ACUTE EFFECTS OF PLYOMETRIC AND RESISTANCE TRAINING ON RUNNING ECONOMY IN TRAINED RUNNERS

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INTRODUCTION: Running economy (RE) is one of three (along with $\dot{V}O_2$ max and lactate threshold) primary contributors to aerobic performance (Bassett & Howley, 2000; Brandon, 1995; Daniels, 1985) and is defined as the steady state $\dot{V}O_2$ for a given velocity (Morgan, Martin, & Krahenbuhl, 1989). Assuming steady state aerobic conditions, an individual with superior RE can run faster at a given submaximal $\dot{V}O_2$ compared to an individual with an identical $\dot{V}O_2$ peak (Daniels, 1985). Additionally, differences in RE often explain the performance variance in athletes with comparable aerobic capacities (Morgan et al., 1989).

Numerous studies have shown that chronic resistance training (RT) or plyometric exercise improves RE in runners without negatively affecting aerobic capacity or body mass (Johnson, Quinn, Kertzer, & Vroman, 1997; Millet, Jaouen, Borrani, & Candau, 2002; Paavolainen, Hakkinen, Hamalainen, Nummela, & Rusko, 1999; Saunders et al., 2006; Storen, Helgerud, Stoa, & Hoff, 2008; Turner, Owings, & Schwane, 2003). However, studies directly examining the acute effects of RT on running economy show conflicting results. Doma and Deakin (2014) report no difference in RE 6 hours post-strength training, but a decrease in time to exhaustion running performance after high intensity (6RM) workloads (Doma & Deakin, 2014). The same authors have also reported that the cost of running at 70% and 90% of ventilatory threshold was significantly greater the day after training, when strength training was performed prior to endurance training (Doma & Deakin, 2013), but not vice versa. Alternatively, Scott et al. (2003) showed no alterations in RE 24-30 hours after a moderate repetition submaximal RT protocol of lower body exercises created to induce soreness. In a highly aerobically trained group of runners, RE was impaired at one and eight hours after a total body resistance program involving 3 sets of 6 repetitions at the 8RM for five exercises but not at 24 hours (Palmer & Sleivert, 2001). Conversely, Burt et al. (2013) reported a 4-5% impairment in RE 24-48 hours after an initial bout of squatting-induced muscle damage, although the effect was nonexistent following a subsequent bout of squatting.

The purpose of the present study was to determine the acute effects of a single, lower-body plyometrics and resistance training (PRT) session on RE in male collegiate distance runners. This investigation is unique in the use of a well-trained (VO_2 peak= 62.5± 7.8 ml/kg/min) subject pool, the addition of plyometrics to a RT protocol in order to increase external validity of results, as well as measuring RE immediately after the PRT protocol. It was hypothesized that the PRT protocol would cause an impairment in RE lasting at least 24 hours.

METHODS: Before testing commenced, all procedures were approved by the lead author's university Institutional Review Board and all subjects provided informed consent. Nine members of local collegiate cross-country teams volunteered for the study. Subjects (mean age = 20.6 ± 1.1 yrs, body mass 63.9 ± 8.5 kg) were required to have engaged in RT at least once in the last three months to ensure uniformity regarding the repeated bout effect (Burt et al., 2013; Clarkson & Hubal, 2002) and could not be taking any dietary supplements other than multivitamins or minerals. All subjects were running a minimum of six days per week with a range of 50-100 miles per week and have been training competitively for four to eight years.

All subjects performed a continuous 12 minute RE test immediately followed by a PRT protocol or a resting period (CON). The RE test involved six minutes of running at a pace corresponding to 60% $\dot{V}O_2$ peak and, without a rest period, six additional minutes at 80% $\dot{V}O_2$ peak. Only metabolic data from the last two minutes of each stage were analyzed in order to minimize the chance of using non steady-state $\dot{V}O_2$ measurements. These paces were calculated from previous VO_2peak testing and chosen to mimic common training intensities for the subject pool. Paces were also chosen to provide low enough workloads to ensure steady-state conditions would be met within four minutes. Steady-state conditions were further verified by ensuring less than a 10% change in $\dot{V}O_2$ occurred per minute within the collection period (Reeves et al., 2004). It was a general assumption that an intensity of 80% $\dot{V}O_2$ peak would be below lactate threshold for the highly trained subject pool (Bellotti et al., 2013). Due to recent criticisms of solely using relative $\dot{V}O_2$ as the determinant of RE (Shaw et al., 2014), energy expenditure (EE) was calculated for each exercise intensity with use of the respiratory exchange ratio (RER) (Lusk, 1928). The PRT protocol consisted of three sets of five repetitions of barbell squats, Romanian dead lifts and barbell lunges at 85% 1RM with a two-minute rest between sets and exercises; lateral lunges were completed using resistance bands and step distance that corresponded to the 5RM. Each load was calculated from previous 1RM testing. Additionally, subjects performed three sets of five repetitions of box jumps and depth jumps with the same two-minute rest interval. The same apparatus (45 cm vertical height) was used for both jumps.

Immediately post-PRT or resting period (CON), subjects completed another RE test, identical in methodology to the previous one. An additional (third) RE test took place 24 hours later. All subjects were recommended to eat the same meals at the same time intervals between the second and third RE tests, although dietary intake data was not available for analysis. Six days after the post-24 hour RE test, the groups crossed over and performed the alternate protocol.

