

Acute Beetroot Juice Supplementation and Repeated Maximal Effort in Elite Swimmers: A Randomized Double-Blind Study

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Beetroot juice (BRJ) has been proposed as an ergogenic aid due to its high nitrate content, yet evidence from field-based studies in elite swimmers remains limited. This study investigated the acute effects of concentrated BRJ ingestion on performance and physiological responses during repeated maximal 200-m front-crawl efforts in elite male swimmers. Twelve elite swimmers (age: 20 ± 2 years, body fat: $7.1\% \pm 2.5\%$, 200-m personal best: 115.7 ± 3.4 s) completed a randomized, double-blind, counterbalanced trial. Participants consumed either 140 ml of concentrated BRJ (Beet It Sport) or a custom-made, nitrate-depleted placebo (PL) matched for sensory characteristics, 2 hr before performing two maximal 200-m front-crawl time trials, separated by 60 min of passive recovery. Blood samples were collected upon arrival and immediately after each time trials, and 200-m completion time, blood lactate concentrations, and ratings of perceived exertion were recorded. No significant differences were observed in completion time for either the first (PL: 116.7 ± 3.0 vs. BRJ: 117.2 ± 3.1 s, $p = .19$) or the second 200-m time trial (PL: 117.8 ± 2.6 vs. BRJ: 117.8 ± 3.3 s, $p = .98$), nor in the change between trials (PL: 1.1 ± 1.5 vs. BRJ: 0.5 ± 1.3 s, $p = .40$). Likewise, lactate concentrations and ratings of perceived exertion values did not differ between conditions ($p > .05$). In conclusion, acute BRJ supplementation did not enhance 200-m front-crawl performance, lactate responses, or perceived exertion in elite swimmers under competition-like conditions.

Keywords: nitrate supplementation, high-performance athletes, front-crawl performance

Elite athletes are constantly striving to enhance their performance. Among numerous controlled and uncontrolled factors influencing athletic outcomes, nutritional interventions play an important role. Notably, the use of specific, safe and ergogenic supplements, such as creatine, caffeine, sodium bicarbonate, beta-alanine, and dietary nitrate, commonly ingested via beetroot juice (BRJ), has been shown to improve key aspects of performance, including muscular strength, endurance capacity, and postexercise recovery (Maughan et al., 2018).

BRJ, a rich source of dietary nitrates and antioxidant phytochemicals, has shown promise as an ergogenic aid due to its capacity to increase nitric oxide (NO) bioavailability. Beetroot-derived nitrate, via the nitrate–nitrite–NO pathway, has been reported to improve vasodilation and consequently increase blood flow and reduce the oxygen cost of exercise through enhanced mitochondria biogenesis and improved efficiency of cellular respiration during submaximal exercise, thereby allowing athletes to perform the same workload with a lower oxygen demand (Affourtit et al., 2015; Bailey et al., 2009, 2015). It has also been shown to improve tolerance to high-intensity efforts and enhance recovery between repeated bouts of intense exercise (Rojas-Valverde et al., 2021). Animal studies further suggest that elevated nitrate availability can increase calcium ion release from the sarcoplasmic reticulum, resulting in greater contractile force production in fast-twitch muscles in mice (Hernández et al., 2012), thus enhancing muscle efficiency. Collectively, these mechanistic findings demonstrate a potential ergogenic effect of NO_3^- supplementation in recreationally active, young, healthy males (Seneffeld et al., 2020), as well as a prophylactic role for certain cardiovascular diseases

(McDonagh et al., 2019). However, the ergogenic effects of beetroot can be attributed not only to nitrates but also to a variety of phytochemical compounds with antioxidant activity, which could, among other things, regulate postexercise oxidative stress and increase NO bioavailability. Studies comparing the administration of BRJ with inorganic nitrates have shown that BRJ may have additional effects on oxygen economy, endurance sport performance, and recovery (Zoughaib et al., 2024).

Swimming is an intensely demanding sport, with many key events lasting 20 s to 4 min, where even very small time differences can decisively influence race outcomes, particularly in short-distance competitions. Indicatively, a performance variation as small as 1.6% at the World-class level can be the deciding factor between winning a medal or not (Mujika et al., 2002). As a result, many swimmers, particularly those competing at the elite level, use sports supplements to optimize their performance. In fact, swimmers have been found to exhibit a higher prevalence of supplement use compared with athletes in other sports (Domínguez et al., 2025), with 97% of elite Australian swimmers reported using supplements and/or sports foods continually during a 12-month training period (Shaw et al., 2016), and more recently, 86.9% of elite swimmers reported continuous supplement use, with no significant differences observed between men and female athletes (Moreno, Veiga, et al., 2022). It is also important to highlight that the schedules of major swimming competitions typically involve two or three rounds (heats, semifinals, and finals), with elite athletes often participating in both individual and relay events within short recovery intervals, further emphasizing the demand for strategies to support performance and recovery.

Most studies investigating the effects of beetroot consumption on performance indices, however, have focused on cycling and running, with the majority of them reporting inconclusive

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results. Notably, the positive outcomes were primarily observed in moderately trained individuals (Hlinský et al., 2020; Senefeld et al., 2020).

