EFFECTS OF TRADITIONAL VS. ALTERNATING WHOLE-BODY STRENGTH TRAINING ON SQUAT PERFORMANCE

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ABSTRACT
Ciccone, AB, Brown, LE, Coburn, JW, and Galpin, AJ. Effects of traditional vs. alternating whole-body strength training on squat performance. J Strength Cond Res 28(9): 2569–2577, 2014—Traditional strength training with 80% of 1 repetition maximum (1RM) uses 2- to 5-minute rest periods between sets. These long rest periods minimize decreases in volume and intensity but result in long workouts. Performing upper-body exercises during lower-body rest intervals may decrease workout duration but may affect workout performance. Therefore, the purpose of this study was to compare the effects of traditional vs. alternating whole-body strength training on squat performance. Twenty male (24 ± 2 years) volunteers performed 2 workouts. The traditional set (TS) workout consisted of 4 sets of squats (SQ) at 80% of 1RM on a force plate with 3-minute rest between sets. The alternating set (AS) workout also consisted of 4 sets of SQ at 80% of 1RM but with bench press, and bench pull exercises performed between squat sets 1, 2 and 3 with between-exercise rest of 50 seconds, resulting in approximately 3-minute rest between squat sets. Sets 1–3 were performed for 4 repetitions, whereas set 4 was performed to concentric failure. Total number of completed repetitions of the fourth squat set to failure was recorded. Peak ground reaction force (GRF), peak power (PP), and average power (AP) of every squat repetition were recorded and averaged for each set. There was no significant interaction for GRF, PP, or AP. However, volume-equated AP was greater during the TS condition (989 ± 183) than the AS condition (937 ± 176). During the fourth squat set, the TS condition resulted in more repetitions to failure (7.5 ± 2.2) than the AS condition (6.5 ± 2.2). Therefore, individuals who aim to optimize squat AP should refrain from performing more than 3 ASs per exercise. Likewise, those who aim to maximize squat repetitions to failure should refrain from performing upper-body multijoint exercises during squat rest intervals.

KEY WORDS periodization, fatigue, rest, power, velocity

INTRODUCTION
Both athletes and the general population commonly use resistance training with goals that usually include muscular strength, power, hypertrophy, and endurance. Based on the goal(s), resistance training workouts should use appropriate loads, repetitions per set, number of sets, and rest intervals. Traditional strength training normally uses 2- to 5-minute rest periods between sets (4). Therefore, completing whole-body strength workouts with multiple sets of lower-body and upper-body exercises may require long rest periods. Thus, traditional strength training is time consuming. Unfortunately, lack of time is the single most commonly reported barrier to regular exercise (8). Furthermore, National Collegiate Athletic Association rules limit the total athlete training time, including mandatory supervised strength and conditioning workouts (17).

In an effort to decrease rest time and increase workout efficiency, between-set rest intervals may be decreased. Unfortunately, this strategy can potentially decrease both exercise intensity and volume. In contrast, alternate sets of opposing muscle groups ( supersets) or rotating through a series of isotonic exercises that target different muscle groups (circuit training) may be used. These strategies allow maintenance of relative rest periods between like exercises while decreasing absolute rest intervals and total workout time. The small existing body of literature suggests that these strategies facilitate shorter workouts without impairing exercise intensity or volume (2,5,19,20). However, upper-body high-intensity aerobic exercise performed before lower-body high-intensity aerobic exercise has been observed to impair lower-body high-intensity endurance (6,18,25). This discrepancy may be explained by the relatively greater muscle mass used in the high-intensity aerobic studies, whereas relatively lesser muscle mass was used in the isotonic resistance studies. Thus, rotating through isotonic resistance exercise workouts that use a high amount of total

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muscle mass may impair resistance exercise performance and subsequent adaptations.

