ACUTE BEETROOT JUICE ADMINISTRATION IMPROVES PEAK ISOMETRIC FORCE PRODUCTION IN ADOLESCENT MALES

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ACUTE BEETROOT JUICE ADMINISTRATION IMPROVES PEAK ISOMETRIC FORCE PRODUCTION IN ADOLESCENT MALES

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ABSTRACT

The purpose of this study was to examine the effects of acute beetroot juice (BR) administration on repeated sprint performance and isometric force production in adolescent males. Twelve male adolescents (16.8 ± 1.0 yrs; 178.8 ± 9.2 cm; 74.8 ± 12.5 kg; peak height velocity: 2.53 ± 1.2 yrs) participated in this double-blind, placebo-controlled, crossover designed study. Participants consumed 2 x 70 mL of BR (~12.9 mmol NO\textsuperscript{3−}; Beet It Sport\textsuperscript{®}) or a nitrate-depleted placebo (PL) 2.5 hours prior to performing isometric mid-thigh pulls (IMTP) and four repeated 20-second Wingate sprints (S1–S4) interspersed with 4 minutes of rest. Sprint data was analyzed by a 2 x 4 (group x time) repeated measures ANOVA while a dependent t-test was used to compare conditions for IMTP peak force. A significant main effect for time (p < 0.05) was observed for peak power (PP), average power (P\textsubscript{avg}), and fatigue index (FI) across sprints. Compared to S1, S4 resulted in significant decreases in PP (p < 0.000; -16.6%) and P\textsubscript{avg} (p = 0.000; -21.8%) and FI was significantly elevated (p < 0.000; 15.2%). No significant group x time interactions were observed between conditions for PP (p = 0.402), P\textsubscript{avg} (p = 0.479), or FI (p = 0.37). IMTP peak force was significantly higher (p = 0.004; 13.9%) following BR consumption compared with PL. The repeated sprint protocol resulted in significant fatigue while BR did not influence sprint performance. However, it appears BR administration may improve peak force production in adolescent males.

Key Words: dietary nitrates, high-intensity interval training, anaerobic exercise, youth, nitric oxide
INTRODUCTION

Beetroot juice is a dietary source of nitrate (NO$_3^-$) which is a precursor for nitric oxide (NO). Humans derive NO endogenously through the nitric oxide synthase (NOS)-catalyzed oxidation of L-arginine and exogenously via reduction of inorganic NO$_3^-$ from food or dietary supplements (Thompson et al. 2016). Once absorbed, NO$_3^-$ is concentrated in the saliva where it is reduced to nitrite by facultative anaerobic bacteria on the tongue. Nitrite (NO$_2^-$) is then reduced to NO in the stomach or enters systemic circulation (Christensen et al. 2013; Boorsma et al. 2014). Nitric oxide plays a crucial role in cardiovascular health, as increasing NO concentrations have been shown to reduce blood pressure, improve vascular integrity and inhibit monocyte adhesion (Omer et al. 2012).

Dietary NO$_3^-$ via beetroot juice (BR) has garnered attention among physically active populations as an ergogenic aid. Specifically, both acute and chronic BR administration have been shown to reduce oxygen cost during submaximal exercise (Bailey et al. 2009; Bailey et al. 2010; Cermak et al. 2012; Muggeridge et al. 2013; Muggeridge et al. 2014) and improve exercise performance as measured by time-to-task failure or exhaustion (Bailey, Winyard et al. 2009; Larsen et al. 2010; Breese et al. 2013). When exercise intensity increases, BR also appears to improve performance during maximal effort anaerobic both in a laboratory setting (e.g. 30s Wingate, cycle ergometry) and in a sport-specific manner (e.g. yo-yo test, repeated sprint) (Breese et al. 2013; Kelly et al. 2013; Kramer et al. 2016; Thompson et al. 2016; Wylie et al. 2016). However, anaerobic exercise creates a shift toward a different biological mechanism for NO generation. Unlike the oxygen-dependent NOS pathway, the nitrate-nitrite-NO pathway does not require oxygen and is, in fact, upregulated when the body experiences hypoxia (Lundberg et al. 2015). Upregulation of this NO pathway has been shown to improve blood flow and force
production specifically in type II muscle fibers (Hernández et al. 2012; Ferguson et al. 2013). Thus, it is reasonable to speculate that an increased bioavailability of NO via dietary sources could improve sprint performance and force production outcomes.