By contrast, only a limited number of studies have specifically explored the impact of nitrate supplementation on swimming performance, and their findings have been mixed. For example moderately trained master swimmers who consumed 5.5 mmol of nitrate via BRJ for 6 days showed improved performance, characterized by a reduced aerobic energy cost and increased workload at the anaerobic threshold (Pinna et al., 2014). In an interval protocol study (6×100 m), acute BRJ supplementation (~ 6.4 mmol nitrate) resulted in slightly faster mean times, but these differences did not reach statistical significance (Moreno, Morencos, et al., 2022). Moreover, Lowing and his colleagues indicated that acute administration of a high dose of dietary nitrate (~ 12.5 mmol) delivered as BRJ did not benefit short-distance swimming performance (168-m swim test; Lowings et al., 2017). Esen et al. (2019) found no significant performance enhancement in 100-m or 200-m front-crawl events following a 3-day consumption of 140 ml of nitrate-rich juice (~ 12.9 mmol nitrate). These findings are in accordance with those from Moreno et al. (2024), who also reported no performance improvement nor any changes in physiological responses (lactate and heart rate) or subjective perception (ratings of perceived exertion [RPE]), after a single dose of BRJ (6.4 mmol nitrate) during an intermittent swimming protocol ($2 \times 6 \times 100$ m) although a better recovery between efforts was observed.

Finally, recent systematic reviews in swimming (Domínguez et al., 2025; Huang et al., 2024; Jones et al., 2018), as well as an umbrella review across multiple sports by Poon et al. (2025), suggest that nitrate supplementation may improve certain performance outcomes, particularly time-to-exhaustion and muscular endurance. However, they also highlight the difficulty in drawing firm conclusions due to the limited number of studies available. This uncertainty is further attributed to variations in dosage, supplementation duration (acute vs. chronic), the participants' training level (predominantly moderately trained swimmers), and the use of noncompetitive distances in testing. In this context, a 200-m front-crawl race is an intense, highly physiological demanding event, requiring simultaneously high energy contribution of both aerobic and anaerobic metabolic pathways (Figueiredo et al., 2011). Although beetroot supplementation has been linked to improved performance indices mainly in endurance activities, the efficacy of acute beetroot supplementation in short-duration, high-intensity efforts like the 200-m swim, but requiring more than 60% aerobic contribution, remain inconclusive.

Consequently, this study aimed to investigate the acute effects of beetroot supplementation on performance in two consecutive 200-m front-crawl swims in elite swimmers. By focusing on this rarely studied, high-level athletic population, the present research seeks to evaluate the potential performance benefits of acute beetroot intake under conditions that closely replicate competitive settings. Moreover, given the fact that elite swimmers often compete in both individual and team events with limited recovery period, this study offers insight into the effectiveness of beetroot supplementation in an elite sprint swimming context.

Methods

Participants

Fifteen elite male swimmers with systematic participation in National and International Championships were initially recruited

for this randomized double-blind, crossover study. Ultimately, 12 completed the study. One participant failed to attend and was therefore excluded from the analysis, and two more participants withdrew on the test day due to acute health issues (high fever and severe dizziness). A CONSORT flowchart is shown in Figure 1. Their average age was 20 ± 2 years, with a body fat percentage of $7.1\% \pm 2.5\%$, and a personal best time of 115.7 ± 3.4 s in the 200-m front crawl. Their best performance in the 200-m front crawl was above the 90th percentile of the national record and 88th percentile of the world record (693 ± 61 World Aquatics points), which according to the framework of McKay et al. (2022) can classify these swimmers as a mixture of Tier 2 and Tier 3 athletes. Detailed physical characteristics are presented in Table 1. All participants were fully informed of the study procedures and provided written informed consent. The study was conducted in accordance with the principles of the Declaration of Helsinki, and the experimental protocol was approved by the Ethics Committee of Harokopio University (Reg. No. 17-2020).

Study Procedures

Each participant completed two testing sessions separated by a 1-week washout period to ensure adequate recovery and elimination of any residual effects of supplementation. The 1-week washout period has been proven to exceed the time required for plasma nitrate and nitrite concentrations to return to baseline following BRJ ingestion, thereby minimizing potential carry-over effects (Kelly et al., 2014; Wylie et al., 2013). Both sessions were conducted in the same 25-m indoor swimming pool, under controlled environmental conditions with constant water (24°C – 25°C) and ambient (27°C – 28°C) temperatures. All trials were performed at the same time of day for each participant to minimize circadian influences on performance. The trial was balanced and double-blinded. An independent researcher prepared the supplements in identical, opaque bottles labeled “A” or “B” according to the randomization schedule (Research Randomizer, <https://www.randomizer.org>). Only this researcher had access to the code; participants, coaches, and all investigators responsible for data collection and analysis remained blinded until all data were processed. In the first session, six swimmers ingested the BRJ supplement and six ingested a placebo (PL), and vice versa.

During the week preceding each trial, swimmers performed training sessions of similar intensity and volume, as coordinated between the researchers and their coaches. On the day before data collection, the swimmers completed a low-intensity training session to avoid data bias due to fatigue. Participants were instructed to refrain from nitrate-rich foods and any use of mouthwashes known to disrupt nitrate metabolism for 48 hr prior to testing and during the entire week to avoid the use of any dietary supplements. Participants recorded their diet 2 days before the first testing session and were asked to follow the same diet 2 days before the following testing session.

