Journal of Strength and Conditioning Research, 2006, 20(1), 141–144

Influence of Exercise Order in a Resistance-Training Exercise Session

Luuk P.B. Spreuwenberg,[1] William J. Kraemer,[2] Barry A. Spiering,[2] Jeff S. Volek,[2] Disa L. Hatfield,[2] Ricardo Silvestre,[2] Jakob L. Vingren,[2] Maren S. Fragala,[2] Keijo Häkkinen,[3] Robert U. Newton,[4] Carl M. Maresh,[2] and Steven J. Fleck[5]

[1]Department of Movement Sciences, University of Maastricht, Maastricht, Netherlands; [2]Human Performance Laboratory, Department of Kinesiology, University of Connecticut, Storrs, Connecticut 06269; [3]Department of Biology of Physical Activity, University of Jyväskylä, Jyväskylä, Finland; [4]School of Biomedical and Sports Science, Edith Cowan University, Joondalup, Western Australia, Australia; [5]Department of Sport Sciences, Colorado College, Colorado Springs, Colorado 80903.

Abstract. Spreuwenberg, L.P.B., W.J. Kraemer, B.A. Spiering, J.S. Volek, D.L. Hatfield, R. Silvestre, J.L. Vingren, M.S. Fragala, K. Häkkinen, R.U. Newton, C.M. Maresh, and S.J. Fleck. Influence of exercise order in a resistance-training exercise session. *J. Strength Cond. Res. 20(1):141–144. 2006.*—The order of resistance exercises within a training session may have a vital impact on the quality of the constituent exercises performed. However, very few studies have documented the specific influence of exercise order. Therefore, the purpose of this study was to examine the effect of exercise order on back squat performance in the context of a whole-body workout. Nine resistance-trained male subjects (age: 24 ± 4 years, body mass: 81.5 ± 15.3 kg, resistance-training experience: 7 ± 4 years) performed the back squat exercise (4 sets at 85% of 1 repetition maximum) on 2 separate occasions in a balanced, crossover design. During one protocol, the squat exercise was performed first (protocol A); during the other protocol, it was performed after a whole-body resistance-exercise session (protocol B). Number of repetitions, average power, and rating of perceived exertion (RPE) were collected during each set of the squat exercise. All subjects performed significantly ($p < 0.01$) more repetitions during set 1 when they performed protocol A (8.0 ± 1.9 repetitions) compared with protocol B (5.4 ± 2.7 repetitions). The average power for each set was higher during protocol B compared with protocol A. There were no significant differences in RPE values between the 2 protocols. In conclusion, performing the barbell back squat first in an exercise session allowed the completion of more total repetitions. However, this study showed that performing the squat exercise after a whole-body workout session may result in greater power output if the squat is preceded by a power exercise (i.e., hang pull). This phenomenon may have been due to postactivation potentiation.

Key Words. performance, postactivation potentiation, power output, resistance exercise, strength

Introduction

In 1983, Kraemer (7) first identified the acute program variables for resistance training: exercise choice, number of sets, resistance used, rest-period length, and the order of exercises. Although most of these variables have been extensively studied over the past 2 decades (8), few scientific data exist regarding the effect of the exercise order on exercise performance (1, 13, 14).

Initial investigations of the influence of resistance-exercise order have found decrements in performance during exercises performed last in the session (1, 13, 14). Sforzo and Touey (13) found a 75% decline in bench press performance and a 22% decline in squat performance during the first set (at 85% 1 repetition maximum [1RM]) when other exercises (e.g., leg and arm extensions) were performed first during the session. Similarly, Augustsson et al. (1) showed that subjects could perform fewer repetitions during the leg press if it was preceded by leg extensions. This finding was associated with less neural activity of the leg musculature, as measured via electromyography (EMG). More recently, Simao et al. (14) found that the number of repetitions performed at a 10RM was decreased during resistance exercises performed later in a session. This finding applied to multiple- and single-joint exercises.

