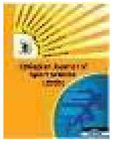

Concurrent Training and its Acute Effect on Running Performance

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ABSTRACT

Purpose: This study examined the acute effects of concurrent training on running performance. Methods: Twenty-five male and 15 female moderately trained individuals were evenly assigned into concurrent training (CCT) and strength-training (ST) groups. The CCT group undertook strength training on alternating days combined with endurance training on consecutive days for 6 days. One week later, the CCT group conducted 3 consecutive days of endurance training only to determine whether fatigue would be induced with endurance training alone (CCT-Con). Endurance training was undertaken to induce endurance-training stimulus and to measure the cost of running (C_R), rating of perceived exertion (RPE), and time to exhaustion (TTE). The ST group undertook 3 strength-training sessions on alternating days. Maximal voluntary contraction (MVC), rating of muscle soreness (RMS), and rating of muscle fatigue (RMF) were collected prior to each strength and endurance session. Results: For the CCT group, small differences were primarily found in C_R and RPE (ES ¼ 0.17–0.41). However, moderate to large reductions were found for TTE and MVC (ES ¼ 0.65–2.00), whereas large increases in RMS and RMF (ES ¼ 1.23–2.49) were found prior to each strength- and endurance-training session. Small differences were found in MVC for the ST group (ES ¼ 0.11) and during CCTC on for the CCT group (ES ¼ 0.15–0.31). Conclusion: Combining strength training on alternating days with endurance training on consecutive days impairs MVC and running performance at maximal effort and increases RMS and RMF over 6 days.

***Keywords**: endurance training, running economy, running time to exhaustion, strength training.*

Introduction

Running performance is the amount of time it takes to complete a motor task constrained by the regulations of a running event and can be significantly improved with athletic training (Vikmoen et al., 2016). Running performance is complex and dependent on a complex interaction of physiological, biomechanical, and endurance, flexibility, and coordination (Blagrove, Howatson, & Hayes, 2018). Which requires a combination of several training methods that might be the best option to improve adaptation to athletics training (Boullosa et al., 2020). Furthermore, due to the nature of the competition schedule or training time, available running events often perform a combination of

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endurance h training on the same day (Enright, 2014). This combination is called the concurrent training method (Sendeike & Gebreegziabher, 2020).

The effect of concurrent training has been widely investigated by researchers. Some of them provide strong evidence that after concurrent training intervention muscle hypertrophy, strength, and power adaptations were mostly attenuated after concurrent training interventions strength training stimuli (Terzis et al., 2016; Tsitkanou et al., 2017; Wilson et al., 2012). Conversely, Boullosa et al. (2020), Ferrari et al., (2021), Doma & Deakin (2015), and Gäbler et al. (2018) state that combining training of strength and cardiorespiratory fitness within a training cycle could increase performance more than single-mode training.

In the other study, Berryman et al. (2019), a strength training intervention (upper and lower body, 3 sets, 4-6 repetitions, twice weekly) was added to the sprint interval training intervention, as was a concurrent regimen consisting of a sprint protocol (4-6 all-out cycling efforts lasting 20 seconds each, with a 2-minute recovery interval between repetitions). There was a 24-hour gap between the two training types. While VO2max was considerably improved only in the concurrent group, there were no variations in maximal force (1RM, upper and lower body) between interventions, indicating that both situations improved.

Another study shows that eight weeks of concurrent strength and endurance training has beneficial effects on musculoskeletal power, maximal oxygen uptake, and a record level of running (Saud & Nabia, 2016). Other findings are contradictory or ambiguous, which could be due to methodological discrepancies between researchers. For instance, studies yielding mixed results have shown that concurrent training can interfere with strength and endurance (Haff & Triplett, 2015), positively affect strength (Taipale et al., 2010), and muscular or aerobic endurance (McNamara & Stearne, 2013) and negatively affect power (Wilson et al., 2012). To date, there are several knowledge gaps on how to properly prescribe concurrent training to achieve the best dose-response, especially regarding the optimal intensity or volume and mode of the aerobic component. According to a research review in athletics, there are a few studies on the effect of concurrent training on running performance. As well as there are a few studies that have compared the effects of concurrent training on running performance when strength training combined with endurance training on running performance have been reported. Consequently, this study investigated the acute effects of concurrent strength and endurance training methods on the performance of long-distance runners.