Several varying sprint and dietary nitrate supplemental protocols have been employed recently with equivocal findings. For instance, Wylie et al. (2016) found that mean power output (MPO) increased during repeated 6-second Wingate sprints with BR whereas Muggeridge et al. (2013) found that a single dose of BR (~5 mmol NO$\text{}_3^-$) did not improve MPO during repeated 10-second sprints in trained kayakers. Furthermore, studies examining the ergogenic effects of dietary NO$\text{}_3^-$ on isometric strength are inconclusive (Folland et al. 1999; Fulford et al. 2013; Haider and Folland 2014; Flanagan et al. 2016; Porcelli et al. 2016). However, mounting evidence suggests that dietary nitrate consumption may alter maximal force capabilities of skeletal muscle. It was recently demonstrated that 3 days of dietary nitrate consumption improved neuromuscular efficiency in resistance trained males (Flanagan et al. 2016) while others have reported enhanced skeletal muscle contractile properties (Haider and Folland 2014), reduced PCr cost of muscular contraction (Fulford et al. 2013), and increased muscle force production (Whitfield et al. 2016). Furthermore, while acute BR protocols have been more widely implemented in studies investigating aerobic exercise, there is still a lack of data regarding acute BR supplementation prior to performance of anaerobic or isometric tasks.

While prevalence of ergogenic aid usage has been examined in youth (McDowall 2007), direct effects of dietary supplements have scarcely been explored. Additionally, it has previously been found that youth athletes do not always produce the same physiological response to ergogenic dietary strategies as their adult counterparts (Turley et al. 2007). Therefore, the purpose of this study was to determine the effects of an acute BR dose (~12.9 mmol NO$\text{}_3^-$) on
physical performance during a repeated sprint Wingate protocol and isometric mid-thigh pull in adolescent male athletes. We hypothesized that, compared to a placebo, BR would increase peak and average power output throughout four repeated sprints, reduce fatigue and improve force production.

**METHODS**

**Participants**

Sixteen active adolescent males were recruited to participate in this study. All volunteers and their legal guardians were informed of the experimental procedures, completed health and activity questionnaires, and provided written informed consent and assent. The Institutional Review Board of Lipscomb University approved the study. All health and activity questionnaires were reviewed by a medical doctor prior to participation in the study. One volunteer was excluded after medical screening for a chronic health condition and three participants were dropped for failure to comply with the supplemental protocol. Therefore, a total of 12 adolescent males (16.8 ± 1.0 yrs; 178.8 ± 19.2 cm; 74.8 ± 12.5 kg) participated. All participants were considered recreationally active, participating in ≥ 3 hours of planned physical activity per week as confirmed by the health and activity questionnaire.

**Experimental Design**

The participants reported to the laboratory on three separate occasions. During visit 1, researchers collected anthropometric data and participants were familiarized with the experimental protocols. The participants were then randomly assigned in a double-blind, crossover, placebo-controlled study design to receive 140 mL of either nitrate-rich beetroot juice
(BR) or nitrate-depleted placebo (PL). During visits 2 and 3, participants performed an isometric strength test and a repeated sprint test after consuming the assigned supplement. A period of at least 72 hours separated experimental trials.

Participants were asked to follow their normal dietary and exercise patterns, but instructed to avoid strenuous exercise and alcohol and caffeine consumption 24 hours before each test, and anything other than water 3 hours before testing. Each participant recorded their dietary intake 24 hours prior to and the day of visit 2. They were provided a copy of the dietary recall and instructed to follow it as closely as possible for visit 3. For each participant visits occurred at the same time of day.

**Body Composition**

Body fat percentage was estimated using air displacement plethysmography using the BODPOD® (COSMED, Rome, Italy). Prior to each test, the BODPOD was calibrated according to the manufacturer’s instructions using a two-point calibration. It was first calibrated with the chamber empty, and then with a cylinder of known volume (50.434 L). Prior to testing participants were instructed to wear tight fitting compression shorts and a swimming cap, as well as to remove all metal, including jewelry and watches. Body mass was measured to the nearest 0.01 kg using the system’s calibrated scale. Thoracic gas volume was estimated using the BODPOD software, which uses standard prediction equations. Participants were instructed to sit in the chamber, breath normally, but minimize any movement during the measurement process. A minimum of two trials were performed, and if measurements were not within 150 ml of each other, a third trial was conducted.
**Peak height velocity**

To provide an estimation of the maturity status of our participants, years from PHV were estimated using standing height, seated height, body mass, and age. Standing height was measured using a stadiometer (Health-o-meter, Bridgeview, IL, USA). Seated height was measured on the same stadiometer with the participant seated, ensuring the lower lumbar was in contact with the wall. Leg length was calculated by subtracting seated height from standing height. The equation used to calculate years from PHV was adopted from Mirwald et al. (2002).