Although previous studies of exercise order found similar responses in performance (1, 13), these investigations leave important questions to be answered. For example, Sforzo and Touey (13) found that performance during the back squat was less affected than was the bench press. The authors hypothesized this was attributed to minor involvement or fatigue of lower-body synergist and stabilizer muscle groups (e.g., glutei, lower back muscles, abdominal muscles) during the single-joint exercises that preceded the back squat. On the basis of these findings, it would be of interest to elucidate changes in back squat performance after a whole-body workout that fatigued all muscle groups. Augustsson et al. (1) used machine-based exercises; therefore, the effect of the pre-exhaustion on the more neurally complicated free-weight exercises (e.g., squat, bench press, deadlift) remains poorly studied. Additionally, no study has investigated the influence of exercise order on power output. Therefore, the purpose of this study was to examine the effect of exercise order on free-weight back squat performance in the context of a whole-body workout.

Methods

Experimental Approach to the Problem

A balanced, crossover design was used to determine the effect of exercise order on squat performance. Subjects performed 2 identical whole-body resistance-exercise sessions. The only difference between the 2 sessions was the placement of the squat exercise in the exercise sequence: during one protocol, the squat exercise was performed first (protocol A); during the other protocol, it was performed last (protocol B). Number of repetitions, average power, and rating of perceived exertion (RPE) were collected during each set to compare the quality of the 2 differently placed squat exercises. These data would give further insights into the actual effect of the order of exercise on exercise performance within a workout session.

Subjects

Subjects for this study were 9 healthy, resistance-trained men (age: 24 ± 4 years, height: 176 ± 7.7 cm, body mass: 81.5 ± 15.3 kg, percent body fat: 9.7 ± 2.6%, resistance-training experience: 7 ± 4 years) who were free from injury. Before participating in the study, each subject was informed of the potential risks associated with the study and provided written consent. The Institutional Review Board of the University of Connecticut approved all study procedures.

Procedures

Each subject visited the Human Performance Laboratory on 4 occasions. Visit 1 consisted of preliminary screening (medical history and activity form) and measurement of basic anthropometric variables: age, height, mass, and skinfolds (chest, abdomen, and thigh) for determination of percent body fat (6). After a 5-minute warm-up on a cycle ergometer (Monark Ergomedic, Monark Exercise AB, Vansbro, Sweden), subjects were carefully familiarized with the specific exercises by using proper technique. Because all subjects had vast resistance-training experience, familiarization and practice was minimal.

During visit 2, barbell back squat 1RM was determined by previously described methods (9). Additionally, 8–10RM loads for the bench press, lunges, bent-over rows, arm curls, stiff-leg deadlift, sit-ups, and hang pulls (in this order) were determined by performing each exercise with a weight that would allow only 8–10 repetitions to be performed. (The hang pull is an exercise that begins from the "hang" position of the clean, with the bar just slightly below the knees, and is performed with rapid hip, knee, and ankle extension. This lift is also known as the second pull of a clean.) This information was needed for the whole-body resistance-exercise session used during visits 3 and 4.

During visits 3 and 4, each subject performed a whole-body resistance-exercise workout. The important difference between these visits was the placement of the squat in the exercise sequence of the workout, that is, first (protocol A) or last (protocol B) in the exercise sequence. The order of the 2 sessions was randomized and separated by 48–72 hours. Additionally, all subjects were asked not to perform any vigorous exercise between visits 3 and 4.