Day of the Measurement

After a morning of fasting, the swimmers arrived at the training pool more than 2 hr before the first 200-m time-trial (TT) test. Upon arrival at the swimming facility, the time of entry was recorded, and the first blood sample was collected.

Participants then received either a dose of 140 ml of concentrated BRJ (Beet It Sport) or a PL beverage matched for taste, color, and appearance. Beet It Sport was chosen for its high nitrate content (~ 8 mmol nitrate per 140 ml), which has been validated and used in

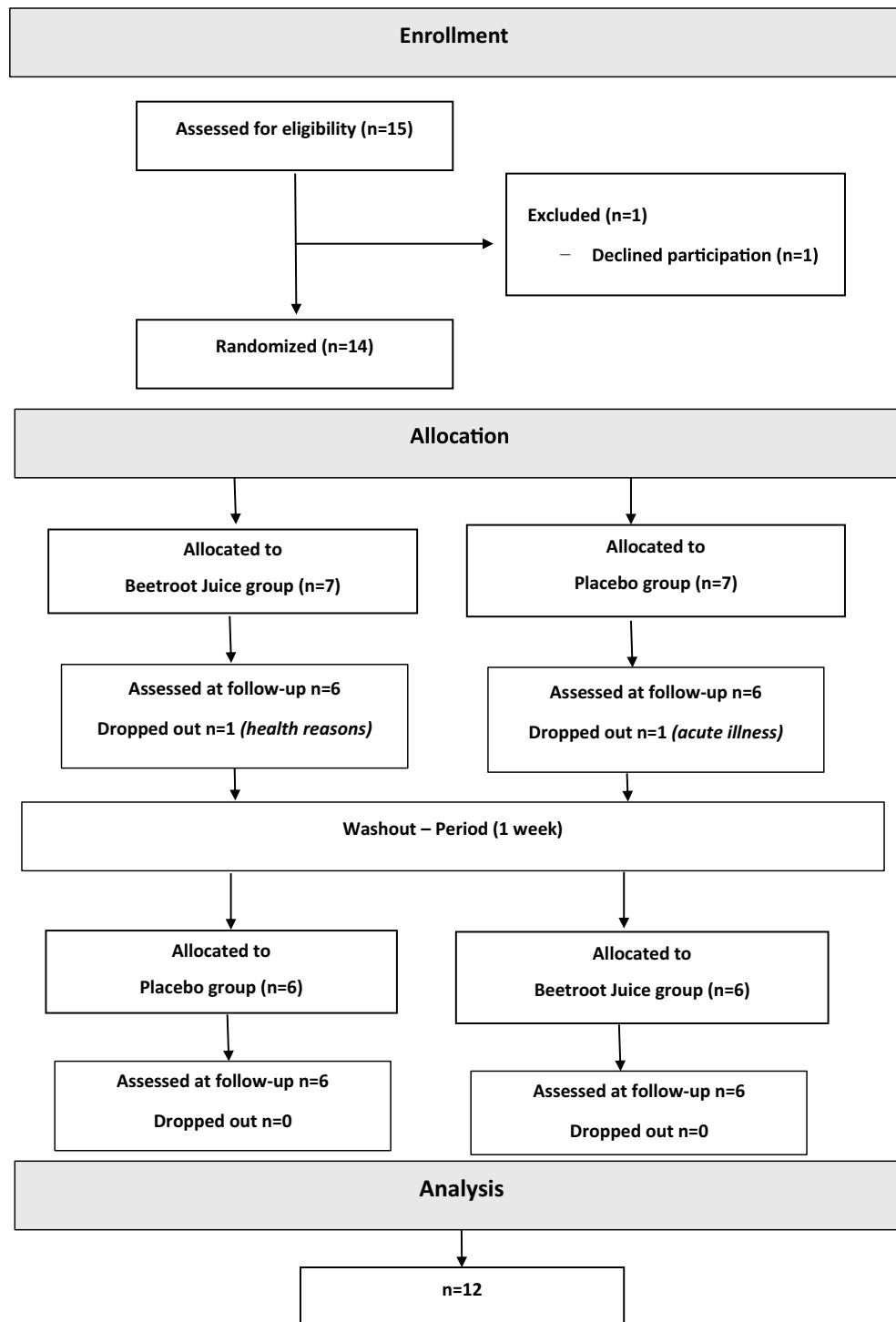


Figure 1 — Consolidated Standards of Reporting Trials flowchart.

numerous prior studies. This acute dose was selected in order to align with competition scenarios where single-dose supplementation 2–3 hr pre-race is a common practice, despite evidence suggesting that chronic protocols may better engage long-term adaptations. The PL drink was prepared by two independent, experienced dietitians based on the label information and organoleptic characteristics of Beet It Sport. Salt, fructose, and organic pea protein were used to match the amounts of sodium, free sugars, and

protein contained in Beet It Sport. The same quantity of lemon juice was added, and the color of the PL drink was matched to that of Beet It Sport using food coloring. A single batch of the PL was prepared and stored in identical bottles to those of Beet It Sport in the freezer until the day of the experiment. The composition of the two drinks is presented in Table 2.

Following supplementation, the swimmers completed a questionnaire regarding their swimming history and dietary habits.

