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Kinetic Analysis of Complex Training Rest Interval Effect on Vertical Jump Performance

RANDALL L. JENSEN[1] AND WILLIAM P. EBBEN[2]

[1]*Physical Education Instruction Facility, Northern Michigan University, Marquette, Michigan 49855;*
[2]*Strength and Conditioning Clinical Faculty, Marquette University, Milwaukee, Wisconsin 53201.*

ABSTRACT

Complex training has been recommended as a method of incorporating plyometrics with strength training. Some research suggests that plyometric performance is enhanced when performed 3–4 minutes after the strength training set, whereas other studies have failed to find any complex training advantage when plyometrics are performed immediately after the strength training portion of the complex. The purpose of this study was to determine if there is an ergogenic advantage associated with complex training and if there is an optimal time for performing plyometrics after the strength training set. Subjects were 21 NCAA Division I athletes who performed a countermovement vertical jump, a set of 5 repetitions maximum (5RM) squats, and 5 trials of countermovement vertical jump at intervals of 10 seconds and 1, 2, 3, and 4 minutes after the squat. Jump height and peak ground reaction forces were acquired via a force platform. The pre-squat jump performance was compared with the post-squat jumps. Repeated measures ANOVA determined a difference ($p \leq 0.05$) between genders and that jump performance immediately following the squat exercise was hindered (0.66 m), but no effect ($p > 0.05$) was found comparing subsequent jumps (0.72–0.76 m) to the pre-squat condition (0.74 m). When comparing high to low strength individuals, there was no effect on jump performance following the squat ($p > 0.05$). In conclusion, complex training does not appear to enhance jumping performance significantly and actually decreases it when the jump is performed immediately following the strength training set; however, a nonsignificant trend toward improvement seemed to be present. Therefore to optimize jump performance it appears that athletes should not perform jumps immediately following resistance training. It may be possible that beyond 4 minutes of recovery performance could be enhanced; however, that was not within the scope of the current study.

Key Words: contrast training, power, plyometrics

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Introduction

Complex training combines biomechanically comparable high-load resistance training followed by plyometric exercises on a set-for-set basis and has been proposed as a way to improve the quality of the plyometric training stimulus (4). Ebben and Watts (4) reviewed the literature on complex training describing previous research and offered recommendations for program design. However, since data were limited, recommendations were tentative regarding the optimal amount of rest between sets of resistance training and subsequent plyometrics in the complex. Anecdotal recommendations ranged from almost no rest up to 10 minutes. Research in this area has previously been described as complex training, the contrast method, or has examined the ergogenic warm-up effect associated with weight training exercises performed prior to explosive movements such as the vertical jump (1, 3, 5, 7, 10–13). Results of these studies suggest that there may be an optimal time of recovery between the resistance training and plyometric portions of the complex, and that gender and training status (strength) may influence complex training performance.

Verkhoshansky and Tetyan (12) assessed the effectiveness of 16 weeks of training with complex pairs of exercises such as squats followed by jump squats on a set-for-set basis. No numerical data were given, but the authors concluded the complex training group outperformed the other 2 groups. These authors were the first to describe and investigate complex training and recommended performing plyometrics soon after the resistance training portion of the complex to take advantage of the possible heightened excitability of the central nervous system.

However, some evidence suggests that complex training with plyometrics performed almost immediately after the resistance training set offered no benefit to the plyometric performance. For example, previous research evaluated upper-body complex training by examining the effect of the bench press on force production and motor unit recruitment during the medicine ball power drop (3, 10). Results revealed no statistically significant difference in motor unit activity or peak or mean ground reaction forces associated with the plyometric exercises performed 10 seconds after the weight training exercise. These findings raise

Pre-squat	5RM Squats	10 sec post squat	1 min post squat	2 min post squat	3 min post squat	4 min post squat

Figure 1. Research protocol depicting timing of jumps relative to 5RM squat exercise.

questions about the effectiveness of upper-body complex training and the appropriateness of short rest intervals between components of the complex.

On the other hand, Evans et al. (5) examined a complex of bench press and medicine ball put and found a statistically significant increase in medicine ball put when performed after the 5 repetitions maximum (5RM) bench press in the complex condition. This study offers support for the potential effectiveness of upper-body complex training and suggests that 4 minutes of intracomplex rest may be more effective.

Evidence suggests that lower-body complex training may be effective provided there is adequate intracomplex rest. For example, Radcliffe and Radcliffe (11) demonstrated that 4 sets of 4 repetitions of the power snatch, performed prior to the standing long jump, improved the standing long jump performance when performed 3 minutes after the ''warm-up'' power snatch exercise. However, an increase in standing long jump performance was not present for women. Young et al. (13) demonstrated improved loaded countermovement jump performance following a set of 5RM squats compared with the same type of jump performed before the 5RM squats. Jump performance was especially enhanced for stronger individuals. This study used a 4-minute rest protocol between the 5RM squats and the loaded countermovement jump.

