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Short Term High-Repetition Back Squat Protocol Does Not Improve 5-km Run Performance

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ABSTRACT

International Journal of Exercise Science 13(7): 1770-1782, 2020. The purpose of this study was to evaluate the hypothesis that a novel high-repetition, low-resistance back squat training protocol, designed to stimulate high-intensity interval training, improves 5-km run performance. Fifteen runners [4 male, 11 female; 150 + minutes of endurance exercise/week; age = 22.7 ± 2.0 y; 21.5 ± 2.2 kg/m² BMI] in this single-group test-retest design completed two weeks of back squats consisting of three sets of 15-24 repetitions at 60% of estimated one-repetition max (1RM), three times per week (1-2 days of rest between sessions). Outcome tests included a 5-km outdoor timed run, laboratory indirect calorimetry to quantify substrate oxidation rates during steady-state submaximal exercise (60% and 70% heart rate max (HRmax)), and estimated 1RM for back squats. Back squat estimated 1RM increased by 20% (58.3 ± 18.5 to 70.2 ± 16.7 kg, $P < 0.001$). However, 5-km run times due to the back squat protocol did not significantly change (Pre-Squats: 23.9 ± 5.0 vs. Post-Squats: 23.7 ± 4.3 minutes, $P = 0.71$). Likewise, the squat training program did not significantly alter carbohydrate or lipid oxidation rates during steady-state submaximal exercise at 60% or 70% of HRmax (P values ranged from 0.36 - 0.99). Short term high-repetition back squat training does not appear to impact 5-km run performance or substrate utilization during submaximal exercise.

KEY WORDS: Barbell training, lower body resistance exercise, long-distance running, carbohydrate and fat utilization

INTRODUCTION

Intense, sprint-type anaerobic exercise (commonly referred to as high-intensity interval training, HIIT) improves aerobic exercise capacity (9,17–19). The nature of the "sprints" used in these protocols vary but in general consist of 30 second intervals of maximal effort cycling, interspersed by recovery periods lasting three minutes (9,17,18). The improvements in endurance performance seen in recreationally active individuals after HIIT training appear to be at least partly attributable to increases in muscle content of oxidative mitochondrial enzymes (8,18,30), including signaling proteins for mitochondrial biogenesis (3,29), enhanced muscle buffering capacity (17,33), and increased glycogen stores (17). These improvements in performance and adaptations in muscle also appear to occur in as little as six sessions over two weeks (9,17) and signals for mitochondrial biogenesis increasing after just one HIIT session (29,43).

In many respects, back squat strength training may impose similar physiologic demands on the body as anaerobic sprint cycle training, especially from a metabolic perspective (6). Further, back squats have been shown to be safe as well as effective in preventing against lower body injury and significantly increasing lower body strength (14,24,36). Programs designed to improve endurance performance often center on increases in training load, and subsequently expose athletes to an increased risk of injury (12,45). Running injury prevalence has been shown to affect ~20-80% of runners (46). Methods to improve exercise performance while minimizing injury risk (e.g., back squatting) would be highly desirable.

A typical set of strength training, consisting of 8 – 12 repetitions with a load equivalent to 70-80% of 1RM causes muscle failure in approximately 30 seconds (28). With somewhat lighter loads and more repetitions, a set of strength training exercise can last 60 seconds or even longer. In this timeframe both HIIT training and high-repetition strength training put high demands on ATP-PC (alactic) and anaerobic glycolysis (lactic) energy systems. Based on these likely similarities, it is plausible that high-repetition back squat training could have similar effects as HIIT training, in that it might improve endurance performance. Further, HIIT has been shown to increase the capacity for skeletal muscle lipid oxidation and work output during sub-maximal exercise, suggestive of a glycogen sparing effect (2,8). Considering the benefits and similarities described above regarding strength training and HIIT, no studies to date have examined the effects of a short term back squat protocol on 5-km running performance. As evidenced by Hurst and Board, the 5-km outdoor run time trial is a reproducible exercise performance test which is indicated by an intraclass correlation coefficient of 0.984 (25).

The primary purpose of this study is to evaluate the effects of two weeks of a novel high-repetition back squat exercise on 5-km running performance in recreational endurance athletes. A secondary purpose of this study was to assess the effects of the squat protocol on substrate utilization in endurance athletes. If the protocol is found beneficial, high-repetition back squat exercise training could be an effective strategy for runners, and possibly other endurance athletes, to improve their performance.