Table 1 Participant Characteristics

Characteristics	<i>n</i> = 12
Age (years)	20.2 ± 2.2
Body mass (kg)	76.8 ± 6.6
Height (cm)	180 ± 5.5
Body mass index (kg/m ²)	23.5 ± 1.2
Arm span (cm)	115.8 ± 2.2
Body fat (%)	7.1 ± 2.5
Fat mass (kg)	5.1 ± 1.6
Fat-free mass (kg)	71.8 ± 6.4
Years of training	15.2 ± 3.4
Training volume (km/week)	34.2 ± 11.6
200-m personal best (s)	115.7 ± 3.4

Note. Values are presented as mean ± SD.

Table 2 Composition of the Placebo and Beet It Sport Supplements

Components/nutrients	Placebo	Beet It Sport
Concentrated beetroot juice (per 140 ml)	-	137.2 ml
Lemon juice (per 140 ml)	2.8 ml	2.8 ml
Energy (Kcal/140 ml)	114	116
Fat (g/140 ml)	0	0.14
Carbohydrates (g/140 ml)	22.4	23.8
Sugars (g/140 ml)	22.4	18.2
Protein (g/140 ml)	6.0	4.0
Salt (g/140 ml)	0.62	0.58

Subsequently, anthropometric measurements were taken, including height, body mass, and arm span. Swimmers were only wearing a dry textile swimsuit during all anthropometric tests. Body mass was measured with a calibrated electronic weight scale (SECA, 884). Height was measured using a stadiometer (Seca GmbH) to the nearest 0.1 cm, with the athletes' weight equally distributed on their feet and their head, back, and buttocks on the vertical line of the height gauge. Body mass index was calculated by the formula body weight/height². For the arm span measurement, participants stood in an upright position with their back against the wall, arms fully extended laterally at 90° abduction, and fingers fully outstretched. The arm span was considered the distance between the tips of the middle fingers of each hand and measured with a flexible anthropometric measuring tape.

Body composition was evaluated via a Lange skinfold caliper (Model 68902, Cambridge Scientific Industries, Inc.) using male seven-site skinfolds (triceps, chest, midaxillary, subscapular, abdomen, suprailiac, and thigh) taken on the right side of the body. Each skinfold measurement was performed twice at each site, and only if the difference exceeded 2 mm was a third measurement performed. The average of two measurements within 2 mm was recorded. The recorded measurements were then used to estimate the fat mass (in kilograms), fat-free mass (in kilograms), and body fat percentage (%), with the use of the equations by Jackson and Pollock (1985). All anthropometric measurements were performed by a trained physical education professional, and a standardized procedure was implemented, along with a systematic calibration of the devices (e.g., weight scales and skinfold caliper), in order to ensure maximum validity and accuracy.

Sixty minutes following supplementation, participants engaged in a standardized 30-min warm-up in the pool, identical for all swimmers. The latter was followed by 20 min of passive recovery. Shortly after, a second venous blood sample was collected, RPE was assessed using the Borg scale, and a fingertip capillary blood sample was obtained to determine blood lactate concentration (Lactate Scout+, SensLab GmbH). Then, and after 2 hr postsupplement ingestion, the first 200-m maximal front-crawl TT took place. Upon completion of the 200-m, RPE was assessed, and within the first 30 s of recovery, blood lactate concentration was measured.

Sixty minutes after the completion of the first 200-m TT (i.e., 3 hr after the athletes' arrival at the swimming pool), during which participants remained at rest doing only some stretching exercises, the entire procedure was repeated. This included the collection of a venous blood sample a few minutes prior to the second 200-m TT, followed by RPE assessment and fingertip blood sampling for lactate measurement before and after the 200-m effort. Blood lactate and RPE were selected as standard, field-practical outcomes used in applied swimming research. The 60-min passive recovery between the two 200-m trials was chosen to reproduce the approximate interval between rounds in short-course competition schedules, thereby enhancing ecological validity. All 200-m TTs commenced with a diving start from diving blocks, and performance times for each 200-m effort were recorded using a digital stopwatch (FINIS 3X300, Finis Inc.) by two independent time-keepers. The primary outcome was the average of dual times. The study's protocol is presented in Figure 2.

Blood Collection and Isolation of Serum

Blood samples were collected by a trained phlebotomist from an antecubital arm vein using a disposable 21-gauge needle. Ten (10) ml of blood was collected in vacutainers without anticoagulant. The samples of each protocol day remained at 4 °C until the end of the experiment and then were transferred to the biochemistry lab where serum was isolated by centrifugation (1,500 × g, 20 min, 4 °C). Serum samples were aliquoted and stored at −80 °C until analysis.

Determination of Total Nitrate/Nitrite in Serum

Total nitrate/nitrite (TNOx) was determined by a commercially available kit (Cayman Chemical, Item 780001) according to manufacturer's instruction. Briefly, the serum samples were initially deproteinized by ultrafiltration with 10-kDa spin filters. The determination of TNOx in the filtrate is based on the reduction of nitrate to nitrite by nitrate reductase and the determination of nitrites by the Gries reaction. A deep purple azo compound, which is determined photometrically, is formed. The interassay and intraassay coefficients of variation were 6.1% (*n* = 6) and 5.2% (*n* = 7), respectively.

Statistical Analysis

Normal distribution of the data was assessed using the Kolmogorov–Smirnov test. For the variables followed parametric distribution, the results are presented as mean ± SD. A paired *t*-test analysis was employed in order to evaluate the effect of the supplementation in the study variables.