**Cardiovascular measurements**

Upon arrival to the laboratory for visits 2 and 3, participants were equipped with a heart rate monitor (Polar Electro, Kimpele, Finland) after which they lay in a supine position for a minimum of 5 minutes. Blood pressure was measured with an automated blood pressure cuff (Microlife USA, Inc, Clearwater, Florida) on the participant’s upper right arm. Three measurements of blood pressure and heart rate each were recorded three times at the end of a 5-minute supine rest. The average of the three measurements was used for data analysis. Heart rate was also recorded immediately following each sprint during the Wingate repeated sprint test. Immediately following sprint 4, blood pressure was also obtained in the same fashion as described above.

**Isometric mid-thigh pull**

After pre-testing blood pressure and heart rate measurements, participants conducted a warm-up on a stationary bike for 5 minutes. The mid-thigh position was determined for each athlete before testing by marking the midpoint distance between the knee and hip joints. Each participant was instructed to assume his preferred second pull power-clean position by self-
selecting his hip and knee angles. The height of the barbell was then adjusted up or down (± 2.54cm) using pre-drilled, numbered positions on the weight rack to make sure it was in contact with the mid-thigh. The participant’s barbell setting was recorded at the familiarization visit and used in all subsequent trials. Each participant was strapped to the barbell with wrist straps and instructed to relax before the command “GO!” to avoid precontraction. All participants were instructed to pull upwards on the barbell as hard and as fast as possible and to continue their maximal effort for 4 seconds. The force-time curve for each trial was recorded from dual force plates (PASCO, Roseville, CA, USA) with a sample rate of 1,000 Hz. Each participant performed three pulls separated by at least 3 minutes of rest and the trial with the highest peak force value was used for further analysis. Peak force was defined as the highest force achieved during the 4-second isometric test minus the participant’s body weight in Newtons. This was in accordance with previous studies that used similar predetermined time bands when calculating force and demonstrated high reliability (Haff et al. 2015).

Anaerobic sprint test

Following the IMTP, participants performed a modified Wingate protocol on a mechanically braked cycle ergometer (Monark Ergomedic 894E, Vansbro, Sweden). The protocol consisted of four 20-second maximal effort sprints against a resistance equivalent to 7.5% of the individual’s body mass, interspersed with 4 minutes of rest, a design adapted from previously published research (Barker et al. 2014). During familiarization, each participant’s maximum revolutions per minute (RPM) were recorded. Seat height was selected based on a knee angle of 35 ± 5º when the participant’s leg was in the bottom position of a cycling revolution, which was verified by a goniometer. The 20-second bout began when the weight basket was manually dropped as participants reached their max RPM as determined during their
familiarization visit. Each participant was instructed to remain seated throughout the sprint. Data were collected at a sampling rate of 50 Hz on Monark ATS software. Peak power (PP) was defined as highest power output obtained in watts (W), mean power output (MPO) was defined as the average power in W generated, and fatigue index (FI) was defined as the drop from PP to the lowest power during the sprint (W/s).

**Supplementation Protocol**

Participants were instructed to refrain from using antibacterial mouthwash and chewing gum during the supplementation period because these have been shown to disrupt nitrite bioavailability by killing the bacteria in the mouth required to convert nitrate to nitrite (Govoni et al. 2008; Webb et al. 2008). In addition, subjects were asked to abstain from using BR or other supplements during the study. Participants recorded their food intake for the 24 h preceding the first experimental trial and were asked to replicate this diet for their subsequent experimental trial. On the day of experimental testing, participants consumed either BR (2 x 70 mL, ≈6.45 mmol NO$_3^-$/70 mL; Beet It Sport, James White Drinks, Ltd., Ipswich, UK) or PL (2 x 70 mL, ≈0.0034 mmol NO$_3^-$/70 mL) 2.5 hours prior to the onset of testing. The PL was created by passage through an ion-exchange resin, selectively removing NO$_3^-$ ions (Lansley et al. 2011). The BR and PL drinks were both purchased from the same supplier (James White Drinks, Ltd., Ipswich, UK). Both products were packaged identically and marked by a researcher with unique 3-letter codes for random assignment. Only one researcher, who was not involved in any experimental testing, knew which codes corresponded with each product. Participants arrived at the laboratory 2 hours after consumption and returned their empty bottles to ensure compliance.
**Statistical analysis**

