Acute Effects of High-Intensity Endurance Exercise on Subsequent Resistance Activity

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ABSTRACT

This study investigated the effect of high-intensity endurance on subsequent isoinertial and isokinetic resistance exercise. One woman and five men (mean ± SD: age = 20.3 ± 2.5 years; body mass = 75.1 ± 10.2 kg; height = 177.8 ± 10.3 cm) performed isoinertial and isokinetic resistance exercise under control conditions (no experimental intervention) and after an acute bout of high-intensity endurance exercise. Endurance exercise consisted of five 5-minute bouts of incremental cycle exercise at between 40 and 100% of peak cycle ergometer oxygen consumption (peak \(\text{VO}_2\)). Isoinertial resistance exercise consisted of three sets of squats with a load of 80% of one repetition maximum. Isokinetic resistance exercise consisted of five repetitions of leg extensions performed at five different contractile speeds (1.05, 2.09, 3.14, 4.19, and 5.24 rad-s\(^{-1}\)). Significant reductions in isokinetic torque at 0.52 rad from full extension (\(T_{30}\)) were observed after high-intensity endurance exercise. Endurance exercise also caused significant reductions in the number of isoinertial squat lifts performed. Plasma lactate values, measured before subjects performed resistance activity, were significantly higher after high intensity endurance exercise (6.16 ± 2.28 mmol-L\(^{-1}\)) when compared with the control condition (0.50 ± 0.45 mmol-L\(^{-1}\)). It was concluded that an acute bout of high-intensity endurance exercise may inhibit performance in a subsequent bout of resistance activity.

Key Words: strength training, concurrent training, acute fatigue


Introduction

Many athletes perform strength and endurance training concurrently in an effort to achieve adaptations specific to both forms of training. However, a number of researchers have shown that strength development during concurrent strength and endurance training is compromised when compared with training exclusively for increased strength development (7, 10, 13). The reasons for impaired strength development during simultaneous strength and endurance training are not fully understood (4, 8).

Craig and colleagues (6) have proposed an acute fatigue (prefatigue) hypothesis to explain the phenomenon of strength inhibition during concurrent training. They suggested that residual fatigue from the endurance component of concurrent training reduces the tension developed during the strength element of concurrent training. Since the degree of muscular tension is thought to be the critical stimulus for optimal strength development (3), an impaired ability to develop tension may then lead to less than optimal strength development. Jacobs (12) has also suggested that impaired strength development during simultaneous strength and endurance training may be due to individuals performing strength training when they have not recovered from a bout of endurance training performed in close proximity. Consequently, there is a need to investigate the effects a bout of endurance exercise has on resistance activity.

The purpose of this study was to determine if strength performance was impaired after a bout of high-intensity endurance exercise.

Method

Subjects

One woman and five men volunteered to participate in this experiment. Subjects were university students who regularly performed recreational exercise but were not training specifically for any particular sport. The study was approved by The University of Queensland Medical Research Ethics Committee. Subjects also provided written informed consent prior to participation in the experiment. All procedures were performed within the Human Performance Laboratories of the Department of Human Movement Studies at The University of Queensland.

Initial Measurements

Prior to the commencement of the experiment, all subjects were required to report to the laboratory for two
pretesting sessions. The first pretesting session involved familiarization with testing procedures and the measurement of height, weight, and squat lift one repetition maximum (1RM). Measurement of peak cycle ergometer oxygen consumption (PVo$_2$) was performed during the second pretesting session.

Squat lift 1RM was measured after a warm-up consisting of eight repetitions with a light load. Subjects then performed a single repetition with a much heavier load. The weight was then progressively increased until the subject could not successfully complete one repetition. A lift was deemed to be successful when subjects could lower the bar such that a knee angle of 90° was achieved and then raise the bar back to the upright starting position. Subjects received approximately 4 minutes rest between each attempt.