Although research suggests that upper-body multijoint supersets do not impair exercise volume or intensity, and whole body alternating single-joint/multijoint strength training does not impair exercise volume or strength gains, there is a paucity of research focusing on whole body alternating multijoint exercises. Therefore, the purpose of this study was to compare the effects of traditional vs. alternating whole-body strength training on squat performance.

METHODS

Experimental Approach to the Problem

To compare the effects of whole-body traditional strength training vs. alternating strength training on squat performance, each subject completed 2 workouts in a counterbalanced fashion. Workouts were separated by at least 48 hours and no longer than 1 week. One workout consisted of 4 sets of squats (SQ) at 80% of 1 repetition maximum (1RM) with 3-minute rest intervals between traditional sets (TSs). Another workout (alternating set [AS]) also consisted of 4 SQ at 80% of 1RM with bench press (BPR), and bench pull (BPU) exercises performed between squat sets 1 and 2, 2 and 3, and 3 and 4 in an alternating manner. Bench press and BPU exercises were also performed at 80% of 1RM. Between-exercise rest intervals were approximately 50 seconds, resulting in a 3-minute interval between squat sets. For all exercises, sets 1–3 were performed for 4 repetitions, whereas set 4 was performed to concentric failure. Total number of completed repetitions of the fourth SQ set to failure was recorded. Additionally, peak ground reaction force (GRF), peak power (PP), and average power (AP) of every SQ repetition and set were recorded on a force plate.

Subjects

Twenty healthy resistance-trained men (age = 24 ± 2 years, mass = 84.6 ± 10.0 kg, height = 177.7 ± 7 cm, SQ 1RM = 151 ± 21 kg, BPR 1RM = 111 ± 15 kg, BPU 1RM = 71 ± 9 kg) between the ages of 20 and 29 volunteered to complete this study. Subjects were considered trained if they had participated in a minimal average of 3 resistance training workouts per week over the past year, and could back squat at least 1.5 times their body mass. Inclusion criteria also consisted of an absence of current musculoskeletal injury or any illness that would impair exercise performance. Before data collection, subjects signed an informed consent document approved by the University Institutional Review Board.

Baseline Testing and Familiarization

Subjects attended 1 preliminary visit. During this visit, study details were outlined and subjects signed the informed consent. Body mass was measured through an electronic scale (ES200L; Ohaus Corporation, Pinebrook, NJ, USA) and height through a stadiometer (Seca, Ontario, CA, USA). After anthropometric measurements, subjects performed
a dynamic warm-up of walking lunges, high-knee pulls, and Frankensteins over two 15-m lengths. After warm-up, 1RM testing in order of SQ, BPR, and BPU exercises was done. For the preliminary trial and all experimental trials, each exercise was performed with a 2-second eccentric phase followed immediately by an “as fast as possible” maximal velocity concentric phase. A metronome cadence of 60 beats per minute dictated eccentric repetition velocity.

One-repetition maximum testing protocols included sets of 10, 6, 3, and 1 repetition(s) at 50, 75, 85, and 95% of estimated 1RM (1). Subjects continued to attempt incrementally greater resistance until failure. Three-minute rest intervals separated each set with 5 minutes between exercises. After 1RMs, subjects familiarized themselves with the workout by completing 1 round of successive SQ, BPR, and BPU exercises.

Barbell back SQ were performed in a power rack (Muscle Maxx Power Rack; Power Systems, Inc., Knoxville, TN, USA) to parallel, which was signified by the beep of an electronic level (Safety Squat; Bigger Faster Stronger, Salt Lake City, UT, USA). Experimenters marked each subject’s leg to ensure between trial placement replication (Figure 1).

Barbell BPUs were performed on a raised bench to allow for full range of motion. Subjects laid prone with their arms extended down grasping a barbell, which they pulled vertically to their chest then lowered back to the start position (Figure 2).
Barbell BPRs were performed supine with head, back, and gluteal muscles contacting the bench, and feet flat on the ground. Subjects began each repetition with the barbell supported by their vertically extended arms, then lowered it until it contacted their chest then returned back to the start position (Figure 3).

