Acute Effects of Strength Exercise on Subsequent Endurance Performance

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Introduction

There is a growing body of literature demonstrating the benefits of adding strength training to a progressive endurance training programme [1–3]. Some of the postulated mechanisms that are responsible for optimising endurance development as a result of strength training include changes in muscle fibre type recruitment, increased muscular contractility, a reduction in the proportion of type 2X fibres, and a shift toward muscle phenotypes that are fatigue resistant yet powerful [2, 4]. Although coaches are encouraged to implement strength training for endurance athletes, if appropriate recovery is not accounted for between each mode of training session, carry-over effects of fatigue can be induced from strength training sessions and negatively impact on the ability to perform optimally during subsequent endurance training sessions [5–7].

In fact, a number of studies have previously shown deterioration on indices of performance measures [5–11]. A summary of these findings is presented in Table 11.1. Therefore, continually experiencing strength training-induced fatigue during subsequent endurance training sessions may impair the quality of endurance training sessions and possibly lead to a state of over-reaching, overtraining, or injuries [17, 18], all of which are not beneficial in optimising endurance development. For example, studies have shown that strength training-induced fatigue reduces time-trial performances [13] and time-to-exhaustion [6, 7] whilst increase physiological cost of exercise (e.g. oxygen consumption and heart rate) and rating of perceived exertion at a constant sub-maximal intensity [8, 19]. If endurance athletes are

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Table 11.1 The summary of findings based on studies that have examined the acute effects of a single bout of strength training on subsequent endurance performance

Study	Sample	Training background	Strength training exercises	Endurance performance measures	Results
Deakin [12]	Males ($n = 9$)	Highly trained cyclists who also had been undertaking strength training	Incline leg press at 6RM for 6 repetition of 4–6 sets	Cycling efficiency test	Significant impairment in cycling efficiency 3 h post strength training
Burt and Twist [13]	Males ($n = 7$) Females ($n = 1$)	Recreationally active collegiate students undertaking 2 endurance training sessions per week with no exposure to strength training for 6 months	Plyometric vertical jump exercises for 10 repetitions of 10 sets	Cycling time-trial performance	Significant reduction in cycling distance covered for up to 48 h post plyometric training
Gee et al. [14]	Male ($n = 7$)	Highly trained club rowers who also had been undertaking strength training	Snatch, clean, back squat, deadlift, bench press, bench pull and weighted sit-ups at 75–85% of 1RM for 5–15 repetitions of 3–4 sets	Rowing time-trial performance	No changes in rowing time-trial performance measures 24 h post strength training
Doma and Deakin [6]	Males ($n = 14$)	Trained and moderately trained runners with no exposure to strength training for 6 months	Incline leg press, leg extension, and leg curls performed at 6RM for 6 repetitions of 4–6 sets	RE and running TTE	No changes in VO_2, but significant reduction in running TTE for up to 24 h post strength training
Burt et al. [8]	Males ($n = 9$)	Healthy individuals partaking in 2–3 endurance sessions per week	Back squats at 80% of body mass for 10 sets of 10 repetitions	Running economy	Significant increase in VO_2 for up to 48 h post strength training

Doma and Deakin [7]	Males ($n = 15$)	Moderately trained runners with no exposure to strength training for 6-months	Incline leg press, bench press, and bench pulls performed with a condition at high intensity (3 sets of 6 repetitions at 6RM) and low intensity (3 sets of 20 repetitions with load equated for work)	RE and running TTE	No changes in VO_2, but significant reduction in running TTE for up to 6 h post strength training following the high intensity strength training session. No changes observed following the low intensity strength training session
Doma et al. [15]	Males ($n = 14$)	Healthy individuals partaking in 2–3 running sessions per week with no exposure to strength training for 6 months	Back squats, single-leg leg horizontal leg press, leg extension, and leg curls at 6RM for 6 repetitions of 3 sets	RE and running TTE	No changes in VO_2, but significant increase in RPE during the RE test reduction in running TTE for up to 24 h post strength training
Doma and Deakin [5]	Males ($n = 16$) Females ($n = 8$)	Moderately trained runners with no exposure to strength training for 6 months	Incline leg press, leg extension, and leg curls performed at 6RM for 6 repetitions of 4–6 sets	RE and running TTE	No changes in VO_2, but significant increase in RPE during the RE test and reduction in running TTE for up to 24 h post strength training
Doma et al. [16]	Males ($n = 12$)	Healthy individuals partaking in 2–3 running sessions per week with no exposure to strength training for 6 months	Back squats, single-leg leg horizontal leg press, leg extension, and leg curls at 6RM for 6 repetitions of 3 sets	RE and running TTE	No changes in VO_2, but significant increase in RPE during the RE test and reduction in running TTE for up to 24 h post strength training

to train in such a state, they may experience difficulty in covering particular distances, compromise pacing and/or struggle to meet training goals for the session.