To compare the kinetics of the variables between the two interventions a two-way (Time [Baseline, Before first 200-m TT, Before second 200-m TT] × Condition [PL, BRJ]), repeated-measures analysis of variance was used for statistical analyses. Sphericity was checked by Mauchly's test, and Greenhouse–Geisser

correction on degrees of freedom was done if necessary. When interaction between time and condition was found, simple effects were investigated, and Bonferroni correction was applied.

Statistical significance was tested at the $p < .05$ probability for type I error. p values are presented for two-sided, two independent sample tests. Statistical analyses were performed with the use of Stata Statistical Software, Release 12 (StataCorp LP).

Results

TNOx concentration was increased in BRJ compared with the PL condition (Effect of time: $F=264.11$, $p < .001$; Effect of Time $\times$ Intervention: $F=1,061.32$, $p < .001$; Effect of Intervention: $F=839.77$, $p < .001$). Post hoc multiple comparisons analysis showed that the concentration of TNOx was increased at 2 and 3 hr in the BRJ arm (baseline: 27.8 ± 10.9 , 2 hr post: 454.2 ± 43.2 , 3 hr post: 392.4 ± 39.0 nmol, $p < .001$). In the PL condition, a statistical significance was observed only from baseline to 3 hr

postconsumption (baseline: 23.2 ± 4.6 , 2 hr post: 31.4 ± 10.0 , 3 hr post: 30.9 ± 8.1 nmol, $p = .02$).

Swimmers performed two 200-m front-crawl TTs under the two experimental conditions. Performance time in 200 m was no different between repetitions and conditions (Effect of time: $F=2.396$, $p = .137$; Effect of Time $\times$ Intervention: $F=0.834$, $p = .360$; Effect of Intervention: $F=0.072$, $p = .791$). The performance time for the first 200 m was BRJ: 117.3 ± 3.2 versus PL: 116.7 ± 3.0 s, and the performance time for the second 200 m was BRJ: 117.8 ± 3.3 versus PL: 117.8 ± 2.6 s (Figure 3).

No statistically significant difference was observed in the change (Δ) between the first and second 200-m TTs between the PL condition (mean $\Delta = +1.1$ s, 95% confidence interval $[-0.1, 2.1]$, Cohen's $d=0.74$ [Moderate]) and BRJ (mean $\Delta = +0.5$ s, 95% confidence interval $[-0.4, 1.4]$, Cohen's $d=0.38$ [small]) conditions ($p = .40$).

Blood lactate concentration was measured following each 200-m TT under both conditions. No significant differences were

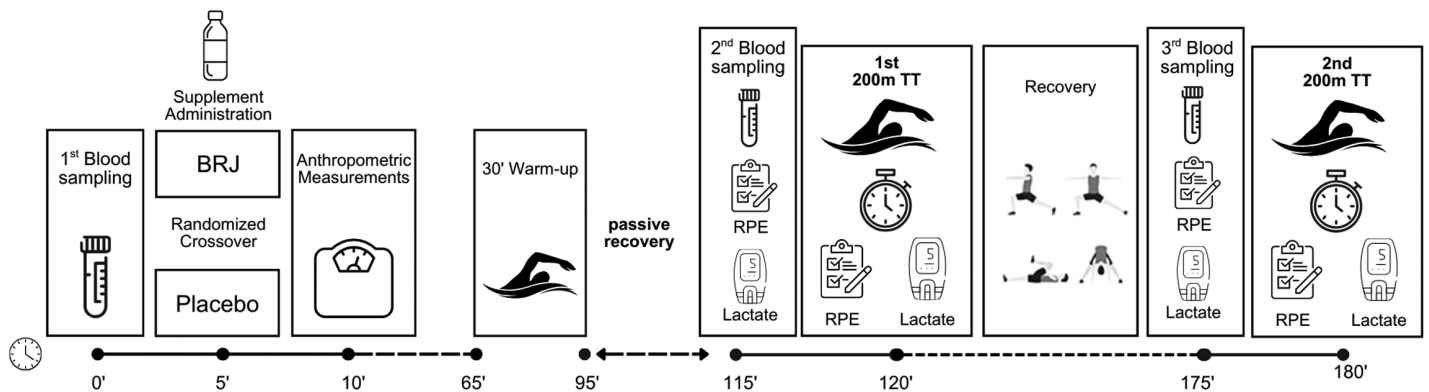


Figure 2 — Timeline of experimental procedures applied in both BRJ consumption and PL conditions. PL = placebo; TT = time trial; RPE = rating of perceived exertion; BRJ = beetroot juice.