**Experimental Trials**

Each of the 2 experimental trials (TS and AS) began at the same time of day ($\pm$ 1 hour). Subjects performed the same general dynamic warm-up as they did on their preliminary trial. This was followed by 2 consecutive specific warm-up sets, separated by 3-minute rest intervals. The TS-specific warm-up consisted of 2 consecutive SQ sets for 10 and 3 repetitions at 50 and 80% of 1RM, whereas the AS-specific warm-up included 2 rounds of alternating SQ, BPR, and BPU exercises for 10 repetitions at 50% of 1RM followed by 3 repetitions at 80% of 1RM. After the specific warm-up, subjects completed either a TS or AS workout. During both workouts, subjects completed the first 3 SQ for 4 repetitions, whereas the fourth set was performed to concentric failure. For both workouts, all squat repetitions were performed on a force plate (AMTI, Watertown, MA, USA), sampling at 1,000 Hz and with a barbell collar-mounted linear velocity transducer (Model V-80-L7M, Unimeasure, Inc., Corvallis, OR, USA) interfaced with a personal computer running custom LabVIEW software (version 2012; National Instruments, Austin, TX, USA). Ground reaction force, PP, and AP variables were analyzed through the same custom LabVIEW software. For each set, GRF, PP, and AP values were averaged.

**Volume-Equated Variables**

Because the number of completed fourth set repetitions to failure was not controlled, normal averages of GRF, PP, and AP may be misleading. Therefore, GRF, PP, and AP were also analyzed in a manner that equated each subject's number of completed repetitions between TS and AS conditions. This was accomplished by determining which condition resulted in the least number of fourth set repetitions.
repetitions and then only that number of repetitions was considered for both conditions. For example, if subject 1 completed 7 fourth set TS repetitions and 5 AS repetitions, only repetitions 1–5 for both conditions were considered in the averaging of volume-equated GRF, PP, and AP.

**Statistical Analyses**

SPSS 20.0 was used to perform all statistical analyses (IBM Corporation, Somers, NY, USA). Descriptive data (mean values and SDs) were calculated for all variables. Three 2 × 3 (condition × set) repeated measures analysis of variance (ANOVA) tests were used to analyze differences in GRF, PP, and AP. Three 2 × 3 (condition × set) repeated measures ANOVA tests were also used to analyze differences in volume-equated GRF, PP, and AP. A 1-way ANOVA examined repetitions of the fourth set between workouts. Statistically significant interactions were followed up with LSD analyses for pairwise differences. An a priori alpha of 0.05 defined significance.

**RESULTS**

For repetitions to failure in the fourth set, the TS condition was greater than the AS condition (Figure 4). There was considerable intersubject variability; however, 12 of the 20 subjects (60%) exhibited fewer repetitions during the AS condition (Figure 5).

For GRF, there was no significant interaction (Table 1), but there was a main effect for set where sets 2 and 3 were greater than set 4 (Table 2). For PP, there was no significant interaction (Table 1), but there was a main effect for set where set 1 was greater than sets 2, 3, and 4 and sets 2 and 3 were greater than set 4 (Table 2). For AP, there was no significant interaction (Table 1), but there was a main effect for set where set 1 was greater than sets 2, 3, and 4 and sets 2 and 3 were greater than set 4 (Table 2). There were no main effects for condition for GRF, PP, or AP (p > 0.05) for any analysis.