Whilst there is strong evidence to suggest that strength training-induced fatigue acutely impairs endurance performance, the magnitude of this phenomenon appears to be dependent on the strength training background, training intensity, and the recovery period following a strength training exercise. Therefore, this chapter will discuss the impact of strength training-induced fatigue on endurance performance and how strength training background and training variables (i.e. intensity, volume, and recovery) may affect this phenomenon. Finally, a number of recommendations are provided for coaches to minimise the carry-over effects of fatigue induced by strength training sessions on subsequent endurance training sessions.

Strength and Endurance Training Background

Strength Training Background

The recovery dynamics following a strength training session is highly dependent on the level of exposure to previous strength exercises [20–23]. The magnitude of muscle damage and neuromuscular fatigue is attenuated following the initial bout of strength exercises in individuals who have not previously been exposed to strength exercises, known as the repeated bout effect (RBE) [24]. In addition, the magnitude of muscle damage and impaired muscular contractility is greater acutely post strength exercises for strength-untrained individuals compared to strength-trained individuals [25]. Therefore, strength training background has a marked influence on the impact of strength training-induced fatigue on subsequent endurance performance. For example, typical lower body strength training sessions (e.g. squats and leg press) at moderate-to-high intensities have been shown to impair running economy measures for up to 48 h post in strength-untrained individuals [8, 15]. However, running economy measures have also been reported to remain unchanged 6–8 h following similar strength training protocols in strength-trained individuals [7, 19].

Based on the RBE phenomenon, individuals with previous strength training exposure may experience less fatigue following strength training. However, this is not to suggest that strength training-induced fatigue is completely avoidable, given that muscle damage and attenuation in muscle function have been observed for up to 48 h following strength training sessions in individuals previously exposed to strength trained [26–28]. Furthermore, studies have shown that running economy measures were still impaired for up to 48 h following two strength training bouts [5] and running time-to-exhaustion impaired for 24 h following three strength training bouts [16]. These findings suggest that muscle damage and neuromuscular fatigue can still occur in strength-trained individuals, and that strength training-induced fatigue is not avoidable despite increasing the number of strength training bouts in strength-untrained individuals, particularly for running performance measures.

Our previous studies have also shown that running time-to-exhaustion was impaired 24 h following a lower body strength training session in moderately endurance-trained runners despite these participants having been exposed to a flush-out period (i.e. undertaking a number of strength training sessions prior to study commencement to alleviate possible RBE effects during the course of the study) [5, 9]. Accordingly, if incorporating endurance training sessions for individuals with minimal exposure to previous strength training, extra care should be taken for at least 48 h post exercise.

Endurance Training Background

In comparison to strength training background, there has been limited research examining the effects that endurance training background has on the magnitude of acute strength training-induced attenuation on endurance performance. In a study by Skurvydas et al. [29], indirect muscle damage markers (i.e. muscle soreness, creatine kinase [CK], and isokinetic torque) were measured prior to and 48 h following eccentric knee extension exercises separately for endurance-trained and -untrained individuals. The results showed that the magnitude of reduction in isokinetic torque was significantly greater for the untrained individuals compared to their endurance-trained counterparts, despite no differences between groups in muscle soreness and CK. Similarly, Snieckus et al. [30] reported no changes in muscle soreness and CK values between endurance-trained and -untrained individuals, despite a greater reduction in muscle force generation capacity for untrained individuals for up to 48 h following eccentric knee contractions. Collectively, these findings suggest that endurance-trained individuals appear to be more resistant to symptoms of exercise-induced muscle damage (EIMD) with respect to muscle function compared to their untrained counterparts. However, these studies brought about EIMD via isokinetic knee contractions, as opposed to traditional resistance exercises that involve both concentric and eccentric contractions. In addition, neither of these studies [29, 30] compared the effects of EIMD on endurance performance measures (e.g. running economy, running time-to-exhaustion) between endurance-trained and -untrained individuals. Therefore, more research is necessary to make specific recommendations for endurance-untrained individuals when commencing both strength and endurance training simultaneously. Nonetheless, given that we have previously reported associations between reduction in muscle force generation capacity and measures of running performance [5–7, 9, 15, 16], a greater degree of caution should be taken with EIMD for individuals that are both strength and endurance untrained, particularly when commencing a concurrent training programme.