However, it remains unknown whether strength-training sessions performed on alternating days (i.e., 48hrof recovery between strength-training sessions) would affect the quality of daily endurance-training sessions on consecutive days(i.e., 24hr of recovery between endurance-training sessions) as measured by endurance performance. The purpose of the present study was to examine the acute effects of concurrent training on running performance

Objectives of the Study

The objective of the study is through examining the acute effects of concurrent training on alternating-day strength training coupled with consecutive-day endurance training on running performance or RE and running time to exhaustion (TTE) during a 6-day period. It was hypothesized that running performance would be impaired during the entire 6-day period when alternating-day strength training is combined with consecutive-day endurance training.

METHODS

Participants

Twenty male and15 female moderately trained runners were assigned to a concurrent-training (CCT) group (n ¼ 12, female ¼ 4; M_{age} ¼ 18.8 ^ 3.9 years; M_{height} ¼ 1.75 ^ 0.1m; $M_{bodymass}$ ¼ 74.7 ^ 13.8 kg; mean maximal oxygen consumption [VO$_2$max] ¼ 57.1 ^ 8.5 mL·kg^{21}min^{21}; mean six repetition maximum [6RM] leg press ¼ 229.6 ^ 83.1 kg; mean 6RM leg extension ¼ 67.7 ^ 14.2 kg; mean 6RM leg curls ¼ 34.8 ^ 9.0 kg; mean knee extensor torque ¼ 282.5 ^ 70.4 Nm) that undertook both strength- and endurance-training sessions, or a strength-training (ST) group (n ¼ 12; M_{age} ¼ 17.5 ^ 3.3 years; M_{height} ¼ 1.70 ^ 0.1 m; $M_{bodymass}$ ¼ 69.4 ^ 10.0 kg; mean VO$_2$max ¼ 59.5 ^ 5. mL·kg^{21}min^{21}; mean 6RM leg press ¼ 251.4 ^ 56.8kg; mean 6RM leg extension ¼ 64.8 ^ 12.6kg; mean 6RM leg curls ¼ 33.6 ^ 9.0 kg; mean knee extensor torque ¼ 304.2 ^ 67.0Nm) that only performed strength-training sessions.

The participants were matched for gender, fitness level, and muscular strength between the CCT and ST groups. The participants had been participating in high intensity running sessions (i.e., greater than 85% of predicted maximum heart rate) at least twice a week for the previous 12 months and had not performed high-intensity lower-extremity strength-training exercises (i.e., less than 12 repetitions maximum) for 6 months prior to commencement of the study. Biological variations were controlled by conducting the tests at the same time of day, with participants wearing the same shoes for every test, refraining from high-intensity physical activity for at least 24hr prior to testing, and refraining from caffeine and food intake for at least 2hr prior to testing. Participants were required to maintain their training intensity and volume during the study. However, participants were required to refrain from any form of physical activity during Weeks 6 and 7 for the CCT group and during Week 4 for the ST group. Each participant completed informed consent before taking part in any testing procedures, which were approved by the Institutional Human Research Ethics Committee and were run in accordance with the Declaration of Helsinki.

An in-house study on the reliability of the RE and maximal voluntary contraction (MVC) tests previously showed a small within-subject coefficient of variation (CV) for cost of running (C_R), rating of perceived exertion (RPE), torque production, and TTE (CV ¼ 2.5%, 3.6%, 8.3%, and 9.2%, respectively) for endurance-trained men (n ¼ 14 ; Doma, Deakin, Leicht, & Sealey, 2012). Based on a

nomogram for the estimation of measurement error via the use of CV (statistical power of 90%; Atkinson & Nevill, 2006), percentage worthwhile differences of the current sample size (n ¼ 12) for C_R, RPE, torque production, and TTE were found to be 3%, 4.5%, 10%, and 11%, respectively.

