a 1RM lift, subjects performed a series of submaximal sets of 8, 5, 2, and 1 repetitions with increasing loads. The aforementioned warm-up procedures did not change during the 3 testing sessions. As such, all subjects performed stationary cycling and static stretching before each of the 3 strength-testing sessions. All measurements for testing were made with the same test administrators and with the same positioning on the squat exercise. After each testing session subjects performed several stretching exercises.

During the first testing session, subjects performed a series of sets with increasing weight until their 1RM squat was determined. The subjects rested for at least 4 minutes between the 1RM trials. The 1RM was recorded as the maximum resistance that could be lifted through the full range of motion, using good form only once. If the weight was lifted with the proper form, the weight was increased by approximately 1–10 kg, and the subject attempted another repetition. The increments in weight were dependent on the effort required for the lift and became progressively smaller as the subject approached the 1RM. On average, the 1RM was determined within 6 trials. Failure was defined as a lift falling short of the full range of motion in at least 2 attempts spaced at least 4 minutes apart. Throughout all testing procedures, an instructor to subject ratio of 1:1 was maintained, and all testing took place in the afternoon in a university strength and conditioning center. Uniform verbal encouragement was offered to all subjects.

During the second and third testing sessions, subjects performed either 3 double-leg TJ or 2 DJ 30 seconds before each 1RM attempt. The order of treatments for the second and third testing sessions was counterbalanced, i.e., during the second testing session half the subjects performed the TJ first and the other half performed the DJ, and during the third testing session half the subjects performed the DJ first and the other half performed the TJ. The double-leg TJ is a medium-intensity plyometric drill performed by explosively jumping upward while quickly pulling the knees to the chest. The DJ is a high-intensity plyometric drill performed by stepping from a box to the floor with both feet and then immediately jumping as high as possible. For the purpose of this study, a 43.2-cm box was used. The double-leg TJ and DJ are biomechanically comparable to the squat exercise and are described in detail elsewhere (5). All subjects had previous experience in performing the plyometric exercises used in this study.

Statistical Analyses

A one-way analysis of variance (ANOVA) with repeated measures was used to determine whether any significant differences existed between the 1RM scores after the 3 testing sessions. When appropriate, Bonferroni posthoc comparisons were used. The statistical power for the *N* size used ranged from 2 to 63%. Statistical significance was set at $p \leq 0.05$, and analyses were conducted using the SPSS statistical package (version 10.0, SPSS, Inc., Chicago, IL). All values are presented as mean ± *SD*.

Results

No injuries occurred throughout the study period, and the testing procedures were well tolerated by the subjects. The results for the 1RM squat after the first testing session and the sessions in which subjects performed TJ and DJ before the squat exercise were 139.6 ± 29.3 kg, 140.5 ± 25.6 kg, and 144.5 ± 30.2 kg, respectively. The performance of DJ before the squat exercise resulted in a significantly greater 1RM lift than did the first testing session performed without plyometric exercises ($p < 0.05$). No order effects were observed.

Discussion

These data suggest that high-intensity plyometric exercise performed before 1RM testing can have a significant influence on squat performance in male athletes. In our study 2 DJ performed 30 seconds before a 1RM attempt significantly increased 1RM squat performance by 4.9 kg (3.5%) when compared with the results from the first testing session, which did not include plyometric exercise. The volume of the plyometric exercise used in this study was kept low on purpose to guard against exercise-induced fatigue, which could lead to deterioration in neuromuscular performance (13). To our knowledge, no other study has investigated the acute effects of plyometric exercise on 1RM squat performance. It should be underscored that subjects in this study were strength-trained male athletes who had previous experience in performing plyometric exercises.