Previous research by Ebben et al. (3) and Jensen et al. (10) used almost no recovery (<10 seconds). However, results demonstrated no statistically significant improvement in the plyometric condition of the complex pair. Alternately, research by Radcliff and Radcliffe (11), Young (13), and Evans (5) allowed between 3 and 4 minutes rest between the resistance training and explosive movements. Results suggest an ergogenic advantage associated with performing the explosive exercises with this degree of recovery.

The rest interval between the strength training and plyometric set is an important complex training variable (4). Short intracomplex rest intervals may take advantage of the heightened stimulation of the neuromuscular system (4, 12). On the other hand, adequate rest between sets of strength or power exercises is necessary for the recovery of the phosphagen system (9). In fact, recovery may be 70% complete after 30 seconds and nearly 100% complete within 3–5 minutes (9). Adequate bioenergetic recovery from previous sets of resistance training exercise may result in increased power output in the plyometric condition of the complex.

The investigators hypothesized that there was an optimal length of recovery between the resistance training and plyometric component of complex training that allows recovery of the phosphagen system without loss of the heightened stimulation of the neuromuscular system. The purpose of this study was to determine if there is an ergogenic advantage associated with lower-body complex training and determine if there is an optimal rest interval between the resistance training and the plyometric component of complex pairs. This study also evaluated the effect of strength and gender on complex training performance.

Methods

Experimental Approach to the Problem

Independent variables included rest interval (denoted by different jump repetitions), gender, and strength (defined as squat load). This study examined dependent variables such as the subject's peak ground reaction force and jump height for 1 countermovement vertical jump performed on a force platform before and 5 countermovement vertical jumps performed on a force platform after a set of 5RM squats. In other words, the jump performed before the squat set served as a baseline for examining the influence of the set of squats on the jumps performed after the squat. Jumps were performed at intervals of 10 seconds and 1, 2, 3, and 4 minutes after the squat set (see Figure 1). All data were collected during a single testing session within 10 minutes total time. A pilot test found no intrajump effect of vertical jumps. As a result, variations in jump height and ground reaction forces can be attributed to the effect of the set of 5RM squats and the recovery period as opposed to the previous set(s) of vertical jumps.

The 5RM was used to employ strength as the primary component as opposed to muscular endurance. Previous research and complex training recommendations have employed a 5RM (3, 5, 8, 10, 11, 13), which represents a training intensity that resulted in previous complex training performance enhancement (13).

Subjects

Subjects included 21 NCAA Division I athletes (10 women, mean ± *SD*, age = 19.6 ± 1.0 years, weight = 78.0 ± 16.9 kg; 11 men, age = 21.4 ± 1.9 years, weight = 82.4 ± 15.9 kg). All subjects participated in an anaerobic sport (including volleyball; wrestling; high and long jumps; and shot, discus, and hammer throws); have trained with the squat and plyometric exercises; and were without lower-extremity injury. Other principles guiding subject selection included obtaining permission from the athlete's coach, limiting involvement to athletes who were in the power phase of their training cycles and who were not in-season, and offering gender-inclusive opportunity to participate. Subjects performed no strength or plyometric training in the 48 hours prior to data collection. Subjects completed a Physical Activities Readiness Questionnaire and signed an informed consent form prior to participation in the study. The informed consent form described the research as well as the potential benefits and risks associated with participation in the study.

Instrumentation

The countermovement vertical jumps were performed on a 2 cm thick aluminum platform (76 × 102 cm) bolted directly to a force plate (OR6-5-2000, AMTI, Watertown, MA). Ground reaction forces were determined through vertical displacement of the force plate that was connected to an amplifier (SCA-3, AMTI); filtered (100D, Bio Pac Systems Inc., Goleta, CA); and streamed continuously through an analog to digital converter (MP100A, Bio Pac) to an IBM-compatible notebook computer and diskette. All data were collected at 1,000 Hz, real time displayed, and saved with the use of computer software (AcqKnowledge 3.2, Biopac Systems Inc., Goleta, CA).

Test Procedure

Some sources indicate that stretching results in the acute attenuation of strength or power. However, these studies failed to examine pre-activity stretching protocols of durations and intensity that are typical for athletes. For example, in the protocol used by Fowles et al. (6), subjects perform 13 stretches lasting 135 seconds each. In fact, according Church et al. (2), warm-up and static stretching resulted in no decrease in vertical jump performance. As a result, warm-up exercises were performed prior to the test exercises to prevent injury and prepare subjects for the high-load squats and jumps.