METHODS

Participants

A power analysis conducted with G*POWER 3.1.5 (University of Kiel, University of Dusseldorf, and University of Mannheim, Germany) determined that 15 participants were needed in the present study for a power of 0.80, with an effect size of 0.78 and an $\alpha = 0.05$. Healthy individuals aged 18-30 years were recruited from the St. Louis, Missouri metropolitan area. Volunteers completed a medical history and medications questionnaire, which was used along with criteria from the American College of Sports Medicine to classify each individual as low, moderate, or high risk for medical complications during exercise (34). Both moderate- and high- risk individuals were excluded. Subjects were required to be recreational or higher-level endurance athletes who performed at least 150 minutes of endurance exercise per week. There was no specific 5-km completion time necessary to participate in this study. Subjects also must not have performed lower body resistance training within six weeks of beginning the study. The average subject characteristics correspond to a normal weight body mass index (21.5 ± 2.2 kg/m^2), young adult (age = 22.7 ± 2.0 years), with a female to male ratio of 11:4. For the female, average height was 164.5 ± 6.7 cm and weight was 56.1 ± 8.5 kg. For men, average height was 177.8 ± 9.9 cm and weight was 72.8 ± 12.8 kg. All participants provided written informed consent prior to participation and the Saint Louis University Institutional Review Board for the protection of human subjects approved the protocol. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (35).

Protocol

Study design: This study was an uncontrolled single-group test-retest design, in which subjects underwent outcomes assessments before and after the 2-week squat exercise training protocol. The outcome tests were conducted in the following order: 5-km run, assessment of substrate oxidation rates during exercise, and finally estimated one-repetition max (1RM). There was approximately 15-20 minutes between the 5-km and substrate oxidation assessments and approximately five minutes between substrate oxidation measures and estimated 1RM.

Training intervention: The squat training protocol consisted of six sessions of high-repetition barbell back squats over two weeks with 1 - 2 days of rest in between sessions. The participants were required to perform three sets of squats (end range-of-motion was defined as thighs parallel to the floor) per session with approximately two minutes rest between sets. The initial load for the squats was set at 60% of 1RM, which was determined at the initial assessment by means of the Berger Prediction Table (4). The load was either increased or decreased by 2.3 – 4.5 kilograms as needed to allow subjects to complete 15-24 repetitions in each set of squats. The subjects were encouraged to use maximal or near-maximal effort during every set (e.g., continue exercise until volitional fatigue or within one or two repetitions of volitional fatigue, as has been used in other studies) (18,41). To increase safety and consistency, a power rack equipped with safety bars was utilized and each squat training session was supervised by American College of Sports Medicine Certified Personal Trainers.

Endurance exercise performance: The endurance exercise performance test was a 5-km run that took place using the Saint Louis University's outdoor 400-meter track (12.5 laps). Run time information was not provided and participants were not allowed to time themselves but were informed to complete each time trial in the least amount of time possible. Participants were equipped with Polar FT1 heart rate monitors (Bethpage, NY) and immediately after run completion, heart rate and rating of perceived exertion were obtained (7).

Exercise metabolism: Indirect calorimetry (TrueOne 2400; ParvoMedics, Murray, UT) was used to measure oxygen consumption (VO2) and carbon dioxide production (VCO2) and respiratory exchange ratio (RER) was calculated (VCO2/VO2). Carbohydrate and fat oxidation rates were calculated based on VO2 and VCO2 according to the following equations (10):

Cho (g/min) = -2.909 * VO2 (L/min) + 4.115 * VCO2 (L/min) - 2.539 * Uun

Fat (g/min) = 1.689 * VO2 (L/min) - 1.689 * VCO2 (L/min) - 1.943 * Uun

Uun (urine nitrogen as estimate of protein utilization) was assumed to be zero

Breath-by-breath metabolic measures were performed during steady-state submaximal exercise on a treadmill. Prior to each test, a 3-liter air syringe (Hans Rudolph, Inc., Shawnee, KS) was used to generate a series of flow profiles for calibrating the pneumotach flow meter on the calorimeter. The carbon dioxide and oxygen analyzers were calibrated prior to each test with medical grade gases of known carbon dioxide and oxygen concentrations. The initial treadmill speed was self-selected by the participant usually as a slow walking speed, while the grade on the treadmill was 0% throughout the measure. The speed was subsequently increased by 0.3 - 1.0 mph every two minutes until ~60% heart rate max (HRmax) was achieved. Heart rate goals were determined by calculating age predicted HRmax, using the formula 208 – (0.7 x age)(42). Once heart rate in the ~60% range was achieved, the participant was held at the corresponding speed for 10 minutes. Following, speed was increased in stages until ~70% HRmax was attained and again, the speed was then held constant for 10 minutes. The treadmill speeds in the pre-squat training assessment were then replicated in the post-squat training assessment. Metabolic data averaged over 60 second intervals from the last five minutes of each stage was then averaged to reflect steady-state metabolic responses to exercise.