These numbers are smaller than those in previous reports that have shown statistically significant differences in C_R, RPE, torque production, and TTE (Doma & Deakin, 2013a; Doma & Deakin, 2014; Doma et al., 2015). In addition, a-priori power calculation was conducted for the key dependent variables based on previous studies on male and female participants (Braun & Paulson, 2012; Doma & Deakin, 2013b; Marcora & Bosio, 2007) and showed that a sample size of 12 is sufficient to provide greater than 80% of power at an alpha level of .05.

Research Design for the Concurrent-Training Group

The study was conducted for 7 weeks for the CCT group under controlled conditions (i.e., 238C–248C). During the 1st 5 weeks, a VO$_2$max test, 6RM assessment, three endurance-training sessions, and three strength-training sessions were administered to familiarize the participants with the training and testing protocols. During the

1st week, a familiarization session and VO$_2$max test were conducted. The familiarization session consisted of a 6RM assessment for incline leg press, leg extension, and leg curls. The 6RM assessment (Baechle & Earle, 2008) and VO$_2$max test (Doma, Deakin, & Sealey, 2012) were conducted according to previously described methods on a motorized treadmill (Quinton Q65, Milwaukee, WI, USA). Three familiarity sessions for the endurance-training protocol were conducted with at least 1 day of recovery in between during Week 2.

During Weeks 3 and 4, three strength-training sessions were conducted with at least 4 days of recovery in between to limit repeated bout effects of strength training (Doma et al., 2015). During Week 5, a fifth endurance-training session was conducted with at least 4 days of recovery following the third strength-training session with performance measures (oxygen C_R, RPE, and running TTE) collected for baseline (base end) purposes (see the "Endurance Training Sessions" section for further description). The experimental days were conducted during Week 6 and control days were conducted during Week 7. At least 1 week of recovery was provided between the last endurance-training sessions of the experimental days to the first endurance-training session of the control days. The experimental days were carried out over 6 days consisting of three strength-training sessions performed on alternating days and endurance-training sessions on consecutive days. On Days 1, 3, and 5 of the 6-day period, strength-training sessions were performed 9 hr prior to the endurance-training sessions. The control days consisted of three endurance-training sessions and an MVC test on the 4th day. The control days were essential to determine whether endurance performance would be impaired as a result of endurance training alone during consecutive days. Rating of muscle soreness (RMS) and rating of muscle fatigue (RMF), using a 1-100 visual analog scale (Chen, Nosaka, Lin, Chen, & Wu, 2009), and MVC were collected prior to base end and prior to each experimental and control session.

Research Design for the Strength-Training Group

The study was conducted across 4 weeks for the ST group under controlled conditions (i.e., 238C–248C). The 1st 3 weeks consisted of a familiarization session with 6RM assessments, a VO_2max test, and three strength-training sessions to limit repeated bout effects of strength training (Doma et al., 2015). The ST group did not undertake endurance-training sessions and therefore was not familiarized with the protocol. During Week 4, three strength training sessions were carried out on alternating days. (RMS and RMF, using a 1-100 visual analog scale (Chen et al., 2009), and MVC were collected prior to every strength session during Week 4.

Endurance-Training Sessions

The endurance-training session consisted of a discontinuous incremental RE test, running intervals, and TTE on a motorized treadmill (Quinton Q65, Milwaukee, WI, USA). The endurance-training session was constructed in such a way as to elicit an endurance-training stimulus while collecting running performance measures. The protocol was separated into three stages with participants running at 70% and 90% of the second ventilatory threshold (VT_2) for 10min each during the first two stages. During the third stage, four sets of intervals were undertaken at 110% of VT_2 with work-to-rest ratios of approximately 1:1 (i.e., 1.5 min of running and 2min of passive rest) at 110% of VT_2 followed by TTE at 110% of VT_2). TTE was determined at the participants' point of volitional exhaustion and was incorporated at the end of the endurance training session to ensure that the participants were able to complete the intervals. The VT_2 for each participant was determined by identifying the inflection point of ventilation with respect to carbon dioxide production on a scatter diagram