Before resistance-exercise protocol, 5 minutes of submaximal cycling was performed as a standard warm-up. Additionally, before the first set of the squat exercise, subjects completed a squat warm-up consisting of 10 repetitions at 50% of 1RM. During protocol A, subjects performed only the barbell back squat exercise because no data were collected during subsequent exercises. During protocol B, subjects performed the following exercise protocol: bench press, lunges, bent-over rows, arm curls, stiff-leg deadlift, sit-ups, hang pulls, and barbell back squat (in this order). These exercises were chosen to appropriately stimulate and pre-exhaust all major muscle groups. The squat exercise was performed for 4 sets at 85% of 1RM for as many repetitions as possible; other exercises were performed for 3 sets of 8–10RM. Subjects performed repetitions with a volitional velocity. An exception to this was for the hang pull; during this exercise, subjects were asked to perform repetitions explosively (i.e., with a fast repetition velocity). Sets and exercises were interspaced by 2-minute rest periods; however, approximately 4–5 minutes interspaced the hang pull and the first set of back squat in protocol B, which allowed for equipment set-up and the squat warm-up.

During the squat exercise, dependent variables were number of repetitions, average power, and RPE. A repetition was counted only if it was completed through a full range of motion by using proper technique. The power data were collected with a calibrated position transducer FITRO Dyne Sports Powerlizer (Tendo sport machines, Trencin, Slovak Republic) attached to the barbell. The FITRO Dyne measures the average power output for each repetition. Distance and time were measured with a linear transducer and an internal timing mechanism. The mass of the load (85% 1RM) was entered into the computer to allow power calculation. Average power output for each set was determined by using the average power for each repetition in that particular set. Immediately after each set, subjects were asked to provide an RPE on a scale that ranged from 0 to 10 (2).

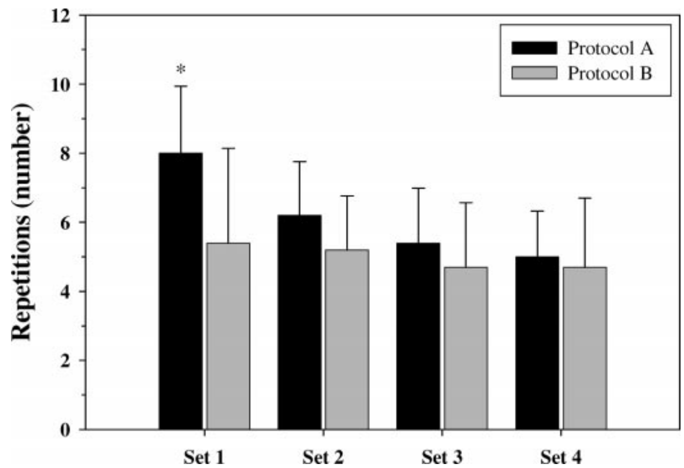

FIGURE 1. Effect of order on number of repetitions performed during each set of protocol A (squat first) and protocol B (squat last). * Significantly greater ($p < 0.05$) than corresponding value for protocol B.

Statistical Analyses

Descriptive statistics (mean, *SD*s, and *SE*s) were computed for all variables; data are reported as mean ± *SD*. A 2-way (2 × 4; order × sets) repeated-measures analysis of variance was used to assess each primary outcome variable (repetitions, average power, and RPE). In the case of a significant finding, Tukey post hoc tests were used to determine specific pairwise differences. Additionally, Pearson product moment correlations were calculated to investigate potential relationships between among variables. Statistical significance was set at $p \leq 0.05$.

RESULTS

Significantly ($p < 0.05$) fewer repetitions were performed during the back squat when it was preceded by the whole-body resistance-exercise workout (Figure 1). Subjects could perform 8.0 ± 1.9 repetitions during this first set of protocol A and 5.4 ± 2.7 repetitions during the first set of protocol B (a difference of 32.5%). Furthermore, sub-

TABLE 1. Effect of exercise order on average power output (W) (data are mean ± *SD*).

Set	Protocol A	Protocol B	% Difference
1	423.5 ± 128.32	461.9 ± 117.24*	−8.3
2	412.1 ± 133.39	446.5 ± 132.56*	−7.7
3	420.2 ± 148.18	428.7 ± 136.47*	−1.9
4	402.1 ± 138.37	421.2 ± 121.88*	−4.3

* Significantly greater ($p < 0.05$) than corresponding value for protocol A.