Exercise and dietary control: Participants were advised to maintain their usual regimen of endurance training throughout their participation in the study and were instructed to continue to not engage in any lower body strength exercise. The participants kept a food and beverage journal and an exercise activity log for two days prior to the pre-squat training testing session and then used the recorded information to follow a similar diet and activity pattern leading up to the post-squat training testing sessions. Researchers photocopied the subject's diet and exercise log and distributed them to each subject two days before post-squat training testing. Each participant was continually encouraged to follow their respective regular diet and exercise routine during the entire duration of this study.

Ambient weather conditions: Ambient air temperature, relative humidity, and heat index at the time of each run were acquired from the National Weather Service (www.weather.gov).

Statistical Analysis

Data were summarized as means ± standard deviation. The mean difference scores (e.g. final minus baseline values) were tested to determine if they were significantly different from zero using a paired t-test. Regression analysis were performed to identify predictive relationships among variables. A P-value of < 0.05 was considered significant. Analyses were performed with Microsoft Excel and IBM SPSS Statistics (version 24) software.

RESULTS

Exercise training compliance and muscle strength: All subjects completed the required assessments and squat exercise training sessions according to protocol (100% compliance). Participants verbally expressed their understanding and willingness to adhere to their usual exercise and dietary regimens throughout the study. As evidence of compliance with the training program, and also of the efficiency of the short term back squat training protocol on muscle strength, estimated 1RM for the squat exercise increased by 20%, from 58.3 ± 18.5 to 70.2 ± 16.7 kg ($P < 0.001$) during the training period.

Exercise performance: Five-kilometer run performance did not change in response to squat training ($P = 0.71$). During the post-squat training run, heart rate, as measured immediately after the 5-km run, was 6% higher ($P = 0.062$; Table 1), albeit not quite significantly, and RPE was 8% higher ($P = 0.048$). As depicted in Table 2, ambient air temperature ($P = 0.007$) and heat index ($P = 0.006$) were significantly higher during the post-squat training run; relative humidity did not differ between trials ($P = 0.42$). Because high heat stress may negatively affect exercise performance (20,26,31,38,44,47), we performed a regression analysis to determine if changes in heat stress were predictive of the changes in 5-km run times. However, neither the change in air temperature between trials ($P = 0.29$) or the difference in heat stress ($P = 0.54$) were predictive of the changes in running performance, suggesting that changes in weather did not affect the results. We also used regression analysis to determine if baseline fitness (as approximated by using the pre-squat training run time) was predictive of the changes in running performance. Indeed, it was predictive (beta-coefficient: -0.20 ± 0.09, $P = 0.04$, r-square: 0.28), indicating that runners with slower baseline run times had greater improvements in performance in response to squat training. In light of this finding, we performed a sub-analysis after excluding the slowest runners (> 24 minute baseline 5-km time, n = 6); the analysis of 5-km results remained non-significant ($P = 0.17$). Likewise, we analyzed the results after excluding the fasted participants (< 21 minute baseline 5-km run time, n = 5) and the results remained non-significant ($P = 0.68$). Thus, while the magnitude of change in run times appears to partly depend on baseline fitness, it does not appear that either slow or fast runners could have cancelled out effects in the remainder of the sample. Figure 1 shows the individual responses of the runners for 5-km run times.

Table 1. Effect of high repetition back squat training on 5-km run performance, heart rate, and rating of perceived exertion.

	Pre-Squats	Post-Squats	Delta Scores	*P*-value
5-km Run Time, minutes	23.9 ± 5.0	23.7 ± 4.3	-0.2 ± 1.9	0.71
Heart Rate immediate post exercise, BPM	174.9 ± 18.8	186.2 ± 10.4	11.3 ± 21.5	0.062
RPE at end of 5-km run, 6-20 scale	14.0 ± 2.1	15.1 ± 1.5	1.1 ± 1.9	0.048

Values are means ± standard deviations. Delta scores were calculated as follow-up value minus baseline value. *P*-values reflect the significance of T-tests which compared baseline and follow-up values. BPM, beats per minute. RPE, rating of perceived exertion.