(Neder & Stein, 2006) from the VO_2max test. Oxygen consumption was collected (Power lab ML206, Bella Vista, NSW, Australia) to determine the oxygen C_R, expressed as VO_2 relative to body mass raised to the power of 0.75 and meter ($mL.kg^{20.75}\cdot m^{21}$), which was averaged during the last 5min of the first two stages. Reporting VO_2 typically expressed relative to body mass per minute ($mL.\ kg^{21}\cdot min^{21}$) has been suggested to underestimate the work capacity of lighter individuals and overestimate the heavier individuals at submaximal workloads (Helgerud, Engen, Wisloff, & Hoff, 2001). By expressing VO_2 as C_R ($mL\cdot kg^{20.75}\cdot m^{21}$), we can control the heterogeneity of trained and moderately trained runners. In fact, when previously examining the heterogeneity of trained and moderately trained runners, we were able to reduce the inter individual variability from 11% to 8% by expressing VO_2 from $mL\cdot kg^{21}\cdot min^{21}$ to $mL\cdot kg^{20.75}\cdot m^{21}$, respectively (Doma, Deakin, Leicht, et al., 2012). RPE was collected during the 9th min of the first two stages and every minute during TTE. The RPE of the middle point during the shortest TTE was chosen as the comparison point for all endurance-training sessions (e.g., if 5min was the shortest TTE of a given endurance-training session during the experimental days, then RPE for the 3rd min of TTE of each endurance-training session was compared to base end). For the subsequent sections of the article, RPE collected during the three stages will be reported as RPE 1, RPE 2, and RPE 3, respectively.

Strength-Training Session

Exercises were performed in the order of incline leg press (Maxim MF701, South Australia, Australia), leg extension (Maxim MF701, South Australia, Australia), and leg curls (Maxim MF701, South Australia, Australia). There were six sets for the incline leg press and four sets for the leg extension and leg curls, respectively, with3minofrestbetweeneachset and exercise. The intensity of each exercise was set at 6RM.

Maximal Voluntary Contraction Test

Three 6-sisometric contractions were conducted for extensor torque of the right knee on a custom-built dynamometer chair (James Cook University, Townsville, QLD, Australia). A rest period of 1.5min was provided between each contraction (Doma & Deakin, 2014). The dynamometer chair was calibrated by placing a known weight on the force transducer. The force transducer was attached superior to the medial and lateral malleoli with the knee joint positioned at 1108. Of the three contractions, the largest torque averaged during the 6-s contraction was selected.

Statistical Analysis

The measures of central tendency and dispersion are expressed as mean ^ SD. For within-group comparisons of the CCT group, one-way repeated-measures analysis of variance (ANOVA) was used to determine differences in C_R, RPE, and TTE between the base end and the

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endurance sessions during the experimental days and the endurance sessions during the control days with a covariance for gender. Paired t tests were used to compare C_R, RPE, and TTE between base end and the 1st day of the control days to determine whether adaptation or learning effects occurred as a result of the six endurance- training sessions during the experimental days. For the CCT and ST groups, a two-way (Time £ Group) repeated-measures ANOVA was used to compare MVC measures, RMS, and RMF with a covariance for age and gender. Unpaired t tests were conducted to compare the physical characteristics between the CCT and ST groups. When a statistically significant effect was found, post-hoc analyses with Bonferroni's adjustments were used to determine the location of the difference with the alpha set at .05. Because conclusions based on p values are biased by the sample size (Zhu, 2012), effect size was also computed to estimate the magnitude of differences either before and after exercise sessions or between groups with .2 considered as a small difference, .5 considered a moderate difference, and $ .8 considered a large difference (Cohen, 1969). All data were analyzed using the Statistical Package for the Social Sciences (Version 20).