Previous reports indicate that static stretching may significantly reduce leg strength (12) and jump height (18, 23). Also, Fowles and Sale observed that passive stretching induced a significant decrease in motor unit activation 5 minutes after stretching and a reduction in strength that persisted for 60 minutes (10). These findings suggest that pre-event passive stretching may influence neural mechanisms that may negatively affect muscular performance. Conversely, high-intensity contractions performed during a pre-event warm-up (11) or as part of a training session may positively affect muscular performance (8). Recent findings from Young et al. (24) demonstrate that a loaded countermovement jump improved by 2.8% when it was preceded by 1 set of half squats with a 5RM load. Baker's observations (3) also provide evidence of the short-term enhancement of power performance resulting from high-load strength training. Interestingly, the relative performance gains observed in our study (3.5%) were consistent with those of other studies in which high-load strength training occurred before power training (20, 24).

Although further study is needed, it is believed that performance of a high-load lift before a plyometric exercise may excite the central nervous system, which may in turn allow for a greater explosive effort during subsequent exercises (21). Although it is a matter of speculation, high-load strength training may increase motoneuron excitability and reflex potentiation, which may create an optimal training environment for plyometric training. Also, it is possible that the fatigue associated with a high-load set may force more motor units to be recruited during the plyometric exercise (5, 8, 21). In the present study, however, plyometric exercises were performed before the 1RM squat trials. Thus, the results from other studies may not be directly applicable to our findings.

Nevertheless, it is likely that similar mechanisms (i.e., increased motor neuron excitability, enhanced motor unit recruitment patterns, or increased activation of synergists [or all]) resulting from the DJ may have contributed to the increase in 1RM squat performance in our study. One could suggest that the explosive-type loading used in our study enhanced the excitability of the fast-twitch units and therefore "primed" these units to play a more significant role in the performance of maximal-strength tests. This suggestion is consistent with the findings of others who have reported that explosive-type loading facilitates the function of the neuromuscular system without causing undue fatigue (15). However, this contention is tentative because no tests at the level of neuromuscular activation were performed in our investigation.

These findings suggest that only high-intensity plyometric exercises can enhance neural stimulation to a level that will significantly increase maximal muscle strength. Because higher-threshold motor units (typically type II fibers) are recruited only when high-power outputs are demanded (7), it appears that high-intensity plyometric exercises such as DJ are needed to recruit higher-threshold motor units, which in turn may contribute to enhanced squat strength. Because differences in neuromuscular function between power athletes and endurance athletes have been reported (14), it is important to note that the subjects in this study were primarily college baseball players who had previous experience performing plyometric exercises and conditioning drills. Athletes who perform explosive training may have improved intramuscular coordination (e.g., enhanced motor unit synchronization) and, therefore, may be more likely to benefit from the warm-up procedures used in this study.

Practical Applications

Our findings highlight the important relationship between neuromuscular stimulation and dynamic strength performance. The results of this study suggest that 1RM strength can be enhanced if the testing protocol includes a low-volume set of high-intensity plyometric exercises. In our investigation 2 repetitions of a DJ exercise performed 30 seconds before a 1RM attempt enhanced squat performance in strength-trained male athletes. This is not to say that 1RM testing without a plyometric warm-up is not optimal, but rather that coaches and trainers should consider the potential impact of pre-event exercises on muscular performance. Also, the same warm-up protocols should be performed during pre- and posttraining strength testing sessions.

It must be underscored that all the subjects in this study had performed strength-training exercises and plyometric drills previously, and most of the subjects were college baseball players. As such, the testing protocols used in this study are not recommended for beginners or athletes with limited strength-training experience due to the potential for injury. In addition, the results of this study may not be applicable to women because all the subjects in this study were men. Further studies with a larger sample size to increase statistical power are required. In addition, future studies should examine the precise underlying neuromuscular mechanisms that may explain the performance-enhancing effects of plyometric exercise on maximal-strength training.