Warm-up consisted of at least 3 minutes of low-intensity work on a cycle ergometer. Static stretching included 1 exercise for each major muscle group with stretches held from 12 to 15 seconds. Activity-specific warm-up included participation in 5 repetitions of the back squat at 50% of the 5RM and 3 repetitions at 80% of 5RM. Subjects performed 2 warm-up sets of 5 vertical jumps.

Following the warm-up and stretching exercises, the subjects were allowed at least 5 minutes rest prior to beginning the countermovement vertical jumps and the 5RM squat test. Upon completion of the tests, subjects participated in cool-down and stretching exercises. Cool-down and stretching exercises consisted of 3 minutes of low-intensity aerobic activity and the same static stretches used prior to the test. A certified strength and conditioning specialist (CSCS*D) supervised the subject's warm-up and spotted the subject's squat and countermovement vertical jumps.

Table 1. Mean ± *SD* peak ground reaction forces (n) for men ($n = 11$) vs. women ($n = 10$) across 6 repetitions of vertical jump.

	Women*	Men
Pre-squat jump	1,060.1 ± 150.7	1,505.0 ± 328.3
Post-squat jump, 10 sec	1,024.8 ± 137.9	1,309.3 ± 285.2
Post-squat jump, 1 min	1,067.5 ± 187.0	1,404.0 ± 294.7
Post-squat jump, 2 min	1,069.7 ± 190.0	1,480.0 ± 335.5
Post-squat jump, 3 min	1,027.0 ± 212.7	1,447.2 ± 339.4
Post-squat jump, 4 min	1,019.5 ± 174.4	1,459.3 ± 353.1

* Significantly different from men ($p \leq 0.05$).

Statistical Analyses

Peak ground reaction force and jump height data were analyzed using a 2-way (gender × repetition) mixed analysis of variance (ANOVA) with repeated measures on repetitions ($p \leq 0.05$). To determine if level of strength might influence jump height, subjects were categorized into high and low strength groups according to 1RM squat. The 8 strongest individuals (6 men and 2 women) were categorized into a high strength group, whereas the 8 lowest strength individuals (6 women and 2 men) were designated the low strength group. Fisher's least significant difference post hoc tests were performed to determine differences between repetitions.

Results

Peak ground reaction force (GRF) data (shown in Table 1) revealed a significant difference between genders, but no main effect for repetition or gender × repetition interaction. Post hoc tests revealed that the repetition immediately following the squats was significantly less than all other repetitions for both men and women, but none of the other repetitions differed from each other (Table 2). In addition, as shown in Figure 2, women jumped significantly less than the men; however, there was no gender × repetition interaction.

A 2-way repeated measures ANOVA (strength × repetitions) indicated that although strength level was significantly different for the 2 groups, there was no difference across repetitions or interaction of strength level with repetition for jump height (see Table 3).

Discussion

Previous sources have suggested that the plyometric component of complex training should be performed immediately after the high-load resistance training component (4, 12). In contrast, results of this study suggest that plyometric performance may be impaired if performed soon (10 seconds) after the resistance-training portion of the complex.

The results of this study are consistent with the

Table 2. Mean ± *SD* jump height for men ($n = 11$) vs. women ($n = 10$) across 6 repetitions of vertical jump.

	Jump height (m)		Jump height (in)	
	Women*	Men	Women*	Men
Pre-squat jump	0.56 ± 0.07	0.87 ± 0.13	22.3 ± 2.9	34.3 ± 5.1
Jump, 10 sec post-squat**	0.54 ± 0.06	0.78 ± 0.11	21.3 ± 2.4	30.5 ± 4.2
Jump, 1 min post-squat	0.59 ± 0.08	0.85 ± 0.12	23.3 ± 3.4	33.6 ± 4.6
Jump, 2 min post-squat	0.61 ± 0.07	0.87 ± 0.11	24.0 ± 2.7	34.4 ± 4.4
Jump, 3 min post-squat	0.61 ± 0.08	0.86 ± 0.11	24.1 ± 3.0	33.9 ± 4.2
Jump, 4 min post-squat	0.62 ± 0.08	0.89 ± 0.09	24.4 ± 3.0	35.0 ± 3.7

* Significant different from men ($p \leq 0.05$).
** Significantly different from other repetitions ($p \leq 0.05$).