RESULTS

No differences were found in the physical characteristics between the CCT and ST groups (p . .05). For the CCT group, no differences were found in C_R (p . .05) or RPE (i.e., RPE 1 and RPE 2; p . .05) during the first two stages between the base end and the 1st day of the control days (p . .05), indicating minimal effects of learning or adaptation from the experimental days. During the experimental days for the CCT group, no differences were found in CR at Stages 1 and 2 (p . .05) and for RPE 1 and RPE 2 (p . .05; Table 1). However, a statistically significant increase was found in RPE 3 during the 4 th and 5th days (p , .05). The TTE during the experimental days was statistically significantly less (p , .05) compared with base end (Table 1).

For the MVC collected prior to the endurance-training sessions during the experimental days, torque was statistically significantly reduced during each subsequent day compared with the 1st day (p , .05) except for on the 4th day (p . .05;). RMS and RMF collected prior to the endurance-training sessions during the experimental days were statistically significantly greater compared with those collected prior to base end (p , .05;).

When comparing CR, RPE 1, RPE 2, RPE 3, and TTE between the three endurance-training sessions during the control days for the CCT group, no differences were found (p . .05). Furthermore, no differences were found for torque, RMS, or RMF (p . .05;).

For the MVC tests conducted prior to the strength training sessions, a Group £ Time interaction effect was found for torque, F(1, 2) ¼ 14.68, p , .05. Post-hoc analysis showed the CCT group to be statistically significantly reduced prior to the second and third strength-training sessions and statistically significantly greater than the ST group (p , .05;). Similarly, a Group £ Time interaction effect was found for RMS, F (1 , 2) ¼ 5.18, p , .05, and RMF, F(1, 2) ¼ 5.72, p , .05).

Post-hoc analysis showed that the RMS and RMF prior to the second and third strength-training sessions were statistically significantly greater for the CCT group compared with the ST group (p , .05; Figure 3). Additionally in the CCT group, the RMS and RMF were statistically significantly greater when collected prior to the second and third strength-training sessions compared with those collected in the first strength-training session (p , .05).

DISCUSSION

Strength training has been suggested to repetitively impair the quality of subsequent endurance-training sessions during a concurrent-training program, thereby attenuating endurance adaptation (Chtara et al., 2005). The current study is the first to systematically test this hypothesis by examining running performance during 6 days of what would commonly be prescribed as a microcycle of a concurrent-training program. The results showed that strength training on alternating days in conjunction with endurance training on consecutive days impaired running performance at maximum effort (i.e., TTE; ES ¼ 0.81– 2.00); however, submaximal running performance (i.e., C_R) was unaffected for the majority of the days (ES ¼ 0.09 –0.44).

During the experimental days for the CCT group, TTE was largely reduced when compared with base end (ES ¼ 0.81–2.00) and knee extensor torque showed moderate-to-large reductions during the 6-day period (ES ¼ 0.63–0.84). However, only small differences were found in TTE and knee extensor torque between the endurance-training sessions (ES ¼ 0.07–0.17) and during the control days (ES ¼ 0.15–031), respectively. While knee extensor torque was reduced for the CCT group (ES ¼ 0.61–0.70), such trends were not found for the ST group (ES ¼ 0.11). When compared between groups, RMS and RMF were moderate to largely greater for the CCT group compared with the ST group (ES ¼ 0.77–1.32). Consequently, endurance-training sessions only on consecutive days or strength-training sessions only on alternating days do not appear to affect neuromuscular performance. However, caution should be taken given that a Time £ Age interaction effect was found for RMS, indicating that age differences between groups may have influenced the results. In addition, the control week for the CCT group consisted of three endurance-training sessions, which may differ from the cumulative effects of daily endurance training with a greater number of days (e.g., 6 or more) and thus warrants further research.