Strength and Endurance Training Intensity

Strength Training Intensity

The neuromuscular characteristics differ substantially during strength training sessions performed between heavy and light loads. For example, strength training sessions prescribed with heavier loads to optimise muscular strength development (i.e. ≥85% of 1RM) will result in greater motor unit recruitment, synchronously at higher frequencies [31]. Alternatively, strength training sessions with lighter loads typically would favour recruitment of fewer motor units in a more sequential manner to sustain contractions for longer [31]. Therefore, greater physiological stress is imposed on the neuromuscular system for each repetition during strength training sessions with heavier loads. In line with this conjecture, Thornton and Potteiger [32] showed greater excess post-exercise oxygen consumption following high intensity strength training (8 repetitions at 85% of 8RM) compared to low intensity strength training (15 repetitions at 45% of 8RM) whilst equating for work volume using 9 typical strength exercises. The authors postulated that high intensity strength training may have resulted in greater motor unit recruitment, thereby causing disturbances to the metabolic system. Whilst Thorton and Potteiger [32] only measured physiological responses at rest, the distinct neuromuscular characteristics between different strength training intensities may have profound effects on the way in which strength training-induced fatigue impacts on subsequent endurance performance.

A study conducted by Deakin [12] examined the acute effects of different strength training intensities on sub-maximal cycling performance in strength-trained participants. The participants performed both high (i.e. 6RM) and low intensity (6 sets of 20 repetitions) lower body strength exercises in a counter-balanced, randomised order. Each strength training bout was equated for work with a cycling efficiency test conducted 3 h post strength exercise. The results showed that the high intensity strength training bout increased the physiological cost of cycling to a greater extent than the low intensity strength training bout. Similarly, we also investigated the impact of strength training intensity whilst equating for strength training work, but on sub-maximal and maximal running performance measures 6 h post strength exercise in strength-trained individuals [7]. The findings showed that neither strength training bout impacted on running economy measures (i.e. running at 90% of anaerobic threshold). However, high intensity strength training impaired running time-to-exhaustion (i.e. running at 110% of anaerobic threshold) despite these measures being unaffected post low intensity strength training.

According to the findings by Deakin [12] and our own study [7], it appears that high intensity strength training sessions may acutely impair indices of endurance performance to a greater extent than that of lower intensity when both intensities are equated for work. More recently, Bartolomei et al. [33] reported greater attenuation in muscle force generation capacity and vertical jump performance measures for 48 h following a bout of low intensity, high volume strength exercise compared to a bout of high intensity, low volume strength exercise in strength-trained individuals. Whilst these findings contradict those of Deakin [12] and [7], the work performed by participants in the study by Bartolomei et al. [33] was approximately double during the bout with high volume, low intensity strength exercises. Furthermore, the physical performance measures were based on muscle force production, which makes reference to indices of endurance performance difficult. Nonetheless, these contradictory findings highlight the importance of equating work when examining the acute effects of strength training intensity in a controlled setting. In addition, the results by Deakin [12] and [7] demonstrate the need to take caution when undertaking endurance exercises within hours post strength exercises, particularly following high intensity strength exercises. It is also important to note that typical low intensity strength training sessions (e.g. 3–4 sets of 12–15 repetitions at 50–65% of 1RM) may encompass a greater work volume compared to very high intensity strength training sessions (e.g. 4–5 sets of 1–3 repetitions at 90–100% of 1RM). Therefore, appropriate recovery should also be considered following low intensity strength training if undertaken with a very high volume.

Endurance Training Intensity

Acutely following strength training, the intensity of endurance exercises could be manipulated in order to minimise the impact of strength training-induced fatigue on subsequent endurance training sessions. Several studies have shown that attenuation of running performance measures are augmented during periods of strength training-induced fatigue at higher endurance exercise intensities [5, 7, 9]. For example, we showed no effect on running economy measures several hours to days post strength training although running time-to-exhaustion was impaired [7, 15]. These findings have also been confirmed by others following downhill running [34], further demonstrating the increased sensitivity to changes in endurance performance measures at higher intensities during periods of muscular fatigue.