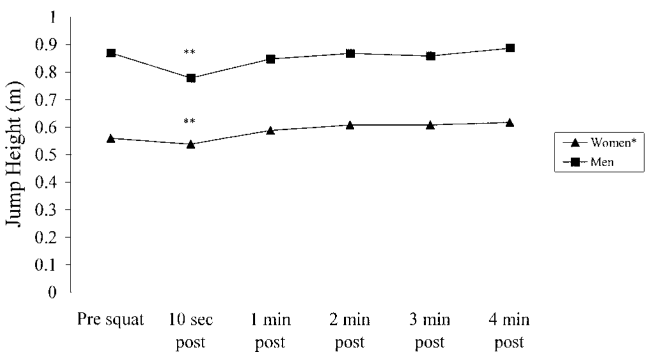

Figure 2. Jump heights for men ($n = 11$) vs. women ($n = 10$) across 6 repetitions relative to 5RM squat exercise. The significant difference between genders ($p \leq 0.05$) is indicated by the asterisk (*). Repetition 2 was lower than all others ($p \leq 0.05$) for both genders as indicated by the double asterisks (**).

lack of ergogenic complex training effect reported in previous research where subjects performed the plyometric component of the complex immediately after the high-load resistance training set (3, 10). In fact, the current study demonstrates a performance decrease associated with performing plyometrics immediately after the high-load resistance training and contradicts the studies by Ebben et al. (3) and Jensen et al. (10), which found no such performance decrease. The difference in results may be due, in part, to the variation in muscle groups (upper- vs. lower-body) used.

Studies by Radcliff and Radcliffe (12), Young (13), and Evans (5) allowed between 3 and 4 minutes rest between the resistance training and ''plyometric-like exercises.'' Their results suggest an ergogenic advantage associated with performing the plyometric exercises with this degree of recovery. In this study, a nonstatistically significant trend implies that up to 4 minutes rest between the high-load resistance training set and plyometric set may be most optimal with subjects jumping approximately 1.35 inches (4 cm) higher than they did in the noncomplex jump. It is possible that the nonstatistically significant trend for improvement in jump performance from 10 seconds post-squat to 4 minute post-squat could reflect recovery of the phosphagen system and its availability for post-squat jump performance (9).

In addition, data from the current study indicated that although women produced lower peak GRF and did not jump as high as men, there was no effect of gender on results across repetitions. Previous research examined the complex training effect with men and women division I basketball players, respectively, with similar results between groups (3, 10). However, unlike other studies that found significant complex training improvement with men, but not women, the non-

Table 3. Mean ± *SD* jump height for high ($n = 8$) and low strength ($n = 8$) individuals for 6 repetitions of vertical jump.

	Jump height (m)		Jump height (in)	
	High*	Low	High*	Low
Pre-squat jump	0.82 ± 0.24	0.64 ± 0.07	32.4 ± 9.6	25.7 ± 2.8
Jump, 10 sec post-squat	0.75 ± 0.19	0.58 ± 0.06	29.6 ± 7.3	23.0 ± 2.3
Jump, 1 min post-squat	0.83 ± 0.20	0.63 ± 0.10	32.7 ± 8.0	26.0 ± 4.0
Jump, 2 min post-squat	0.84 ± 0.21	0.67 ± 0.07	33.3 ± 8.4	26.3 ± 2.8
Jump, 3 min post-squat	0.82 ± 0.20	0.66 ± 0.11	32.3 ± 8.0	26.0 ± 2.3
Jump, 4 min post-squat	0.90 ± 0.17	0.67 ± 0.08	35.3 ± 6.7	26.4 ± 3.2

* Significantly different from low strength group ($p \leq 0.05$).

statistically significant trend toward improvement in complex training jump performance was more pronounced in women than men in the current study. More specifically, before and after complex training, women jumped 0.56 m (22.3 inches) and 0.62 m (24.4 inches) and men jumped 0.87 m (34.3 inches) and 0.89 m (35.0 inches).

Furthermore, previous observations that complex training may be most advantageous for those who are more highly trained are not supported by the findings of this study, which evaluated the effect of strength (defined by squat load) and found no performance enhancement.

Practical Applications

Results from the current study suggest that complex training results in no disadvantageous effect on plyometric performance as long as the plyometric sets are not performed immediately after the high-load resistance training set. Plyometrics performed 1–4 minutes after the resistance training set result in no impaired performance. In fact, training with intracomplex recovery approaching 4 minutes may result in a small but not statistically significant jump performance enhancement. Complex training may be an efficient organizational strategy, allowing incorporation of resistance training and plyometric training in the same facility at the same time. Finally, results of the current study suggest that the effect of complex training is similar for men and women athletes as well as athletes with varying strength levels.

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Address correspondence to Randall Jensen, rajensen@nmu.edu.