In contrast, strength training prescribed on alternating days in conjunction with endurance training on consecutive days may generate an accumulation effect of fatigue as indicated by a sustained reduction in torque prior to the endurance-training sessions, and as a result, it may have impaired running performance at maximum effort. Although some studies have shown that submaximal endurance exercises accelerate recovery from exercise-induced fatigue (Faude et al., 2009; Fujita, Koizumi, Sukeno, Manabe, & Nomura, 2009), the present findings suggest that a combination of moderate- to high-intensity endurance exercise compromises recovery dynamics and increases the duration of fatigue initiated by strength training.

Chtara and colleagues (2005) examined the effects of strength- and endurance-training order on running performance by incorporating groups that undertook strength training prior to endurance training, endurance training prior to strength training, and endurance training only. The results showed suboptimal improvement in 4-km running-time trial performance for the group that undertook strength training prior to endurance training compared with the group that undertook endurance training only. The authors postulated that fatigue generated from strength training may have impeded on the physiological process of optimizing endurance adaptation. Furthermore, Nelson et al. (1990) reported a less- than-optimal increase in VO_2max, mitochondrial density, and concentration of citrate synthase and myokinase for the group that combined strength and endurance training compared with the group that performed endurance training only. The authors suggested that hypertrophic adaptations may have contributed to diluting proteins essential for optimizing endurance adaptation. In light of the findings by Chtara et al., Nelson et al. (1990), and those findings in the current study, the accumulation of fatigue generated by each successive strength- and endurance-training session may impair endurance-training stimuli (Chtara et al., 2005) and thereby cause chronic antagonistic responses between strength and endurance training (Nelson et al., 1990).

Studies have shown 20% to 40% of muscle glycogen depletion following typical resistance-training sessions (MacDougall et al., 1999) and following moderate- to high-intensity endurance exercises (Slivka et al., 2013). Thomson, Green, and Houston (1979) also reported muscle glycogen depletion to predominantly occur in fast-twitch fiber subgroups following exercises at supramaximal work bouts for 10 min as opposed to exercising at submaximal intensities (i.e., 60% of VO_2max) for 2hr. Because the body is highly dependent on fast-twitch fiber groups when running above the anaerobic threshold (Chen et al., 2009), it is reasonable to assume that localized energy depletion may have contributed to the reduction in TTE as a result of the high-intensity exercises in the current study (i.e., strength- and endurance-training sessions).

Muscle glycogen depletion has also been associated with reduction in calcium uptake and calcium adenosine triphosphatase activity (Byrd, Bode, & Klug, 1989). It has been speculated that attenuation of the sarcoplasmic reticular function is a major cause of contractile failure due to the inability to maintain calcium concentration essential for activating the contractile properties of the muscle (Green, 1990). Thus, the attenuation in TTE with concomitant reductions in torque prior to the endurancetraining sessions suggests that an accumulation of neuromuscular fatigue may have been present due to insufficient recovery between each mode of training. Previous studies have shown attenuation in running performance in conjunction with a reduction in muscle force generation capacity (Chen et al., 2009; Chen, Nosaka, & Tu, 2007; Marcora & Bosio, 2007). For example, a previous study (Doma & Deakin, 2013a) showed impaired RE with a concomitant reduction in maximal isometric force the day after strength- and endurance-training sessions. Furthermore, alterations in lower-extremity kinematics were found, suggesting that strength- and endurance-training sessions on the same day may have caused detrimental effects on neuromuscular function and, as a result, attenuated movement efficiency and concomitantly increased energy C_R. Although running kinematics was not examined in the present study, the attenuation in running performance at maximum effort (i.e., TTE) may have been caused by an inefficiency in running gait as a result of neuromuscular fatigue generated by strength- and endurance-training sessions.