An incremental exercise protocol was used to determine PVo$_2$ of all subjects. Each subject began cycling at a workload of 50 watts on an electrically braked cycle ergometer (Excalibur, Lode, Netherlands). The workload was then increased by 25 watts each minute until volitional fatigue. Gas volumes were measured by a turbine ventilometer (Morgan, Kent, England). Concentrations of expired oxygen and carbon dioxide were measured by a gas analysis system (Ametek, Pittsburgh, PA; SOV S3A/1 and COV CD3A).

**Experimental Design**

Subjects performed resistance activity on two occasions, under control conditions (no activity for 48 hours prior to testing) and 30 minutes after a bout of high-intensity endurance exercise. A period of at least 5 days separated each measurement occasion. The order of measurement occasions was randomized.

**Endurance Exercise**

The high-intensity endurance exercise protocol consisted of five 5-minute exercise intervals performed on an electrically braked cycle ergometer (Excalibur, Lode, Netherlands). Each 5-minute exercise interval consisted of 1 minute at 40% of peak cycle ergometer oxygen consumption (peak Vo$_2$) followed by 1 minute at 60% of peak Vo$_2$, then 1 minute at 80% of peak Vo$_2$, and finally 2 minutes at 100% of peak Vo$_2$. Five minutes of passive recovery separated each exercise interval. This particular exercise protocol was selected for two reasons. First, many athletes (particularly those who are likely to be performing strength and endurance training simultaneously) often incorporate high-intensity, interval-type exercise in their endurance training regimens. Second, this particular exercise protocol has been used in other concurrent strength and endurance training studies (2, 7).

**Resistance Exercise**

The resistance exercise performed by subjects in this study consisted of both isoinertial and isokinetic activity. The isoinertial component consisted of three sets of squat lifts performed until failure on a Plyopower system (Plyopower Technologies, Lismore, Australia). The resistance applied during the three sets was equal to 80% of each subject's 1RM. Each set was terminated when subjects failed to lower the bar a sufficient distance such that a knee angle of 90° was achieved. The second criterion for termination of the set was if subjects could not raise the bar after they had lowered it to the correct position. The number of complete repetitions performed during each set was recorded. Sets were separated by a 3-minute passive rest period.

Isokinetic resistance exercise involved five sets of knee extensions performed on a Cybex 6000 (Cybex division of Lumex, New York). Subjects exercised their dominant limb only. Each set was performed at a different contractile speed (1.05, 2.09, 3.14, 4.19, and 5.24 rad-s$^{-1}$). Five repetitions were performed in each set. The order in which the respective contractile velocities were performed was randomized between subjects but remained consistent during each measurement occasion. Torque at 0.52 rad from full knee extension (T30) was measured at each of the five contractile velocities. The order in which the isoinertial and isokinetic exercise was performed was randomized for each individual subject but remained consistent during each measurement occasion.

**Measurement of Plasma Lactate**

Blood samples were collected by venipuncture from superficial veins in the elbow immediately before subjects performed the resistance activity. Plasma concentrations of lactate were determined using a Cobas Mira auto analyzer (Roche Diagnostics, Sydney, Australia). Solutions and reagents used in the analysis process were purchased from Boehringer-Mannheim, Sydney, Australia. Analysis procedures were performed according to manufacturer's instructions.

**Statistics**

Data trends for men and women were very similar; therefore, all data was pooled for analysis. Squat lift repetitions were analysed using a $2 \times 3$ (measurement occasion $\times$ set) repeated measures analysis of variance (ANOVA). A $2 \times 5$ (measurement occasion $\times$ speed) repeated measures ANOVA was used to compare T30 scores. Plasma lactate values were compared using a paired $t$-test. The Fisher's least significant difference (LSD) post hoc procedure was used where necessary. A significance level of 0.05 was adopted in all cases. Effect size (ES) statistics were also calculated to quantify the magnitude of the effect of prior high-intensity endurance exercise on the different strength variables. ESs greater than 0.8 were considered large, above 0.5 were deemed to be moderate, and larger than 0.2 were considered small (18).
Table 1. Subject characteristics (mean ± SD).

