PHYS 380: Molecular and Cellular Biophysics

Enhancing Performance with Beetroot Juice Supplementation: a Comparison Between Elite and Recreational Distance Runners

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Abstract

A few years ago, running magazines began publishing articles touting the benefits of beetroot juice consumption before endurance athletic events. Claims included increased aerobic oxygen uptake, and improved endurance. In this literature review, we compare the response of elite and recreational distance running athletes to beetroot juice supplementation.
Studies indicate that recreational athletes may benefit from both chronic consumption as well as acute consumption. A review by Dominguez states that acute supplementation of beetroot juice within 2-3 hours of exercise reduces oxygen consumption (at or below $VO_{2\ MAX}$ intensity), increases time to exhaustion, and may improve performance at $VO_{2\ MAX}$ intensity.
However, some newer studies suggest that these effects are insignificant in subjects performing at an elite level. Two studies are particularly relevant to elite athletes: one by Boorsma, University of Guelph, 2013; and the other by Balsalobre-Fernández, Universidad Autónoma de Madrid, 2018. The researchers conclude that beetroot juice offers no discernible performance benefit to distance running athletes competing at national level or above.

Key terms: nitric oxide, nitrate, oxygen uptake, distance running, beetroot juice, endurance athletes

Contents

Introduction

1.1 Distance running

1.1.1 Types and competitions

In competition, *distance running* is split between middle-distance ($800\,\mathrm{m}$ to $3000\,\mathrm{m}$), and long-distance ($3000\,\mathrm{m}$ and above). A typical competition occurs on a $400\,\mathrm{m}$ oval running track, or on a closed and measured road course. Athletes aim to either complete the course in as little time as possible, or to obtain the highest possible finishing rank in the field. Either way, an athlete's goal is to run as fast as possible.

Physiologically, performance in competition depends on the athlete's aerobic and anaerobic energy systems, as well as running economy[1, 1]. An athlete's $VO_{2\,\text{MAX}}$and lactate threshold[1] are key metrics of fitness in long- and middle-distance running.[1, 9]. Of course, the relative weight of each factor on performance depends on the race distance: a longer distance relies much more heavily on the aerobic system.

1.1.2 Differences between elite and recreational runners

There is no globally accepted definition of what constitutes an elite athlete, or elite distance runner. For the purposes of this article, we define an elite athlete as one who competes at the provincial, national, or international level. At this level of competition, athletes would undergo rigorous training almost every day of the week, year-round. As a result, we would expect to see highly developed physical adaptations as a result of their training protocol.

On the other end, while a recreational runner can still be competitive[2], a recreational runner would not have accumulated sufficient training volume to develop physical adaptations to the extend that an elite athlete would.

In particular, elite runner have a significantly higher capacity to consume oxygen during aerobic exercise (VO_2), as well as efficient running biomechanics which enable them to require less oxygen consumption for a given effort and pace[2]. These performance metrics will be discussed in more detail in Chapter 2.

1.2 History and popularity of beetroot juice

1.2.1 Initial research

Research interest into beetroot juice and exercise science exploded in 2009 following the publication of a University of Exeter study titled *Dietary nitrate supplementation reduces the O_2 cost of low-intensity exercise and enhances tolerance to high-intensity exercise in humans*. The study analyzed plasma nitrite concentration, blood pressure, oxygen consumption, and time to exhaustion in eight male subjects over a 6 day period, as assessed through a step test[3]. The results suggested that beetroot juice, due to its high concentration of inorganic nitrate, reduced systolic blood pressure and oxygen consumption, and increased time to exhaustion[4].

[1] The maximal intensity an athlete can sustain without significant accumulation of lactic acid.
[2] The vast majority of running competitions are open, such as marathons and road races.
[3] Step tests are a classic estimator of aerobic fitness in which subjects are asked to step on and off a shallow raised platform.[3]