Table 2. Ambient weather conditions during the outdoor 5-km performance runs.

	Pre-Squats	Post-Squats	*P*-value
Temperature, °C	24.6 ± 3.6	28.7 ± 4.2	0.007
Relative Humidity, %	62.1 ± 11.6	66.9 ± 18.8	0.42
Heat Index, °C	25.0 ± 4.2	31.8 ± 7.5	0.006

Values are means ± standard deviations. *P*-values reflect the significance of T-tests which compared baseline and follow-up values. National Weather Service data were acquired from www.weather.gov.

Figure 1. Participant-level 5-km run times from before and after the two week high-repetition back squat training period. Lines represent the changes from pre- to post-squat training for each participant. The solid bars represent the means and the associated values reflect means ± standard deviations. The 5-km runs were performed on an outdoor 400-meter running track. The *P*-value reflects the statistical significance of the difference between trials.

Table 3. Effect of high repetition back squat training on metabolic outcomes during steady-state submaximal exercise.

	Pre-Squats	Post-Squats	*P*-value
Respiratory Exchange Ratio			
60%	0.80 ± 0.05	0.80 ± 0.06	0.98
70%	0.85 ± 0.05	0.85 ± 0.04	0.93
Oxygen Consumption, ml/kg/min			
60%	12.7 ± 5.4	12.8 ± 5.2	0.94
70%	20.3 ± 4.4	21.0 ± 4.7	0.36
Carbohydrate Oxidation, % of EE			
60%	35 ± 17	37 ± 19	0.74
70%	49 ± 16	49 ± 15	0.97
Carbohydrate Oxidation, kcal/min			
60%	1.9 ± 1.6	1.4 ± 1.1	0.42
70%	3.1 ± 1.6	3.2 ± 1.5	0.77
Fat Oxidation, % of EE			
60%	65 ± 16	63 ± 18	0.74
70%	51 ± 16	51 ± 15	0.96
Fat Oxidation, kcal/min			
60%	2.4 ± 1.0	2.4 ± 1.1	0.99
70%	3.0 ± 0.9	3.1 ± 0.9	0.66
Total Energy Expenditure, kcal/min			
60%	3.7 ± 1.8	3.8 ± 1.7	0.86
70%	6.0 ± 1.8	6.2 ± 1.9	0.38
Heart Rate, BPM			
60%	116.1 ± 2.5	115.7 ± 1.7	0.55
70%	135.4 ± 2.9	135.5 ± 1.7	0.83
Heart Rate, % of age-predicted max			
60%	61 ± 2	60 ± 1	0.54
70%	71 ± 1	71 ± 1	0.83

Values are means ± standard deviations. *P*-values reflect the significance of T-tests which compared baseline and follow-up values. EE = energy expenditure. 60% and 70% indicate percentages of age-predicted maximum heart rate.

Submaximal exercise substrate oxidation: During the lower steady-state work rate, percentage of HRmax was equivalent to 61 ± 2% at pre-squats and 60 ± 1% during post-squats testing. At the higher steady-state work rate, percentage of HRmax was equivalent to 71 ± 1% for both conditions. Respiratory exchange ratio at 60% of HRmax at pre-squats was 0.80 ± 0.05 and 0.80 ± 0.06 (P = 0.98) during post-squat testing. RER at 70% of HRmax was found pre-squats of 0.85 ± 0.05 and post-squats of 0.85 ± 0.04 (P = 0.93). In accordance with these findings, and because substrate oxidation rates are calculated from RER values, neither lipid oxidation rates nor carbohydrate oxidation rates (at 60% and 70% of HRmax) were affected by the squat-training program. Further, oxygen consumption (ml/kg/min) at both steady-state work rates was not significantly altered by the training program. Energy expenditure (kcal/min) was found to not be affected by the squat protocol in either steady-state work rate. Table 3 shows all the results from the indirect calorimetry testing, none of which revealed significant differences from pre-squat to post-squat training.