Statistical evaluation of the repeated sprint performance data and cardiovascular measures was accomplished using a two-way (group x time) repeated measures analysis of variance (ANOVA). Prior to the ANOVA, all data were assessed for normal distribution, homogeneity of variance, and sample independence. If assumption of sphericity was violated, a Greenhouse Geisser correction was applied. In the event a significant group × time interaction was observed, independent samples t-tests were performed for each dependent variable at each time point between groups; dependent samples t-tests within each group were performed; and delta scores were calculated and independent samples t-tests between groups were performed. Group differences were further assessed via effect sizes ($\eta^2$; partial eta squared). Effect sizes were interpreted as small (0.01 – 0.059), medium (0.06 – 0.139), or large (> 0.14) as previously recommended (Green et al. 2000). Dependent t-tests were used to analyze IMTP peak force (PF) data. An alpha level was set at $p \leq 0.05$, and all analyses were performed using SPSS version 24.0 (SPSS, Inc., Chicago, IL).

**RESULTS**

All 12 participants completed each experimental test and complied with the supplementation protocol. Participant characteristics are presented in Table 1.

**Repeated Sprint Protocol**

There was no time by group interaction for peak power (PP; $F = 0.857$, $\eta^2 = 0.041$, $p = 0.402$); however, there was a main effect for time ($F = 18.922$, $\eta^2 = 0.486$, $p = 0.000$) with PP significantly decreased for sprint 2 ($p = 0.022$), sprint 3 ($p = 0.001$) and sprint 4 ($p < 0.000$) compared to sprint 1 (Figure 1A).
There was no time by group interaction for average power (\( P_{\text{avg}} \); \( F = 0.667, \eta^2 = 0.032, p = 0.479 \)), but there was a main effect for time (\( F = 55.562, \eta^2 = 0.735, p < 0.000 \)) with \( P_{\text{avg}} \) significantly decreased at sprint 2 (\( p < 0.000 \)), sprint 3 (\( p < 0.000 \)), and sprint 4 (\( p < 0.000 \)) compared to sprint 1 (Figure 1B).

There was no time by group interaction for fatigue index (FI; \( F = 1.012, \eta^2 = 0.048, p = 0.375 \)), but there was a main effect for time (\( F = 9.356, \eta^2 = 0.319, p < 0.000 \)) with fatigue significantly greater in sprint 3 (\( p = 0.008 \)) and sprint 4 (\( p < 0.000 \)) compared to sprint 1 (Figure 1C).

**Isometric Force and Cardiovascular Measures**

Isometric mid-thigh pull peak force (IMTP PF) was significantly higher following BR administration (2,361.7 ± 641.6 N) compared to PL (2,158.3 ± 602.3 N) (\( p = 0.004 \)) (Figure 2).

Cardiovascular responses are represented in Table 2. A significant main effect for time (\( F = 1395.262, p < 0.000, \eta^2 = 0.987 \)) for heart rate was observed across the repeat sprint protocol, with elevated heart rates observed following sprints 1-4 (\( p < 0.000 \)) compared to Pre-exercise values. There was a significant main effect for time (\( F = 92.970, p < 0.000, \eta^2 = 0.816 \)) for systolic blood pressure with the repeated sprint protocol resulting in elevated systolic BP, while no changes were observed in with diastolic blood pressure following the sprint protocol (\( F = 2.516, p = 0.128, \eta^2 = 0.107 \)). There were no significant differences between supplemental conditions for heart rate or blood pressure responses at any time point. However, a trend was observed for pre-exercise systolic blood pressure (\( p = 0.069 \)), with lower values being reported following the BR treatment.
DISCUSSION

The principal finding of this study was that acute administration of a concentrated high-nitrate supplement did not improve repeated sprint performance in adolescent males compared with PL. The modified repeated sprint protocol caused fatigue as indicated by significant declines in peak and average power between S1 and S2, S3, and S4. A novel finding of our study is that BR significantly increased peak isometric force production in adolescent males. Additionally, acute BR administration did not significantly influence cardiovascular measures, though pre-exercise systolic blood pressure tended to be lower with BR than PL.