Surprisingly, the combination of strength- and endurance-training sessions did not increase C_R. In fact, current results showed moderate-to-large reductions in C_R (ES ¼ 0.54–0.93) on Days 4 to 6 of the experimental days suggesting that contractile damage may improve economy in otherwise lower-economy runners possibly due to glycogen depletion or a greater reliance on Type 1 muscle fibers (Chen et al., 2009). Although there were no notable differences in C_R, TTE was largely reduced (ES ¼ 0.81 – 2.00) during the experimental days when compared with base end. These findings are similar to those of Marcora and Bosio (2007), who reported a statistically significant reduction in running-time trial performance with no effect on RE 24hr following repetitive vertical jump exercises. Furthermore, studies have shown that resistive-type exercises caused no effect on RE (Paschalis et al., 2005; Scott et al., 2003), although running TTE was impaired (Doma & Deakin, 2014) 24hr post with a concomitant increase in indirect markers of muscle damage (i.e., creatine kinase and muscle soreness). Collectively, running performance at maximum effort appears to be more susceptible to attenuation than submaximal running performance. Such findings are expected, given that Type 2 fibers are more susceptible to muscle damage than Type 1 fibers (Connolly, Sayers, & McHugh, 2003) and that Type 2 fibers are predominantly recruited when running above anaerobic threshold (Abernethy, Thayer, & Taylor, 1990). Subsequently, strength training may have compromised optimal neural recruitment of Type 2 fibers essential for running above anaerobic threshold in the current study (i.e., TTE at 110% of VT_2). This is further supported by a large reduction (ES ¼ 0.63–0.84) in torque as well as a moderate-to-large increase (ES ¼ 1.23–2.41) in RMS and RMF during the 6 experimental days in the current study, indicating that muscle damage may have contributed to attenuation in running performance at high intensity (i.e., TTE).

Although C_R was unaffected during the experimental days, a moderate increase in RPE was found on the 4th, 5 th, and 6th days (ES ¼ 0.71, 0.72, and 0.78, respectively) of the endurance-training sessions at 70% and 90% of anaerobic threshold. These findings suggest that moderately endurance-trained individuals may perceive running to be harder at submaximal intensities during a typical concurrent training week. Furthermore, the increase in RPE (i.e., RPE 3) at TTE during the 4th and 5th experimental days also suggests that muscle damage may have impaired running performance. Previous studies have shown no differences in RE 24hr post-strength training, although RPE and RMS increased (Doma et al., 2015; Scott et al., 2003). The authors postulated that local muscle pain could be associated with stiffness, decreased range of motion, and the inability to produce optimal force, which increases the perception of effort. Subsequently, muscle soreness may have contributed to an increase in RPE (i.e., RPE 3) and, as a result, impaired running performance at maximum effort in the current study.

CONCLUSION

In summary, performing strength-training sessions on alternating days in conjunction with endurance-training sessions on consecutive days does not affect submaximal running measures. In addition, neither strength training alone on alternating days nor endurance training alone on consecutive days impair muscle force generation capacity. However, performing these modes of training in conjunction with each other may induce localized energy depletion or neuromuscular fatigue (reduced MVC, increased RMS and RMF) that would contribute to a reduction in running performance at maximum or near-maximum effort (TTE).

WHAT DOES THIS ARTICLE ADD?

Previous studies have shown that concurrent training compromises endurance development (Chtara et al., 2005; Nelson et al., 1990) with speculations that fatigue induced by strength training impairs the quality of subsequent endurance training sessions (Chtara et al., 2005). This study is the first to report such an accumulation effect of fatigue during a microcycle of a concurrent-training program when resistance training is typically prescribed every other day (Kraemer et al., 2002)and endurance training is prescribed on consecutive days (Faude et al., 2009). According to the present findings, the quality of high-intensity endurance-training sessions may be compromised during concurrent training. Subsequently, greater recovery periods may be required between strength- and endurance-training sessions and/or to manipulate the intensity and volume of training from moderately trained runners. Coaches and health practitioners are encouraged to apply the current findings as an initial basis the of the concurrent-training program and to manipulate the training variables in accordance with the athletes' response and training adaptation. However, caution should be taken for untrained individuals given that the current study incorporated moderately endurance-trained runners. Further research is warranted to determine the level of fatigue induced during concurrent training in an untrained population.

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