For volume-equated GRF, there were no significant interactions (Table 3) or main effects (Table 4). For volume-equated

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**Table 3. Effect of TS vs. AS condition and set on volume-equated squat peak concentric GRF, PP, and AP.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 3</th>
<th>Set 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRF (N)</td>
<td>2,570.49 ± 331.50</td>
<td>2,479.49 ± 397.34</td>
<td>2,549.27 ± 332.11</td>
<td>2,518.10 ± 317.04</td>
</tr>
<tr>
<td>PP (W)</td>
<td>2,538.21 ± 558.56</td>
<td>2,405.77 ± 587.86</td>
<td>2,429.05 ± 510.98</td>
<td>2,324.19 ± 461.89</td>
</tr>
<tr>
<td>AP (W)</td>
<td>1,066.88 ± 199.03</td>
<td>1,004.15 ± 215.85</td>
<td>1,020.42 ± 173.97</td>
<td>956.92 ± 169.83</td>
</tr>
</tbody>
</table>

*TS = traditional set; AS = alternating set; GRF = ground reaction force; PP = peak power; AP = average power.

**Table 4. Effect of set (collapsed across condition) on volume-equated squat peak concentric GRF, PP, and AP.**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 3</th>
<th>Set 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRF</td>
<td>2,524.99 ± 364.42</td>
<td>2,533.69 ± 324.58</td>
<td>2,541.28 ± 318.81</td>
<td>2,471.24 ± 324.62</td>
</tr>
<tr>
<td>PP</td>
<td>2,471.99 ± 573.21</td>
<td>2,376.62 ± 486.44</td>
<td>2,365.49 ± 515.74</td>
<td>2,115.38 ± 518.96</td>
</tr>
<tr>
<td>AP</td>
<td>1,035.02 ± 207.44</td>
<td>988.68 ± 171.90</td>
<td>960.35 ± 175.40</td>
<td>866.4 ± 163.22</td>
</tr>
</tbody>
</table>

*GRF = ground reaction force; PP = peak power; AP = average power.
†Significantly greater than set 2 (p ≤ 0.05).
‡Significantly greater than set 3 (p ≤ 0.05).
§Significantly greater than set 4 (p ≤ 0.05).
there was no significant interaction (Table 3), but there was a main effect for set where set 1 was greater than sets 2, 3, and 4 and sets 2 and 3 were greater than set 4 (Table 4).

For volume-equated AP, there was no significant interaction (Table 3), but there was a main effect for set where set 1 was greater than sets 2, 3, and 4, and set 2 was greater than sets 3 and 4, and set 3 was greater than set 4 (Table 4). There was also a main effect of condition for volume-equated AP where TS was greater than AS (Figure 6).

**DISCUSSION**

The primary finding of this study was that performing upper-body exercises during squat rest intervals impaired lower-body workout quality as seen in fewer repetitions to failure and decreased volume-equated AP. Conversely, there were no between condition differences in squat PP, or GRF. This might be explained by the accumulation of central fatigue or greater peripheral fatigue.

There was no difference in AP between conditions, which might be explained by a difference in the number of repetitions completed in the fourth set to failure. Because most subjects completed more repetitions to failure during the TS condition, and these extra repetitions tended to yield the lowest GRF, PP, and AP values, fourth set averages were skewed down, which resulted in misleading results. Once equated for fourth set volume, squat GRF was still not affected by the addition of upper-body exercises, whereas squat AP was. Volume-equated use did not result in statistical outcome changes to any other variable. Therefore, throughout this discussion, volume-equated variables will be addressed. Also, because of the velocity component of PP and AP data being a measurement of barbell velocity, PP and AP data do not reflect center of mass velocity and are likely influenced by changes in trunk coordination (13).

The addition of upper-body exercises may have amplified peripheral fatigue by decreasing blood flow to and oxygenation of leg muscles (3,28). Additionally, the inclusion of upper-body exercises likely increased heart rate above that of TS (2). This increased blood flow demand of upper-body and respiratory muscles (3) may have resulted in less blood flow to and less muscle oxygenation of lower-body muscles during AS, which could have decreased metabolite clearance and increased anaerobic metabolite production (9) of the lower-body muscles. Furthermore, the added upper-body exercises might have decreased circulating blood pH, which could have decreased the clearance rate of force-impairing metabolites (21) in lower-body muscles. All of these prospective mechanisms of increased lower-body muscle metabolite concentrations might have impaired excitation-contraction coupling, resulting in decreased force production (16,23).