It has been postulated that the attenuation in indices of endurance performance at greater intensities may be due to differences in muscle fibre recruitment patterns [34]. Indeed, type 1 muscle fibres are primarily recruited when exercising below the anaerobic threshold, whereas a greater number of type 2 fibres are recruited at exercise intensities above the anaerobic threshold [35, 36]. Given that strength exercises have been shown to cause greater muscle damage in type 2 as compared to type 1 muscle fibres, it is plausible to assume that the ability recruit type 2 fibres are impaired, and as a result, strength training-induced fatigue may compromise endurance performance at higher intensities. Subsequently, caution should be taken when prescribing endurance training sessions at higher intensities, particularly above the anaerobic threshold, during periods of strength training-induced fatigue. Appropriate progression and periodization of concurrent training programme prescription by incorporating a low intensity endurance training session several hours to days following a strength training session may minimise possible negative effects on endurance performance, thereby optimising the quality of endurance training sessions and eventually chronic cardiorespiratory adaptations.

Recovery Following Strength Training

Appropriate recovery in-between strength and endurance training sessions must be accounted for to minimise the carry-over effects of fatigue from one mode of training to the next, when implementing a concurrent training programme. Indeed, the duration of recovery required in-between each mode of training session is dependent on the training variables, particularly the mode of exercise. A typical endurance training session with durations of 40–60 min will allow muscular contractility to recover within hours post exercise [37, 38]. In contrast, heavy strength exercises have been shown to impair muscular contractility for up to 96 h post [39, 40], deplete muscle glycogen for up to 6 h post [12] and possibly induce muscle damage from as early as 8 h and up to 72 h post [41], all of which may impair indices of endurance performance [42].

Several studies have examined the time course recovery acutely following strength exercises on indices of endurance performance. Whilst research in the acute impact of typical strength training on cycling performance is limited, Deakin [12] did examine sub-maximal cycling performance and muscular contractility 3 h following a high intensity lower body strength training session (i.e. incline leg press) at 6RM in trained cyclists with strength training backgrounds. The results showed impaired sub-maximal cycling performance with a concomitant reduction in muscle force production. Similar trends have been observed in several studies on running performance measures. For example, [19] investigated the acute effects of a whole body strength training session (i.e. bench press, squat, upright row, deadlift, seated row, and abdominal exercises) at 8RM on running economy measures 8 and 24 h post exercise in well-trained distance runners with strength training backgrounds. The results showed that running economy was impaired 8 h post although returned to baseline values by 24 h post. We also showed impaired running economy 6 h following a lower body strength training session (i.e. incline leg press, leg extension, and leg curls) at 6RM in moderately trained runners with strength training experience [9]. Using a similar strength training protocol, running economy was not impaired 24 h post exercise, although a reduction was observed in running time-to-exhaustion (i.e. at 110% of anaerobic threshold) [5, 7] in moderately trained runners with strength training experience. In strength-untrained individuals, typical lower body strength training sessions have been shown to impair running economy measures for 48 h post exercise [15].

According to the above-mentioned findings, at least 8 h of recovery may be required in order to not negatively affect endurance performance measurements following a typical strength training session for endurance athletes with strength training experience. However, several days of recovery may be needed for endurance athletes with minimal background in strength training, or in strength de-trained endurance athletes. Regardless of training background, more than 24 h of recovery may be needed to avoid reduced performance following a strength training session if implementing a high intensity endurance training session (i.e. above anaerobic threshold). However, even though acute impairment of measurements related to endurance performance has been observed, that does not mean that there is no training effect of the sessions.

Summary

In conclusion, strength training-induced fatigue can be sustained for several days post-exercise, which appears to have detrimental effects on endurance performance. Accordingly, when implementing an endurance training session following a strength training session, the following training scenarios may require greater recovery periods: (1) undertaking a high intensity strength training session (e.g. ≥6RM) prior to an endurance training session; (2) undertaking a high intensity endurance training session (e.g. above anaerobic thresholds) following a strength training session; (3) strength-untrained individuals; (4) individuals with previous experience in strength training but have not undertaking strength training for several months; and (5) endurance-untrained individuals. The extent to which a bout of strength training may impact on the quality of a subsequent endurance training session may be dependent on the degree of each, or all of these factors. Therefore, it is important to monitor and understand the recovery dynamics of each individual prior to prescribing concurrent training for endurance athletes.

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