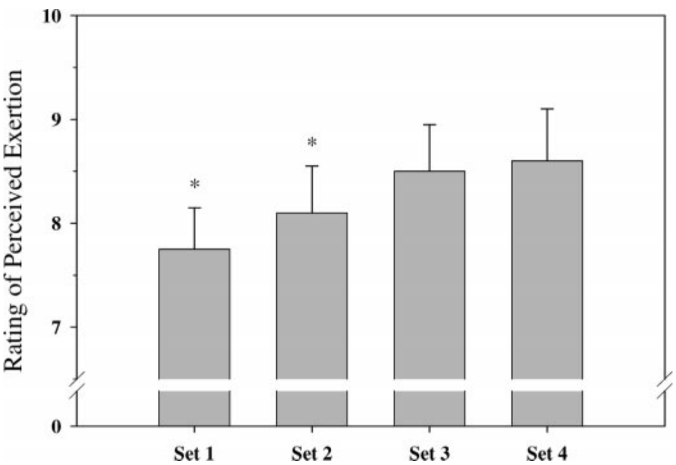

FIGURE 2. Rating of perceived exertion during each set of the study; values for protocol A (squat first) and protocol B (squat last) are pooled. * Significantly ($p < 0.05$) lower compared with sets 3 and 4.

jects performed more repetitions during each set of protocol A; however, these differences were not statistically significant.

Each set during protocol B was performed with a greater power output ($p < 0.01$) than during protocol A (Table 1). The differences in average power between the protocols during each set ranged from 8.3 to 1.9%.

Values for RPE during the 2 protocols were not significantly different. However, after pooling the values for protocols A and B, the first set was significantly lower compared with the RPE of the third and fourth sets. Similarly, the mean RPE of the second set was significantly lower compared with the third and fourth sets (Figure 2).

DISCUSSION

The primary finding of this study was that the exercise order significantly affected squat performance; however, it differentially influenced selected variables. Performing the barbell back squat last in a whole-body resistance-exercise session (a) decreased the total number of repetitions that can be performed and (b) increased the average power during each set.

The decrease in squat repetitions when the squat was last in the workout is not surprising in light of previous studies. Sforzo and Touey (13) found a 22% decrease in the number of repetitions performed during the back squat when it was performed after lower-body single-joint exercises. Similarly, Augustsson et al. (1) found a 15% decrease in leg press repetitions when it was preceded by leg extensions. In the present investigation, a much larger decrease in squat performance was found (32.5%) when the barbell back squat was performed after a whole-body resistance-exercise session. Potential reasons for the larger decrease in repetitions in the present study include (a) the exercise session that preceded the squat stimulated and fatigued all muscle groups, including synergists and stabilizers involved in the squat (e.g., glutei, lower back muscles, abdominal muscles); and (b) as opposed to the leg press exercise used by Augustsson et al. (1), we used the free-weight back squat, which may be more susceptible to fatigue because free-weight exercises are generally considered more neurally complex than are machine-based exercises (i.e., they require more balance and synergistic activation of multiple muscle groups) (8).

The decrease in repetitions performed in a pre-exhausted state is likely due to accumulated fatigue. Linnamo et al. (11) showed that performing 5 sets of 10RM leg extensions was associated with significant central and peripheral fatigue: EMG activity of the thigh musculature decreased, isometric force production decreased, and blood lactate concentrations increased. The authors' findings are further supported by Augustsson et al. (1), who showed that EMG activity was decreased when the leg press was performed after leg extensions. Placing these previous findings in the context of the present study, it is possible that performing 3 sets of 8–10RM for 7 different exercises may have led to significant central and peripheral fatigue that diminished the total number of repetitions performed during the back squat.