<table>
<thead>
<tr>
<th>Age (y)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>PVO₂ (ml·kg⁻¹·min⁻¹)</th>
<th>1RM (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>20.3 ± 2.5</td>
<td>75.1 ± 10.2</td>
<td>177.8 ± 10.3</td>
<td>46.6 ± 4.7</td>
</tr>
</tbody>
</table>

Table 2. The number of repetitions performed during each set of isoinertial squats. Repetitions performed under experimental conditions were significantly lower than repetitions performed under control conditions in each of the three sets (mean ± SD).

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Experimental</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Mean 13.83</td>
<td>8.83</td>
</tr>
<tr>
<td></td>
<td>SD ±5.71</td>
<td>±2.99</td>
</tr>
<tr>
<td>Set 2</td>
<td>Mean 11.17</td>
<td>8.17</td>
</tr>
<tr>
<td></td>
<td>SD ±4.45</td>
<td>±3.60</td>
</tr>
<tr>
<td>Set 3</td>
<td>Mean 10.17</td>
<td>8.83</td>
</tr>
<tr>
<td></td>
<td>SD ±5.04</td>
<td>±3.54</td>
</tr>
</tbody>
</table>

Results

The age, height, weight, and squat lift 1RM of subjects are presented in Table 1. Data are presented as means ± standard deviation (SD). The number of repetitions performed by subjects in each of the three sets of squats was significantly reduced after prior high-intensity endurance exercise (Table 2). Effect size calculations revealed that the effect of prior high-intensity endurance exercise on the number of squat lift repetitions was large in the first set, moderate in the second set, and small in the final set (Table 3). T30 was also significantly reduced in each set of isokinetic leg extensions after endurance exercise (Table 4). Effect size calculations revealed that the effect of high-intensity endurance exercise on T30 was small at all contractile speeds except 2.09 rad·s⁻¹, where a moderate effect was observed (Table 3). Plasma lactate values, measured before subjects performed resistance activity, were significantly higher after high-intensity endurance exercise (6.16 ± 2.28 mmol·L⁻¹) when compared with the control condition (0.50 ± 0.45 mmol·L⁻¹).

Discussion

The results of this study have shown that significant reductions in both isoinertial and isokinetic strength are evident when resistance exercise is performed after an acute bout of high-intensity endurance exercise. The results obtained for isokinetic strength are in agreement with the results of Abernethy (1), who showed that isokinetic leg extension strength was impaired by prior high- and low-intensity endurance exercise. In agreement with the results of the current study, Abernethy (1) observed that reductions in isokinetic leg extension strength after prior high-intensity endurance exercise were, although statistically significant, quite small (~5%). Effect size statistics suggest that reductions in isoinertial squat repetitions caused by a bout of prior high-intensity endurance exercise were much larger than the reductions in isokinetic strength observed in the present study. The effect of prior endur-
ance exercise on isoinertial strength may be of greater practical significance to individuals performing concurrent strength and endurance training because this form of training is performed much more frequently than isokinetic training.

The results of the present study show that strength performance is inhibited by a preceding bout of high-intensity endurance exercise. Craig et al. (6) and Jacobs (12) have suggested that reductions in the quality of strength training, when performed after endurance training, may then lead to less than optimal strength development. Although the present study has provided direct evidence to support their contention that strength training quality is compromised after endurance training, it is still unclear whether this has the potential to inhibit strength development over time.