STATISTICAL ANALYSIS: All data were tested for normal distribution via a Shapiro-Wilk test. Metabolic data were analyzed parametrically using a repeated measures ANOVA, while *post hoc* analysis was performed via Fisher's LSD test. Order effects were also examined. Effect sizes were calculated as Cohen's d (d). Significance was set *a priori* at $p < 0.05$, and all data analysis was performed using SPSS V23.0 (IBM; Armonk, NY).

No order effects were present ($p > 0.05$).

RESULTS: At the 60% $\dot{V}O_2$ peak intensity, ANOVA revealed a significant ($p < 0.05$) elevation in $\dot{V}O_2$ (d = 0.39) and EE (d = 0.22) immediately post-PRT as compared to the CON condition. No significant within or between-trial differences were found for $\dot{V}O_2$ (d = 0.13; d = 0.22, respectively) or EE (d = 0.17; d = 0.22, respectively) at 80% $\dot{V}O_2$ peak, although a non-significant trend was present for between-trial EE ($p = 0.08$) immediately post-PRT.

No significant differences were found for RER during the 60% $\dot{V}O_2$ peak trial. At 80% $\dot{V}O_2$ peak, RER was significantly ($p < 0.05$) reduced 24 hours post-PRT as compared to the CON trial (d = 0.55). There was a non-significant ($p = 0.06$) within-trial trend for RER between the immediately post-CON and 24 hours post-CON time points (d = 0.93).

DISCUSSION: The primary finding of the present study was that a high intensity, lower-body PRT protocol significantly reduced RE at a moderate exercise (60% $\dot{V}O_2$ peak) intensity in highly trained runners, however the attenuation lasted less than 24 hours and was not statistically significant at a higher running intensity (80% $\dot{V}O_2$ peak). Although this was not a mechanism-based investigation, it is assumed that RE was decreased immediately post-PRT due to induced skeletal muscle damage as well as decreases in muscle stiffness. Multiple investigations have identified both force production and muscle stiffness as primary constituents of RE (Arampatzis et al., 2006; Johnson et al., 1997; Nummela et al., 2006; Saunders et al., 2004). High load RT results in a decrease of neural activation in exercised muscle (Hakkinen, 1993) as well as a loss in maximal force production (Warren, Lowe, & Armstrong, 1999). Likewise, high volume plyometric training inhibits force and rate of force production, both functional markers of muscle damage (Drinkwater, Lane, & Cannon, 2009). In conclusion, RE returned to baseline levels within 24 hours after a high intensity, lower body PRT protocol in a highly trained subject pool.

Despite significant research evidence to the contrary, there remains concern in the running community that high intensity resistance or power-oriented training may harm endurance performance. Results from the present study should further alleviate concerns as the acute, deleterious effects of PRT are short-lived among a highly aerobically trained population. However, strength and conditioning coaches should be mindful that aerobic performance depends on multiple physiological factors beyond RE and employ caution when prescribing high intensity power or strength-oriented training within 48 hours of competition.

Table 2. Mean ± *SD* of Metabolic Measurements for 60% VO_2 Peak Trial ($N = 8$)

	Pre		*Post*		*24 Hr. Post*	
	PRT	*CON*	*PRT*	*CON*	*PRT*	*CON*
VO_2 (ml/kg/min)	35.9 ± 3.8	36.3 ± 3.8	37.1 ± 4.2*	35.5 ± 4.0	35.8 ± 4.1	36.1 ± 4.5
EE (kcal/min)	11.1 ± 1.1	11.3 ± 1.3	11.4 ± 1.3*	11.1 ± 1.4	11.0 ± 1.3	11.3 ± 1.6
RER	0.86 ± 0.0	0.87 ± 0.0	0.85 ± 0.0	0.87 ± 0.0	0.86 ± 0.0	0.88 ± 0.0

* Statistically significantly different than CON ($p < 0.05$)

VO_2 = oxygen consumption, EE = energy expenditure, RER = respiratory exchange ratio,

PRT = plyometric and resistance training trial, CON = control trial

Table 3. Mean ± *SD* of Metabolic Measurements for 80% VO_2 Peak Trial ($N = 8$)

	Pre		*Post*		*24 Hr. Post*	
	PRT	*CON*	*PRT*	*CON*	*PRT*	*CON*
VO_2 (ml/kg/min)	51.0 ± 7.1	50.2 ± 7.0	51.9 ± 6.5	50.4 ± 6.9	50.5 ± 6.4	50.4 ± 7.7
EE (kcal/min)	16.0 ± 2.5	16.0 ± 2.4	16.4 ± 2.3	15.9 ± 2.3	15.9 ± 2.2	16.1 ± 2.6
RER	0.93 ± 0.0	0.95 ± 0.0	0.94 ± 0.0	0.93 ± 0.0	0.93 ± 0.0*	0.96 ± 0.0

* Statistically significantly different than CON ($p < 0.05$)

VO_2 = oxygen consumption, EE = energy expenditure, RER = respiratory exchange ratio,

PRT = plyometric and resistance training trial, CON = control trial

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