Interestingly, the average power output for each set was greater when the squats were performed after the whole-body resistance-exercise session (protocol B). It is not possible to compare this finding with previous studies of resistance-exercise order (1, 13) because neither of those studies measured power output. This makes the present investigation unique, as it is the first controlled study to report effects of exercise order on power output.

Because during protocol B the squat exercise was performed immediately after the hang pull, a possible explanation for the increase in power output is a postactivation potentiation (PAP) phenomenon. PAP is an acute increase in muscular performance after previous muscular activity. Specifically, an increase in peak force, faster rate of twitch force development, and decrease in time-to-peak force has been attributed to PAP (5, 12, 15).

Although studies attempting to apply PAP to athletic or resistance-training performance have shown a beneficial affect of PAP, results are inconsistent and equivocal. For instance, Gossen and Sale (4) found that performing a 10-second maximal voluntary contraction (MVC) was unsuccessful in improving knee-extension performance. The authors attributed the lack of performance benefits to insufficient time for recovery from fatigue after the MVC (15 seconds) and suggested that a longer recovery time (4–5 minutes) may have beneficial effects. This suggestion seems quite noteworthy because (a) other studies showing a beneficial influence of PAP have used longer (4-minute) rest periods (16); and (b) during the present study, approximately 4–5 minutes separated the hang pull and the first set of the back squat. Therefore, it is possible that some degree of PAP occurred in the present study, which may account for the increase in power output during each set of the squat during protocol B.

General recommendations for designing resistance-training programs are to perform multiple-joint exercises and exercises involving large muscle groups first (3, 8, 10). Theoretically, this should allow optimal loading for the multiple-joint exercises. Sforzo and Touey (13) and Augustsson et al. (1) confirmed this view and showed that performing small muscle group exercises (e.g., leg and arm extensions) before large muscle group exercises (e.g., squat, bench press) decreased quality aspects of multiple-joint exercises. Additionally, Fleck and Kraemer (3) made note in their textbook (unpublished data) that, upon analysis of the workout logs of 50 football players, players used markedly heavier resistances (195 ± 35 kg vs. 189 ± 31 kg) on heavy days (3–5RM) when they performed squats first in the workout. Similarly, our findings indicate that performing back squats after a whole-body resistance-exercise session decreases the number of repetitions allowed. However, we also demonstrated that power output may be enhanced by performing back squats after other lower-body power exercises (e.g., hang pull). This finding may be quite useful for the exercise practitioner who wishes to increase the power capabilities of athletes. It also raises the important issue of the choices of exercises in the sequence of lifts and which lift precedes another. Obviously, more research is needed to clarify this issue, but this study demonstrates that fatigue does influence a loss in total work capacity in the squat exercise because of the order of the exercise sequence.

On the basis of the findings of this study, an interesting question may be posed: Would similar changes in power output occur if the squat were not immediately preceded by the hang pull during protocol B? Because of the design of the study, it is not possible to determine the relative importance of the hang pull for increasing average power in the squat. It may be that power output would have been less than or equal to the average power in protocol A if not for the hang pulls. Therefore, future investigations should attempt to determine a mechanism or mechanisms for the results found in this study. Potential mechanisms may include catecholamine responses, psychological motivation to complete the workout, and PAP.

Performing the barbell back squat first in an exercise session allowed a maximal number of repetitions to be performed. However, this study also showed that performing the squat exercise last in a workout session, preceded by a power exercise (i.e., hang pull), resulted in greater average power output per set as opposed to performing the squat exercise first. Although previous studies have shown conflicting results for PAP effects, this study indicated that PAP phenomena may influence the power output during subsequent exercises performed within a resistance-training session.

Practical Applications

In the present study, the order of exercise exerted 2 main effects on the squat performance. First, performing the barbell back squat exercise after a whole-body resistance-exercise protocol decreased the number of repetitions that can be performed. Second, performing the squat exercise after a lower-body power exercise (i.e., hang pull) may increase the average power output achieved during each set. Regarding these findings, 2 recommendations can be made: (a) athletes aiming for maximal strength gains should perform multiple-joint, large muscle group exercises first in a session; and (b) athletes striving for maximal power gains in certain appropriate movements may perform a power-type exercises (e.g., hang pull) before strength-type exercises (e.g., back squat).