Our data indicate that acute BR supplementation has no effect on repeated sprint performance in adolescent males. Previous studies have shown that NO$_3^-$ supplementation consistently improved intermittent exercise performance over distances and durations associated with team sports athletes in match-play (Wylie et al. 2013b; Thompson et al. 2015; Thompson et al. 2016; Nyakayiru et al. 2017a). However, research investigating the effects of dietary NO$_3^-$ on maximal effort repeated sprint performance has not demonstrated clear benefits (Christensen et al. 2013; Martín et al. 2014; Wylie et al. 2016). In accordance to the present study, Christensen and colleagues (2013) examined the effects of BR on repeated 20-s sprints and found no benefit after 4 days of supplementation, though rest intervals were significantly shorter (100 seconds) compared to our protocol (240 seconds). Furthermore, Wylie et al. (2016) found no benefit of a 5-day supplemental protocol on 7 x 30-s Wingate sprints interspersed with 4 minutes of rest. However, peak power and mean power output appear to improve when a 24 x 6-s protocol interspersed with 24 seconds of rest is employed, particularly within the first six sprints (Porcelli et al. 2016; Wylie et al. 2016). Maximal sprinting performance during five repeated 20-meter running sprints with 30 seconds of recovery has also significantly improved following 5 days of
BR supplementation in team-sport players (Thompson et al. 2016). These findings suggest that chronic nitrate supplementation may improve repeated sprint performance when maximal bouts last less than 10 seconds and may explain why our 4 x 20-s sprint protocol was unaffected by acute dietary NO$_3^-$ consumption. Although we did not investigate VO$_2$ kinetics or muscular adaptations to exercise, there is a probable explanation for our outcome on repeated sprint performance. We presumably found no difference between treatments because more than half of the ATP required by skeletal muscle during a maximal effort Wingate sprint is provided by the anaerobic glycolytic pathway (Trump et al. 1996). While total ATP cost of muscle force production is reduced by NO$_3^-$ supplementation, this contribution is likely derived from the phosphagen and oxidative systems and not the glycolytic system (Bailey et al. 2010). It appears that short, maximal-effort sprints (< 10 seconds) with brief rest intervals (~20-30 seconds) are most likely to benefit from BR administration, though more evidence is needed to elucidate this claim.

A majority of studies to date have employed a chronic supplemental protocol of at least 2 – and up to – 6 days. Although acute doses as small as 5 mmol NO$_3^-$ have demonstrated ergogenic benefits (Bailey et al. 2009; Bailey, Fulford et al. 2010; Muggeridge et al. 2013; Muggeridge et al. 2014), an approximate 0.12 mmol NO$_3^-$ per kg bodyweight dose appears to be more widely accepted and regarded as a minimum dose for ergogenic benefits (Wylie et al. 2013a). In the present study, it is likely that our supplemental protocol (~12.9 mmol) met sufficient nitrate thresholds as our heaviest participant would have required 11.34 mmol per dose to meet this standard. However, chronic loading with NO$_3^-$ supplementation may provide the greatest advantage, particularly in anaerobic exercise. For example, when well-trained kayakers and team sport athletes ingested an acute dose of BR (~5 mmol NO$_3^-$) prior to performing 10-
second and 8-second sprints, respectively, no ergogenic benefit was observed (Muggeridge et al. 2013; Martin et al. 2014). However, Kramer et al. (2016) found that peak power during a 30-second Wingate improved after 6 days of potassium nitrate supplementation (~8 mmol NO$_3^-$). In the latter study, the Wingate testing protocol commenced 24 hours following the last supplemental dose which deviates from the widely implemented 2.5–3-hour pre-exercise supplementation protocol when NO$_3^-$ and NO$_2^+$ plasma levels peak (Wylie et al. 2013a). The observed increase in peak power seen in Kraemer et al. (2016) supports the suggestion that skeletal muscle participates in overall NO metabolism by serving as a nitrate reservoir (Piknova et al. 2015; Nyakayiru et al. 2017b). As such, it plausible that a loading protocol may have positively influenced repeated sprint performance in our athletes, and future work should investigate various chronic supplementation periods.