DISCUSSION

The purpose of this study was to determine if a novel, short term, high-repetition back squat training intervention yields adaptations that would be characteristic of endurance training. In particular, we proposed that high-repetition back squat training would increase endurance exercise performance, as reflected by 5-km run performance and that it would shift substrate selection during exercise to increase lipid oxidation rate and decrease carbohydrate oxidation. Contrary to our expectations, two weeks of high-repetition back squat training did not alter 5-km run time (pre-squats: 23 minutes and 54 seconds vs. post-squats: 23 minutes and 42 seconds) or substrate selection during steady-state exercise.

Various meta-analyses in the literature overwhelming support the use of HIIT to improve endurance performance (19,40), and in light of the similarities between high-repetition back squat exercise and sprint-interval training (in terms of the duration and intensity of effort during intervals), it's not clear why high-repetition back squat training failed to improve endurance exercise performance. However, several possibilities may be considered. It is possible that the squat training did not improve performance because the study participants may have already been performing some type of interval training as part of their endurance training routine (this was not assessed). If this were the case, they would have already been receiving a training stimulus from their interval training and the squat training might not have had additive effects. Another possible explanation, albeit purely speculative, is that the high-velocity muscle contractions that occur during sprint-interval training are critical for triggering improvements in aerobic metabolic capacity and improving endurance performance (muscle contraction velocity during squat exercise is slow by comparison). However, to our knowledge, no studies have compared metabolic adaptations in muscle that has been trained with the same work rate and differing contraction velocities.

Other explanations for the null findings may relate to the relationship between myocellular adaptations and endurance performance. Although the present study was not designed to evaluate mechanisms, some commentary about mechanisms is warranted. In regards to citrate synthase, not all data shows an increase in its activity as a result of HIIT (39,48). Further, some studies show no significant associations between oxidative enzyme activity and exercise performance (11,15). Beneficial effects such as enhanced PGC-1α and mitochondrial biogenesis are a result of HIIT, but the main determinants of run performance is maximal oxygen uptake (VO_{2max}), fractional utilization of VO_{2max} and running economy (5). A recent systematic review highlights that strength training has no impact on VO_{2max} (3). In addition, this study's strength training protocol may have increased the subjects' body mass, reduced mitochondrial volume density and capillary density, ultimately lowering relative VO_{2max} (27). Further, the training intervention may not have been long enough to induce sufficient adaptations (1,22). However, several studies have demonstrated that high-intensity interval training for two weeks is sufficient for improving endurance performance (9,17,18). Lastly, since no differences were found in regards to oxygen consumption, macronutrient oxidation rates or RER, it is speculated that running economy was not beneficially altered due to the high-repetition back squat protocol and therefore 5-km run time was not affected.

While outdoor endurance performance testing has advantages in that it has greater relevance to real-world endurance performance than laboratory tests, the unpredictable nature of weather can result in potentially confounding effects on exercise performance. Indeed, a limitation in the present study was that heat stress was significantly greater during the post-squat training testing; as heat stress has been shown to reduce some types of endurance exercise performance (13,20,31,38), it is conceivable that the high heat stress may have masked improvements in endurance performance. However, our regression analysis did not identify the between-trial differences in ambient air temperature or heat index as important determinants of the changes in run times. This finding is in agreement with evidence from running performance data from world championship running events between 1999 and 2011 (23), in which 5-km running performance was found to be minimally affected by major differences in ambient temperature (in contrast, performance during longer distance running is greatly impaired, while sprint-type events are improved in high heat conditions). Taken together, our regression analysis paired with evidence form Guy et al. (23) suggest that the changes in heat stress during our study may not have confounded the results. Nonetheless, additional studies with better control of heat stress conditions are warranted. Other possible effects of the changes in heat stress in our study are evident. The trend toward higher heart rates and significant elevation of ratings of perceived exertion in the post-squat training trial are consistent with the notion that higher heart rates are needed to increase cutaneous blood flow for heat dissipation (21) and that heat stress increases effort perception (16,32,37), even when exercise intensity is unchanged.

In conclusion, two weeks of high-repetition back squats did not influence 5-km run performance or cause a shift in the body's use of fuel during submaximal exercise. At this point, short term high-repetition back squat training does not appear to provide benefits for endurance performance but is still advisable to recommend strength training for other purposes. The study did continue to prove the undeniable effects of back squats for increasing lower body strength, even in such a short time frame. These findings strongly suggest for further research on high-repetition back squats and endurance performance using a longer duration protocol.

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