References

1. Augustsson, J., R. Thomee, P. Hornstedt, J. Lindblom, J. Karlsson, and G. Grimby. Effect of pre-exhaustion exercise on lower-extremity muscle activation during a leg press exercise. *J. Strength Cond. Res.* 17:411–416. 2003.
2. Borg, G.A. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exerc.* 14:377–381. 1982.
3. Fleck, S.J., and W.J. Kraemer. *Designing Resistance Training Programs* (3rd ed.). Champaign, IL: Human Kinetics, 2004.
4. Gossen, E.R., and D.G. Sale. Effect of postactivation potentiation on dynamic knee extension performance. *Eur. J. Appl. Physiol.* 83:524–530. 2000.
5. Grange, R.W., R. Vandenboom, and M.E. Houston. Physiological significance of myosin phosphorylation in skeletal muscle. *Can. J. Appl. Physiol.* 18:229–242. 1993.
6. Jackson, A.S., and M.L. Pollack. Practical assessment of body composition. *Phys. Sports Med.* 13:82–90. 1985.
7. Kraemer, W.J. Exercise prescription in weight training: Manipulating program variables. *Natl. Strength Cond. Assoc. J.* 5: 58–59. 1983.
8. Kraemer, W.J., K. Adams, E. Cafarelli, G.A. Dudley, C. Dooly, M.S. Feigenbaum, S.J. Fleck, B. Franklin, A.C. Fry, J.R. Hoffman, R.U. Newton, J. Potteiger, M.H. Stone, N.A. Ratamess, and T. Triplett-McBride. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med. Sci. Sports Exerc.* 34: 364–380. 2002.
9. Kraemer, W.J., and A.C. Fry. Strength testing: Development and evaluation of methodology. In: *Physiological Assessment of Human Fitness.* P. Maud and C. Foster, eds. Champaign, IL: Human Kinetics, 1995. pp. 115–138.
10. Kraemer, W.J., and N.A. Ratamess. Fundamentals of resistance training: Progression and exercise prescription. *Med. Sci. Sports Exerc.* 36:674–688. 2004.
11. Linnamo, V., K. Hakkinen, and P.V. Komi. Neuromuscular fatigue and recovery in maximal compared to explosive strength loading. *Eur. J. Appl. Physiol. Occup. Physiol.* 77:176–181. 1998.
12. O'Leary, D.D., K. Hope, and D.G. Sale. Post-tetanic potentiation of human dorsiflexors. *J. Appl. Physiol.* 83:2131–2138. 1997.
13. Sforzo, F.A., and P.R. Touey. Manipulating exercise order affects muscular performance during a resistance exercise training session. *J. Strength Cond. Res.* 10:20–24. 1996.
14. Simao, R., T. Farinatti Pde, M.D. Polito, A.S. Maior, and S.J. Fleck. Influence of exercise order on the number of repetitions performed and perceived exertion during resistance exercises. *J. Strength Cond. Res.* 19:152–156. 2005.
15. Sweeney, H.L., B.F. Bowman, and J.T. Stull. Myosin light chain phosphorylation in vertebrate striated muscle: regulation and function. *Am. J. Physiol.* 264:C1085–C1095. 1993.
16. Young, W., A. Jenner, and K. Griffiths. Acute enhancement of power performance from heavy load squats. *J. Strength Cond. Res.* 12:82–84. 1998.

Acknowledgments

We would like to thank a dedicated group of test subjects for their participation in the study. There were no conflict-of-interest issues or grant support for this study.

Address correspondence to William J. Kraemer, Ph.D., C.S.C.S., William.Kraemer@uconn.edu.