Existing literature on the effects of NO$_3^-$ on maximal force production is sparse. Our findings indicate that an acute dose of BR significantly improved isometric peak force production in young males. These data are consistent with some previous work evaluating maximal isometric contraction (Folland et al. 1999; Flanagan et al. 2016), but not all (Fulford et al. 2013; Haider and Folland 2014; Aucouturier et al. 2015; Porcelli et al. 2016). Specifically, Flanagan et al. (2016) demonstrated a 4-5% increase in average EMG amplitude during maximal isometric voluntary contractions with 3 days of dietary nitrate supplementation. The authors concluded that nitrate-rich dietary supplementation was responsible for improved neuromuscular efficiency, particularly during fatigue. These neuromuscular advantages were observed during isometric box squats, a movement that requires similar whole-body musculature to the IMTP. When protocols involve isolated movements such as knee extensor exercise, dietary nitrate does not appear to have an ergogenic effect (Fulford et al. 2013; Porcelli et al. 2016). Therefore, it is
possible that nitrate supplementation provides ergogenic benefits when a large amount of musculature is involved. Additionally, our 4-second IMTP test may have been in a better position to detect the positive effects of BR supplementation as maximal efforts <10 seconds have previously been shown to benefit from BR (Porcelli et al. 2016; Wylie et al. 2016). Although we did not assess intramuscular properties during exercise, the significant improvement of peak force generation observed in the present study may be a result of improved contractile efficiency of skeletal muscle (Haider and Folland 2014) and/or a decreased PCr cost of force production (Fulford et al. 2013). Furthermore, previous animal models indicate that nitrate supplementation may augment maximal shortening velocity in fast-twitch muscle fibers by an increased expression of calcium-handling proteins (Hernández et al. 2012). Additional work is needed to understand the nitrate-induced improvements in muscular force production.

Despite previous work that reported a reduction in resting systolic blood pressure (SBP) in response to an acute dose of BR (Muggeridge et al. 2014), we did not observe differences between treatments. However, pre-exercise SBP tended to be lower after BR consumption compared with PL, consistent with existing literature (Muggeridge et al. 2013). Reports of chronic supplementation on resting SBP are inconsistent as some demonstrate reductions with BR (Bailey et al. 2010; Kelly et al. 2013; Thompson et al. 2016) while others do not (Larsen et al. 2010; Cermak et al. 2012). Increased NO bioavailability reduces blood pressure through the relaxation of smooth muscle via soluble guanylyl cyclase activation in the cGMP pathway (Larsen et al. 2006). This NO-mediated signaling mechanism underpins the observed trend for reduced resting SBP in the present study.

**Conclusion**
Our study is the first to examine the effects of acute nitrate supplementation in adolescent males. The results of this study indicate that acute supplementation does not improve performance during four 20-s maximal effort sprints interspersed with 4 minutes of recovery. Several sprint durations and rest intervals have been examined with NO$_3^-$ supplementation and various protocols should continue to be investigated in the future to determine which are most likely to benefit. Our findings also suggest that acute nitrate-rich beetroot juice supplementation can improve force production in adolescent males. From a practical application standpoint, acute nitrate supplementation may benefit training or competition where brief, maximal dynamic movements are utilized (e.g. weightlifting, track & field, team sports) if timing strategies are implemented appropriately.

Conflict of Interest
The authors have no conflict of interest to report.
REFERENCES


**Table 1.** Participant characteristics

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All data presented as means ± SD
Table 2. Heart rate and blood pressure response to repeated sprint protocol

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<td>Pre</td>
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<td>End Sprint 1</td>
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* = significantly elevated from Pre values. BR = Beetroot juice, PL = Placebo; Variables: Pre = resting, Post = immediately following sprint 4. Data presented as means ± SD.
Figure Legend

**Figure 1.** Performance values for (A) Peak Power (B) Mean Power and (C) Fatigue Index across the repeated sprint protocol. BR = Beetroot juice, PL = Placebo. Data presented as means ± SEM. * = significant (p < 0.05) decrease compared to Sprint 1 for both groups. † = significant increase in both groups compared to Sprint 1.

**Figure 2.** Isometric mid-thigh pull peak force values. Dashed lines indicate individual responses to study treatments. Solid line indicates group means ± SEM. BR = Beetroot juice, PL = Placebo. * = significant increase compared with PL (p = 0.004).
Figure 1.

A.

![Graph A](image)

B.

![Graph B](image)

C.

![Graph C](image)

Figure 1.

203x279mm (300 x 300 DPI)