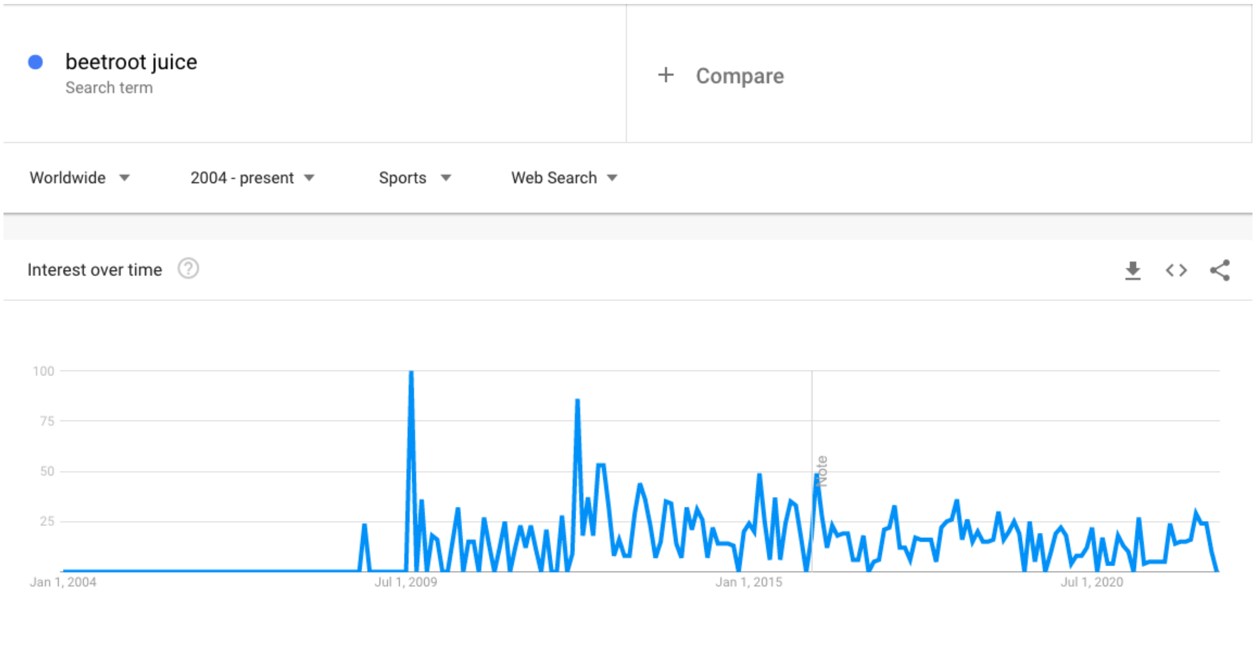

Figure 1.1: Worldwide Google Trend for the query `beet juice` in the `Sports` category. The first spike in 2009 results from the Bailey study at the University of Exeter, followed by a number of popular media articles.

1.2.2 Running and popular culture

Following the publication of the University of Exeter article, various popular science media outlets (for example, Science Daily[5]) reported on the benefits of beetroot juice. In November of 2009, *Runner's World Magazine* writer Amby Burfoot published an article called *Why Blood Dope When Drinking Blood-Red Beet Juice Is Just About As Good?*[6] The hype took off, and the beverage became a staple for runners, both elite and recreational, in their preparation for competition.

1.2.3 Commercial products

The rising interest in beetroot juice within the running community spawned a number of commercial products claiming to deliver these performance benefits to athletes. In the UK, a company called Beet It®advertises sets of 15 bottles of single-serving beetroot juice concentrate containing $400\,\mathrm{mg}$ of nitrates. At time of writing, the case is sold for CAD$62.99 through their Canadian online retail portal. Similar products targeted specifically to athletes are available in the US, UK, and Europe; however Beet It®appears to be the only product on the market which declares the nitrate content on the label. Of course, common beet juice is also available in many grocery stores, although these products are not specifically marketed for their benefits to athletic performance. That being said, it begs the question: are these supplements effective and if so, to whom, and to what extent?

Figure 1.2: Beet It® bottles of commercially available nitrate-rich beetroot juice concentrate. (© Marco Verch, 2019, `https://www.flickr.com/photos/160866001@N07/48881775563`. Obtained under Creative Commons Attribution 4.0 International Public License)

CHAPTER 2

Analyzing performance in distance running

2.1 Glossary of performance metrics in distance running

Table 2.1 outlines some of the key methods by which performance and fitness of distance runners can be evaluated. Each metric has its own benefits and drawbacks, therefor an assortment of multiple metrics are typically used to give a more complete picture of the subject's abilities.