References

1. ADAMS, K. The effect of six weeks of squat, plyometric and squat-plyometric training on power production. *J. Appl. Sport Sci. Res.* 6(1):36–41. 1992.
2. BAECHLE, T., AND R. EARLE. *Essentials of Strength and Conditioning* (2nd ed.). Champaign, IL: Human Kinetics.
3. BAKER, D. Specific strength/power for elite divers: Case studies from the Australian Institute of Sport. *Strength Cond. J.* 2:20–26. 1994.
4. BLAKEY, J.B. The combined effects of weight training and plyometrics on dynamic leg strength and leg power. *J. Appl. Sport Sci. Res.* 1(7):14–16. 1987.
5. CHU, D. 1996. *Explosive Power and Strength.* Champaign, IL: Human Kinetics, 2000.
6. CLUTCH, D. The effect of depth jumps and weight training on leg strength and vertical jump. *Res. Q. Exerc.* 54(1):5–10. 1983.
7. DESCHENES, M. Short review: Rate coding and motor unit recruitment patterns. *J. Appl. Sports Sci. Rev.* 3(2):34–39. 1989.
8. EBBEN, W. A review of combined weight training and plyometric training modes: Complex training. *Strength Cond. J.* 20(5): 18–27. 1998.
9. FORD, H. Benefits of three combinations of plyometric and weight training programs on selected physical fitness test items. *Percept. Motor Skills* 56:919–922. 1983.
10. FOWLES, J., AND D. SALE. Time course strength deficit after maximal passive stretch in humans. *Med. Sci. Sports Exerc.* 29: S26. 1997.
11. GULLICH, A., AND D. SCHMIDTBLEICHER. MVC-induced short-term potentiation of explosive force. *New Studies Athletes* 4:67–81. 1996.
12. KOKKONEN, J., A. NELSON, AND A. CORNWELL. Acute muscle stretching inhibits maximal strength performance. *RQES* 69: 411–415. 1998.
13. KOMI, P. Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. *J. Biomech.* 33:1197–1206. 2000.
14. KYROLAINEN, H., AND P. KOMI. The function of the neuromuscular system in maximal stretch-shortening cycle exercises: Comparison between power- and endurance-trained athletes. *J. Electromyogr. Kinesiol.* 5:15–25. 1995.
15. LINNAMO, V., K. HAKKINEN, AND P. KOMI. Neuromuscular fatigue and recovery in maximal compared to explosive strength training. *Eur. J. Appl. Physiol.* 77:176–181. 1998.
16. MACDOUGALL, J., H. WENGER, AND H. GREEN. *Physiological Testing of the High-Performance Athlete* (2nd ed.). Champaign, IL: Human Kinetics, 1991.
17. MALARECK, I. Investigation on physiological justification of so called ''warming-up.'' *Acta. Physiol. Pol.* 4:543–546. 1954.
18. NELSON, A., A. CORNWELL, AND G. HEISE. Acute stretching exercises and vertical jump stored elastic energy. *Med. Sci. Sports Exerc.* 28:S156. 1996.
19. NELSON, A., AND J. KOKKONEN. Acute ballistic muscle stretching inhibits maximal strength performance. *RQES* 72:415–419. 2001.
20. RADCLIFFE, J., AND L. RADCLIFFE. Effects of different warm-up protocols on peak power output during a single response jump-task. *Med. Sci. Sports Exerc.* 28:S189. 1996.
21. VERHOSHANSKY, Y. Speed-strength preparation and development of strength endurance of athletes in various specializations. *Soviet Sports Rev.* 21:120–124. 1986.
22. WILK, K., M. VOIGHT, M. KEIRNA, V. GAMBETTA, J. ANDREWS, AND C. DILLMAN. Stretch shortening drills for the upper extremity: Theory and clinical application. *J. Orthop. Sports Phys. Ther.* 17:225–239. 1993.
23. YOUNG, W., AND S. ELLIOT. Acute effects of static stretching, proprioceptive neuromuscular facilitation stretching, and maximum voluntary contractions on explosive force production and jumping performance. *RQES* 72:273–279. 2001.
24. YOUNG, W.B. Acute enhancement of power performance from heavy load squats. *J. Strength Cond. Res.* 12(2):82–84. 1998.

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