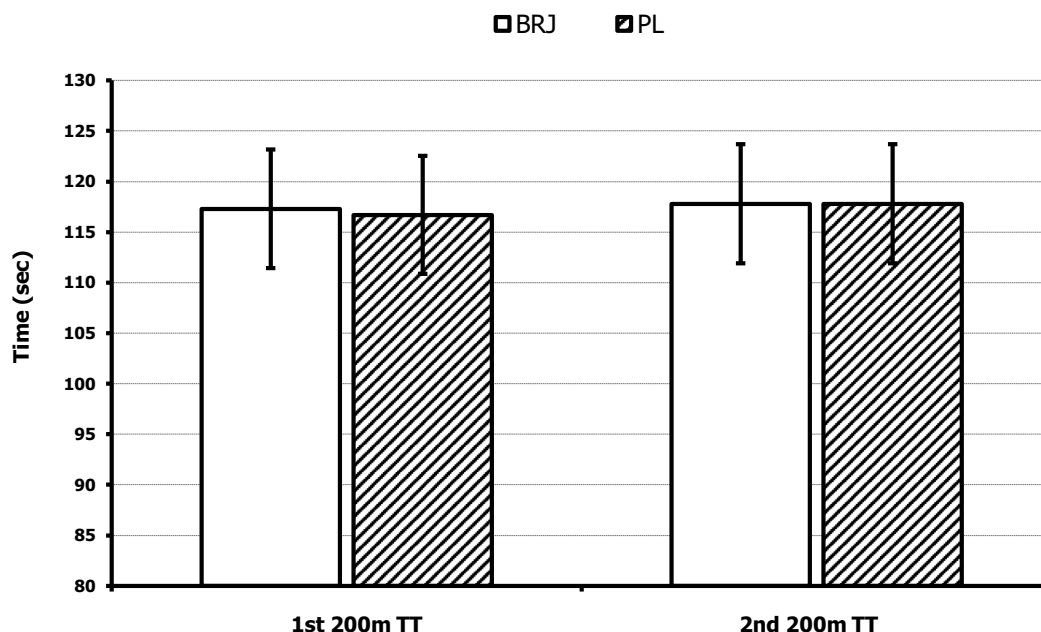


Figure 3 — Mean performance time for the first and second 200-m TT in BRJ and PL. Values are represented as mean $\pm$ SD. PL = placebo; TT = time trial; BRJ = beetroot juice.

observed between conditions ($F=0.001$, $p>.05$). The concentration was increased after each 200-m TT compared with prestart values reaching similar values in BRJ and PL conditions (first 200 m, BRJ: 11.9 ± 2.2 vs. PL: 11.9 ± 2.7 mmol/L, second 200 m, BRJ: 12.7 ± 1.6 mmol/L vs. PL: 12.3 ± 3.3 mmol/L, $F=0.286$, $p>.05$).

Participants' RPE, assessed using the Borg scale before and after each trial, also showed no statistically significant differences between the two conditions (Table 3).

Discussion

The present study investigated the acute effects of dietary nitrate supplementation via BRJ on repeated 200-m maximal front-crawl TTs in elite swimmers. Despite a significant increase in plasma TNOx following BRJ supplementation, no statistically significant differences or practically reliable ergogenic effects of acute BRJ were observed in performance time, blood lactate concentration, or perceived exertion between the beetroot and PL conditions in either trial. The null performance findings occurred notwithstanding confirmed bioavailability, suggesting that acute nitrate elevation alone may insufficiently engage the full spectrum of physiological mechanisms outlined in the introduction, particularly in high-performance athletes whose baseline efficiency already approaches physiological limits.

Compared with the PL condition, serum TNOx concentration was more than 1,000% higher in the BRJ condition at both 2 hr and 3 hr postingestion. This result is consistent with numerous previous studies, confirming that the BRJ intervention effectively increased the circulating reservoir for O₂-independent NO generation to a magnitude associated with performance enhancement (Garnacho-Castaño et al., 2024; Kelly et al., 2014; Wylie et al., 2013). However, despite this substantial increase in the circulating plasma TNOx concentration and by extension for O₂-independent NO generation, BRJ supplementation did not improve swimming performance in either of the 200-m TTs among the elite swimmers participating in the current study. It should be acknowledged, however, that TNOx reflects the combined concentration of nitrate

and nitrite and therefore does not allow for determination of the efficiency of nitrate reduction to nitrite or the subsequent formation of NO; accordingly, conclusions regarding NO-mediated mechanisms remain inferential.

These findings align with previous research reporting limited or no ergogenic effect of acute BRJ supplementation in highly trained athletic populations (Esen et al., 2019; Moreno, Veiga, et al., 2022; Moreno-Herederó et al., 2024). Likewise, in the study by Moreno et al. (2024) the consumption of a single dose of BRJ 3 hr pretesting did not enhance intermittent swimming performance nor did it modify the physiological (lactate) or subjective (RPE) variables. It should be noted, however, that the protocol employed ($2 \times 6 \times 100$ m) did not replicate the demands of actual swimming competition, which in turn may limit the ecological validity of these findings. Similarly, Esen et al., in a study with a relatively similar methodology, especially regarding performance assessment, observed no performance improvements after 3 days of beetroot supplementation in moderately trained swimmers during consecutive 100-m and 200-m TTs. At this point, however, it should be emphasized that the athletes in our study were distinguished at both national and international levels, exhibiting performance metrics in the top percentiles based on World Aquatics scoring. Thus, this advanced training status may render them less responsive to short-term interventions, as their physiological systems are already functioning near maximal capacity, leaving minimal space for additional improvements through acute dietary supplementation. Specifically, elite athletes have higher baseline NO bioavailability and superior vascular function, thereby limiting the scope for further improvement. In addition, their greater oxidative capacity and mitochondrial efficiency may attenuate the potential benefits of nitrate supplementation as these athletes already demonstrate highly developed oxygen delivery and utilization systems. Collectively, these adaptations may reduce the ergogenic potential of dietary nitrate in highly trained populations compared with recreational or moderately trained individuals (Jones et al., 2018; McDonagh et al., 2019; Poon et al., 2025).