Table 2.1: Glossary of performance metrics in distance running

Metric	Abbrev.	Description
Time trial or competition results		In the sport distance running, the ultimate measure of fitness is considered competition performance. In the typical format of a footrace, an athlete competes with the ultimate aim of minimizing their finishing time over a particular distance.[2]
Rating of perceived effort	RPE	An athlete's individual, subjective rating of their own effort level, based on their own sensory feedback. The rating is typically assigned an integer between 0 and 10, where 0 is no effort and 10 is a maximal effort.[2]
Oxygen uptake	VO_2	VO_2 is the rate at which an athlete's aerobic energy system consumes oxygen. An athlete's ability to process oxygen has an upper bound, known as $VO_{2\,MAX}$. An increasing fraction of energy metabolized after this point is done through the anaerobic energy system. This metric is measured in $\mathrm{L/min}$, or in $\mathrm{L/kg/min}$ when adjusted for the athlete's body mass.[2] Related to this: VCO_2 is the rate at which an athlete expels carbon dioxide.
Respiratory exchange ratio	RER	The respiratory exchange ratio describes the numerical ratio of an athlete's volume of inhaled oxygen to the volume of exhaled carbon dioxide (VO_2divided by VCO_2). This indicates how much of the oxygen is being consumed, and is a metric of fitness when compared against the effort level sustained by the athlete during the period of measurement.[2]
Heart rate	HR	Recorded in beats per minute (bpm), a human's heart rate is positively correlated to effort level. The heart's minimum rate is called the Resting Heart Rate (RHR), which occurs when the subject is resting and immobile for a period of time. The maximum heart rate (MHR) is the heart rate occurring at maximal effort, such as when sprinting up a hill. The benefit of heart rate is its ease of measurement, and several models exist to approximate the relationship between VO_2 and HR.[2]
Running economy		Running economy is similar to fuel economy in a vehicle. It is defined as an athlete's instantaneous oxygen consumption relative to their velocity. This gives a measurement of the body's efficiency in converting oxygen to physical work. It is typically measured in $\mathrm{L/min/kg/m \cdot s}$, where $\mathrm{m/s}$ is the athlete's forward velocity.[2]
Muscle oxygen saturation	SmO_2	Measured as a percentage, oxygen saturation is defined by the fraction of inhaled oxygen which is consumed by the muscles. A near-infrared spectroscopy sensor can be placed against the skin to obtain the measurement. [7]
Time to exhaustion	T_{EX}	Time to exhaustion is measured through a test, by which a subject is asked to sustain a fixed physiological workload indefinitely. At some point, the subject will reach a point of exhaustion and fail to sustain the required output. The measured time interval up to the point of failure is called time to exhaustion. [8]

Effects of beet juice

3.1 Beetroot juice and the nitric oxide pathway

Early work by Bailey et al showed that supplementation of beetroot juice reduced the oxygen cost of submaximal exercise, and increase athletes' time to exhaustion[4, 1]. These remarkable effects have been traced back to beetroot juice's tendency to increase nitric oxide (NO) within in the bloodstream.

There are two pathways by which nitric oxide is produced within the body. The first is endogenous, and results from an oxidation reaction of the amino acid L-arginine and the enzyme NOS[9, 1][10, 1].

However, it is the second NO pathway which is of interest in this paper. In this process, illustrated in Figure 3.1, NO is can be produced through a double reduction reaction of nitrate, NO_3^-. Beetroot juice is known to be a uniquely high source of dietary NO_3^-[4].

Dietary nitrate, when consumed, is absorbed into the bloodstream. From there, the nitrate is reduced, yielding nitrite, NO_2^-, by bacteria in the mouth[1]. This nitrite is then "physiologically recycled"[10, 1], and absorbed again into the bloodstream, through the salivary gland, and then into the stomach. Immediately upon reaching the stomach, the bulk of the NO_2^- is reduced, yielding NO.

Nitric oxide has several uses in the body. For the purposes of this article, the key contribution of NO is its tendency to reduce the oxygen cost of aerobic exercise. NO can effectively act to replace oxygen molecules in the Complex IV reaction in the electron transport chain [9, 19]–remarkably reducing the physiological oxygen cost of exercise.

3.2 Elite runners

A double-blind, placebo-controlled crossover study from the University of Guelph presented the first findings on the effect of beetroot juice to elite-level male distance runners[9, 56].

The study tracked male ($n = 8$) subjects in an 8-day period, with data obtained following an acute dose, as well as after 8 days of chronic supplementation of either a placebo or a high-nitrate beetroot juice. Subjects were tested for plasma NO_3^- concentration, and running efficiency (VO_2, VCO_2, RER, and HR) through a submaximal treadmill test followed by an individual $1500\,\mathrm{m}$ time trial on an indoor track[9, 40].

Within 90 and 150 minutes of a single dose, the subjects showed significantly elevated levels of plasma NO_3^- ((37 ± 15) µM at baseline, (615 ± 151) µM 90min after dose, (596 ± 64) µM 150min after dose).