Although some scientists suggest that build-up of interstitial potassium rather than acidity is primarily responsible for fatigue, increased intracellular acidity may have increased the rate of interstitial potassium build-up (18,25) and expression of fatigue. Similarly, the build-up of intracellular metabolites may have indirectly impaired force production through the excitation of group III and/or group IV afferents, which can decrease excitation of alpha motoneurons (22) and other supraspinal factors that seem to play a major role in central fatigue (11).

Central fatigue may stem from decreased central drive (26). Although studies have observed that fatigue of exercised muscles impairs the central drive to that exercised muscle (12,26), no studies have directly measured impaired central drive to nonfatigued muscles. In fact, Taylor et al. (26) observed biceps brachii maximal voluntary contraction (MVC) to have no effect on adductor pollicis MVC. This evidence suggests that it is unlikely that the upper-body exercises performed in the AS condition directly affected central drive to the lower-body muscles involved in the squat exercise. However, because central fatigue of exercised muscles has been observed (12,26), it is possible that additional peripheral fatigue of the lower-body muscles may have increased the amount of central fatigue during the AS condition, which may have contributed to decreased AS AP and repetitions to failure. Central fatigue has been observed to account for 20% of force decrements in maximal effort muscle actions (15) and is accompanied by decrements in voluntary muscle

![Figure 6. Effect of alternating (AS) vs. traditional set (TS) condition on volume-equated squat average power (AP) across all sets. *Significantly greater than AS (p ≤ 0.05).](image_url)
activation (15). Furthermore, Bigland-Ritchie reported that 5 of 9 (~55%) subjects in their study exhibited central fatigue (7), which is a similar percentage to this study (60%). Considering the previously mentioned prospective mechanisms and the intersubject variability, individual differences in buffering capacity may influence a person’s performance when rotating through dissimilar multijoint resistance training exercises. Previous research supports this idea as creatine supplementation has been observed to augment isotonic resistance exercise power and number of completed repetitions (27).

Although previous studies have found that upper-body exercise can impair lower-body performance (6,18), between condition differences in AP and repetitions to failure, the possibility of a psychological bias favoring TS cannot be dismissed as initial expectation of performance can influence task performance (10). Furthermore, scientists have found that initial psychophysical perception of effort during exercise is related to performance. Thus, if subjects in the current study perceived the initial sets of the AS condition to be more difficult than the TS condition, they may have performed less repetitions to failure during the last set and performed less powerful repetitions during the AS condition.

The lesser number of squat repetitions to failure during the AS condition is contrary to the findings of previous studies that used isotonic resistance exercise to examine the effect of exercising dissimilar muscles during the rest interval of a particular muscle group and found no significant effect on repetitions to failure (2,19,20). However, studies implementing high-intensity endurance arm cranking before high-intensity endurance leg kicking exercise have found that the added arm cranking exercise impairs leg kicking endurance (6,18). Although high-intensity endurance exercise is vastly different than isotonic repetitions to failure, similar physiological mechanisms are likely responsible for fatigue in both types of exercise. As previously mentioned, perhaps the current study and the Bangsbo studies may have found an effect of added upper-body exercises on lower-body performance because they incorporated multijoint upper-body exercises, whereas the Alcaraz studies incorporated single-joint exercises. Another explanation may be that upper-body exercises can impair lower-body exercise, but lower-body exercise may not impair upper-body exercise. However, the paucity of research related to the topic makes this idea purely speculative and highlights the clear need for further research in this area.