Although no statistically significant improvements were detected in any of the measured performance indices, the potential practical relevance of small, nonsignificant differences at this elite

Table 3 RPE and Blood Lactate Concentrations Before and After the First and Second 200-m Front-Crawl TTs Under BRJ) and PL Conditions ($N = 12$)

Variable	Condition	First 200-m TT			Second 200-m TT			<i>p</i> of time effect (pre-post)	<i>p</i> of condition effect (BRJ vs. PL)	<i>p</i> of Time $\times$ Condition interaction
		Pre	Post	Δ	Pre	Post	Δ			
RPE	BRJ	2.8 ± 0.7^a	7.9 ± 1.4^a	5.1 ± 1.1	3.3 ± 1.1^b	8.2 ± 0.8^b	4.9 ± 1.7	First 200 m <.001	First 200 m .731	First 200 m .410
	PL	2.6 ± 0.6^a	8.3 ± 0.7^a	5.6 ± 1.1	3.3 ± 0.5^b	8.3 ± 1.1^b	5.0 ± 1.1	Second 200 m <.001	Second 200 m .735	Second 200 m 1.00
Lactate (mmol/L)	BRJ	1.2 ± 0.5^a	12.2 ± 2.3^a	11.0 ± 2.3	2.2 ± 0.8^b	13.0 ± 2.0^b	10.8 ± 2.2	First 200 m <.001	First 200 m .527	First 200 m .500
	PL	1.2 ± 0.5^a	11.5 ± 2.5^a	10.2 ± 2.7	2.5 ± 0.8^b	12.0 ± 3.4^b	9.5 ± 3.1	Second 200 m <.001	Second 200 m .703	Second 200 m .316

Note. Values are mean $\pm$ SD. PL = placebo; RPE = ratings of perceived exertion; TT = time trial; Δ = difference (Post – Pre); BRJ = beetroot juice.

^aSignificant time effect within first 200-m TT, $p<.001$. ^bSignificant time effect within second 200-m TT, $p<.001$.

level must be acknowledged. In sports like swimming, where race outcomes can be determined by fractions of a second, even marginal changes in performance can be decisive for qualification, podium placement, or record achievement. For instance, a mean time difference of just 0.5 s between the first and the second 200-m trial between conditions (e.g., 1.1 ± 1.5 PL vs. 0.5 ± 1.3 s BRJ), although not statistically significant, could influence significantly competitive outcomes in real-world contexts. Such observations underscore the importance of interpreting results not only in terms of statistical significance but also in terms of their competitive relevance.

Importantly, the experimental design was structured to replicate actual competition settings, with trials conducted under standardized and ecologically valid conditions (e.g., same pool, temperature, time of day), and with recovery intervals designed to mirror real-world race formats (e.g., heats, semifinals, and finals or participation in individual and subsequent team race). The performance protocol, consisting of two 200-m maximal efforts separated by 1 hr of passive recovery, realistically simulates the high-intensity demands and recovery patterns commonly encountered in competitive swim meets.

Our study has several strengths, including the use of a double-blind, PL-controlled, crossover design, which adds robustness to the internal validity of the findings, minimizing both subject and experimenter bias. Moreover, another major strength of the study is the inclusion of elite-level athletes, which enhances the applicability of the findings to high-performance settings. In addition, the ecologically valid testing protocol, mimicking actual swim meet conditions, provides practical insights rarely addressed in existing literature. These aspects are also consistent with the recent consensus statement on optimizing elite athlete performance, which emphasizes not only the importance of laboratory findings but also the critical need for well-designed, field-based studies on elite athletes (Bangsbo et al., 2025). However, it should be mentioned that controlled simulation overlooks psychological load, tactical racing, and cumulative fatigue inherent to real competitive environments. Finally, the use of a commercially available, extensively studied high-nitrate supplement (Beet It Sport) for which the nitrate content has been characterized in prior research and applied in numerous performance trials, along with precise timing and control of diet and training volume, increases confidence in the reliability of the supplementation protocol.

Limitations

Despite the aforementioned strengths, several limitations should be acknowledged. First, the acute nature of the supplementation may have limited the potential physiological adaptations required to elicit meaningful performance benefits, particularly in this highly trained population. Prior studies have suggested that chronic nitrate intake may be more effective, predominantly for enhancing mitochondrial function and muscle contractility (Affourtit et al., 2015; Bailey et al., 2009, 2015). It should also be acknowledged that TNOx reflects the combined concentration of nitrate and nitrite and therefore does not allow for the determination of the efficiency of nitrate reduction to nitrite or the subsequent formation of NO; accordingly, conclusions regarding NO-mediated mechanisms remain inferential. Second, although efforts were made to standardize training and nutrition prior to testing, individual variability in nitrate metabolism could have influenced the bioavailability of NO. Third, the sample size may have limited the statistical power to detect small yet practically meaningful differences. Moreover, no a priori sample size calculation was performed; the sample size was