Nelson et al. (16) have shown that strength development is not inhibited during concurrent strength and endurance training in which strength training sessions immediately precede endurance training sessions. However, when the order of training is reversed, strength development is compromised (6). Furthermore, increases in strength observed during same day (strength and endurance sessions performed on the same day) concurrent training were less than strength increases during alternate day (strength and endurance sessions performed on alternate days) concurrent training (17). The results of the above-mentioned studies would suggest that the sequencing of strength and endurance training sessions is an important determinant of the extent of impairment in strength development after concurrent strength and endurance training. However, Collins and Snow (5) found that strength adaptations to combined strength and endurance training were independent of whether endurance training occurred prior to or following strength training. The endurance exercise in the study by Collins and Snow (5) was 20–25 minutes of running at 60–90% of heart rate reserve. The major lower body strength exercise was leg press. Thus, this particular concurrent training study used vastly different endurance and strength exercise protocols from those used in the current study. Therefore, it is difficult to speculate as to the effect of acute reductions in strength performance after endurance exercise, as observed in the current study, on longer term strength development.

This study has shown that the magnitude of impairment in isoinertial strength after high-intensity endurance exercise was greater than the impairment in isokinetic strength. Interestingly, most concurrent training studies utilizing isoinertial forms of strength training have observed interference in strength development (6, 9, 10, 11, 13). However, some exceptions do exist (15). Concurrent training studies using isokinetic strength training have, in general, shown no interference of strength development (2, 16). Again, exceptions do exist at selected speeds of contraction (7). Caution must be used when attempting to compare different studies based solely on the mode of strength training because all of the above-mentioned studies also differ in critical areas such as the mode of endurance training and scheduling of training sessions. Nevertheless, smaller acute impairments in isokinetic strength after endurance exercise may result in lesser or no inhibition in isokinetic strength during concurrent strength and endurance training. Conversely, isoinertial strength performance appears to be more adversely affected by a bout of prior high-intensity endurance exercise and isoinertial strength development appears to be more likely to be inhibited than isokinetic strength during concurrent strength and endurance training.

It has been shown in this study that both isoinertial and isokinetic strength performance is reduced by an acute bout of high-intensity endurance exercise performed approximately 30 minutes beforehand. Possible physiological fatigue mechanisms responsible for the small reductions in isokinetic strength proposed by Abernethy (1) include exhaustion of intramuscular glycogen reserves and changes in electrical properties and/or tissue characteristics of the muscle. Plasma lactate concentrations were still elevated when subjects performed resistance activity after the bout of high-intensity endurance exercise. This may be indicative of an increase in muscle acidosis, which may be responsible for causing the observed reductions in force production (14). However, Abernethy (1) reported similar reductions in isokinetic strength approximately 4 hours after the same high-intensity endurance exercise protocol used in this study. Muscle acid-base status should have returned to normal after 4 hours, yet reduced force production was still evident. These conflicting results make it difficult to speculate on the physiological fatigue mechanisms responsible for causing reductions in strength performance after an acute bout of high-intensity endurance exercise. Clearly, further research is necessary to identify a physiological fatigue mechanism responsible for causing impairments in strength performance observed after a bout of endurance exercise. If a fatigue mechanism could be identified, individuals performing strength and endurance training concurrently may be able to schedule training sessions more appropriately such that they have fully recovered from endurance training sessions before completing strength training sessions. Further research is also necessary to establish an optimal duration of the recovery period necessary between strength and endurance training sessions in order for both modes of training to be performed at optimal intensity.

**Practical Applications**

This study has shown that both isoinertial and isokinetic strength performance is reduced after an acute
bout of high-intensity endurance exercise. The observed reduction in strength performance after endurance exercise may lead to impaired strength development during concurrent strength and endurance training. Therefore, individuals who are performing concurrent strength and endurance training sessions should schedule their training in such a manner that strength training is performed at least 30 minutes after a bout of endurance training. Failure to do so will result in a reduction in the quality of strength training and may lead to a reduction in strength development over time. Perhaps the best approach for athletes and coaches to take when faced with a concurrent training dilemma is to prioritize the components of fitness they wish to develop. For example, if an athlete considers the development of strength to be more important than the development of aerobic fitness at a particular stage of the training cycle, strength training should be performed in an unfatigued state prior to endurance training. Further research is required to establish the exact recovery durations necessary between different forms of strength and endurance training to ensure each mode of training is performed in an unfatigued state.

References


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