The current study’s findings of no between-condition differences in GRF and PP might be explained by the inherent changes in force and velocity due to a combination of muscle length and leverage changes throughout the squat. When participants began the initial concentric portion of the squat, GRF increased as participants gradually achieved more vertical thigh and trunk positions. Power initially increased before a brief drop, which preceded a rapid increase that ultimately resulted in PP. Ground reaction force and PP are instantaneous measurements that peak near the end of the movement where subjects are in a relatively advantageous mechanical upright position. This is similar to previous research that found no effect of fatigue on GRF because it is largely influenced by the mass being moved (14,29). Thus, peak GRF may not accurately reflect the presence or absence of fatigue. Peak power is the product of instantaneous GRF and bar velocity. Although we found no main effects for GRF, the main effect of set for PP is probably due to decreased bar velocity leading into peak GRF. This is supported by the finding of a main effect of set for AP, which suggests that bar velocities were depressed leading into peak GRF. Because of the fluctuations in GRF and bar velocity throughout the squat movement, and PP only reflecting an instantaneous time point late in the squat, it is not surprising that there were no between-condition differences in PP. With no between-condition differences in GRF and PP, it is not likely that end range of motion was affected by the additional upper-body exercises.

Unlike GRF and PP, which are instantaneous measurements, AP is the average of PP over the entire concentric portion of the squat. This is important because GRF and PP are instantaneous time points measured during the most biomechanically advantageous portion of the squat, which neglects the data leading up to and through the “sticking point” portion of the squat. AP data encompass a large portion of the exercise and may be very useful for analyzing changes in squat quality. Previous research has indicated that AP does decrease as more sets are completed (24), which was also observed in the current study. However, this decrease in acute performance may not translate into a decreased training response. Although previous research has found that additional lower-body single-joint exercises did not affect upper-body strength development (1), research has also found that the additional lower-body single-joint exercises had no acute effect on upper-body performance (2). However, these studies examined the effect of additional single-joint exercises on performance, which may have not resulted in as great a blood supply competition and peripheral fatigue magnification than the multijoint exercises in the current study. Other studies have found no effect of antagonist muscle exercise on agonist muscle exercise performance (19,20). However, the close proximity and shared vascular pathways of the opposing muscle groups might have not resulted in as great of a reduction in exercised muscle blood flow as in the current study. Furthermore, Robbins et al. implemented longer 4-minute rest intervals, which may have minimized any fatiguing effect the additional antagonist exercises might have had on the agonist exercises. Therefore, although we observed decreased squat AP in the AS condition, AS workouts may not necessarily result in decreased squat adaptations.
Peripheral, central, and psychological factors have all been observed to affect performance. Because physiological or psychological variables were not collected during this study, explanations of these findings are speculative. Furthermore, the interdependent nature of peripheral and central fatigue makes it difficult to ascertain which is responsible for the decrements of volume-equated AP and PP across sets in both workouts and differences in volume-equated AP and repetitions to failure between conditions. Therefore, both peripheral and central fatigue likely affected performance, especially in the last set to failure, and this effect may have been magnified in the AS condition. It is also difficult to dismiss the potential for psychological influence because this is the first study to report an effect of multijoint upper-body exercises on lower-body resistance training performance. Importantly, although this study did find that rotating through strength exercises did impair acute AP and repetitions to failure, this difference was small and may or may not impair strength adaptations.

**Practical Applications**

When programming time-efficient workouts, caution should be taken as performing upper-body multijoint exercises during SQ rest intervals can decrease SQ repetitions to failure and AP. However, this impairment did not occur until the fourth set. Thus, individuals can perform high-intensity (80% 1RM), AS, multijoint exercises with 50-second rest intervals for 3 sets (each set stopped short of concentric failure) to decrease total workout duration without impairing GRF, PP, or AP. Conversely, individuals who aim to optimize SQ AP should refrain from performing more than 3 ASs per exercise. Likewise, those who aim to maximize SQ repetitions to failure should refrain from performing upper-body multijoint exercises during SQ rest intervals. Although AS through a whole-body strength training workout may result in small but significant acute performance impairment, it is unknown if this acute impairment results in impaired strength gains.

**References**