constrained by the availability of high-performance swimmers. However, when considering elite athletes in general and swimmers in particular, it must be recognized that this is a rare and highly selective population that hardly ever engages in research studies. Consequently, even studies with a modest sample size provide valuable and otherwise exclusive insights as they capture performance characteristics and training adaptations that are uniquely representative of such an elite level. Such contributions therefore hold substantial practical relevance, despite the inherent constraints in participant availability. A further limitation of the present study is that side effects were not systematically recorded; therefore, the tolerability of the supplementation protocol cannot be evaluated. An additional limitation is that, although participants were asked to guess the supplement allocation after completing both trials, the success of participant blinding was not formally quantified and systematically assessed. In addition, the exclusive inclusion of male participants restricts the generalizability of our findings. Finally, future studies should employ electronic time systems as manual timing, although a pragmatic field-based method, lacks sensitivity for the smallest worthwhile changes in elite 200-m swimming, along with the use of more sensitive markers of nitrate action (e.g., muscle oxygenation, blood flow). Finer-grained kinematics were also not captured, limiting mechanistic insight into potential efficiency changes undetectable by total time.

Conclusion

In summary, acute BRJ supplementation did not significantly enhance repeated 200-m front-crawl performance, lactate accumulation, or perceived exertion in elite swimmers under conditions closely replicating real-world competition. However, given the high-performance level of the participants, the competition-specific testing protocol, and the narrow margins that often separate success from failure in elite sport, even small, nonsignificant performance differences may hold practical value. Although acute nitrate supplementation may not yield measurable ergogenic benefits in elite swimmers under the tested conditions, future research should explore the effects of chronic supplementation, consider individualized responses, and employ more sensitive performance and physiological markers to better capture subtle yet meaningful changes in performance at the highest level of competition.

Acknowledgments

The authors would like to thank the athletes for their commitment to the study. **Author Contributions:** All authors contributed significantly to the conception and design of the study, data collection, analysis, and interpretation of results. *Primarily responsible for drafting the manuscript:* Arnaoutis, Vallas. *Processed the data and performed the statistical procedures:* Nomikos. *Performed multiple critical reviews:* Nomikos, Toubekis. *Carried out the literature review, data collection, and contributed to the adjustments of this manuscript:* Arnaoutis, Vallas, Nomikos, Toubekis. All authors approved the final version of the manuscript. **Funding Statement:** This research received no external funding. The study was conducted without financial support from public, commercial, or not-for-profit funding agencies.

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Nontechnical Summary

Elite swimmers are always looking for safe ways to boost their speed and endurance in races, especially events like the 200-m front crawl that mix high-speed bursts and sustained effort. One popular idea is drinking concentrated beetroot juice, which is rich in nitrates. Nitrates are natural compounds from the beetroot plant that can help widen blood vessels, improve muscle oxygen use, and possibly speed up recovery between races. This study tested whether an acute dose of beetroot juice taken 2 hr before swimming could make top-level male swimmers faster or feel less tired during two back-to-back 200-m front-crawl time trials, mimicking the demands of real competitions where athletes race multiple times with about an hour's rest in between.

The researchers recruited 12 elite male swimmers, who compete at national and international levels—their personal best times in the 200-m placed them in the top 10%–12% worldwide. These athletes had low body fat (~7%) and swam high weekly volumes (>30 km), making them a tough group to improve as they are already highly optimized. The experiment used a strict setup: a randomized, double-blind, crossover design where each swimmer tried both the beetroot juice (140 ml of Beet It Sport, containing 8 mmol nitrates) and a placebo drink that looked and tasted similar and had similar calories and nutrients but no nitrates. They drank it after fasting, did a standard warm-up, and then swam two all-out 200-m front crawls from the blocks, with 60 min of rest (light stretching only) between them. Researchers measured swim times (using stopwatches by two timers), blood lactate levels (a marker of muscle fatigue from fingertip pricks), and how hard the effort felt (using a simple 0–10 scale). They also tracked TNOx in blood serum to confirm that the juice raised nitrate levels as expected. Swimmers avoided nitrate-rich

foods and supplements for days before, followed the same diet and training, and tested at the same time of day in a controlled pool.

The beetroot juice worked as planned: it spiked blood nitrate–nitrite levels over 10 times higher than placebo 2 and 3 hr later, proving good absorption. However, it did not improve swim times; the first 200-m averaged 117 s for both drinks, and the second was identical at 117.8 s, with no meaningful slowdown between races either (about 0.5–1 s slower, typical fatigue). Blood lactate rose similarly after each swim (11–13 mmol/L, high effort indicator), and swimmers rated the effort the same (around 8/10 postswim). Statistics confirmed no differences, even accounting for small elite-level changes that matter in races won by 10ths of seconds.

These results add to mixed evidence: although beetroot helps some runners or cyclists (especially less-trained ones) by lowering oxygen needs and aiding blood flow, it often fails in swimming, particularly for elite athletes whose bodies are already super efficient. Possible reasons include needing longer supplementation (days/weeks) for muscle changes or elites having less room to gain from nitrates as their oxygen delivery and muscle power are near perfect. Strengths include real-world testing on true elite swimmers, blinded setup, and competition-like repeats, but limits are the single dose, all-male group; manual timing (less precise than electronics); and no direct muscle oxygen measures.

Overall, this suggests a beetroot shot will not give elite swimmers an edge in 200-m repeats, but small time differences could still matter competitively. Coaches might test individuals or try longer protocols. Future work could involve women, chronic use, or tech like oxygen sensors for deeper insights into why nitrates do not always translate to faster swims.