Despite the great increase in plasma NO_3^-, Boorsma concluded that the beetroot juice supplement produced no statistically significant effect on any of the perfomance quantifiers[9, 63]. The $1500\,\mathrm{m}$ time trials showed no significant difference or order effect across the four trials (acute placebo, chronic placebo, acute supplement, chronic supplement). Similarly, the treadmill tests yielded no significant changes in VO_2, VCO_2, RER, and HR[9].

Boorsma did note that 2 out of the 8 subjects did respond to the beetroot juice supplement to a higher degree than average [9, 69]. These two subjects showed an improvement in their $1500\,\mathrm{m}$ time trial that exceeded the coefficient of variation for elite males at this distance[9, 60], which suggests that the supplement may have a meaningful effect on their performance. Boorsma notes that these two athletes were on the lower (but not bottom) end of the performance

[1] It is worth noting that these bacteria are critical to the conversion process. Many of the studies references in this literature forbit their test subject from using mouthwash for the duration of the study period. It has been demonstrated that interfering with the bacterial cultures would prevent the conversion of nitrates[11].

range for the surveyed athletes, and suggests that their improvement may come as a result of their lesser physical training adaptations relative to the other subjects[9, 61]. It may also be possible that some fraction of elite athletes do respond well to beetroot juice supplementation. A study done on elite cyclists in 2012 elicited a similar response: 2 out of 8 elite cyclists showed a reduction in $\mathrm{VO_2}$at medium and low intensity efforts[13, 8]. More research is necessary to determine the cause, but Christensen notes that the composition of fast versus slow twitch muscle fibers could be one possible factor[13, 8].

Balsalobre-Fernández, from the Universidad Autónoma de Madrid, conducted a study on elite male runners ($n = 12$) training at the High Performance Center of Madrid. Athletes were given either a beetroot juice supplement (or a placebo) to consume for a period of 15 days.

Eight variables were tracked in each subject: RPE, muscle oxygen saturation, RER, $\mathrm{VO_2}$ and $\mathrm{VO_{2\,MAX}}$, heart rate, $\mathrm{T_{EX}}$ (time to exhaustion), and leg stiffness. The study finds that statistically significant effects were only found for RPE, $\mathrm{SmO_2}$, and $\mathrm{T_{EX}}$. These variables showed improvements (as measured in standardized mean differences between placebo and experimental and 90% confidence interval) of $-2.17\,(-3.23, -1.1)$ out of 10, $0.72\,(0.03, 1.41)\,\%$, $1.18\,(-0.14, 2.5)\,\mathrm{s}$, respectively. All remaining variables showed an unclear relationship to beetroot juice consumption in comparison to the effects observed in the placebo group.

It is worth noting that the variables which do indicate a possible relationship with beetroot juice supplementation in the Balsalobre study are not tracked in Boorsma's study, so no comparison can be made. However, both studies agree that there is no clear relationship between beetroot juice supplementation in elite male runners with respect to $\mathrm{VO_2}$,$\mathrm{VO_{2\,MAX}}$, and RER (and therefore also not in running economy). These results are consistent with prior findings in studies on elite athletes from other sports, such as flatwater kayaking[14] and cycling[13] in concluding that beetroot juice does not appear to enahance performance in elite athletes.

3.3 Recreational runners

Studies indicate that recreational athletes may benefit from both chronic consumption as well as acute consumption. A review by Dominguez states that acute supplementation of beetroot juice within 2-3 hours of exercise reduces oxygen consumption (at or below $\mathrm{VO_{2\,MAX}}$ intensity), increases time to exhaustion, and may improve performance at $\mathrm{VO_{2\,MAX}}$ intensity[12, 13].

A study from Brazil, by Fernandes de Castro, tested a group of 14 male runners for maximum HR, RPE, $10\,\mathrm{km}$ run time trial, glycogen, and maximum lactate concentration following baseline, chronic supplementation, or a placebo[15, 19]. In this case, the chronic supplementation was only three days. The study concluded that none of the variables had a statistically significant relationship to beet juice supplementation[15]. This is not necessarily in disagreement with the literature, since the review by Dominguez does not claim that beetroot juice improves those particular variables [12]. With regards to the $10\,\mathrm{km}$ results: it should be noted that less experienced athletes may not pace themselves optimally during a race effort, and thus the conditions are uncontrolled in this regard. This is shown in the study, as most subjects began their effort too fast and dropped their pace with each subsequent kilometer[15, 20]. Using a controlled experiemental setup consisting of a treadmill, and analyzing $\mathrm{VO_2}$ would enable the observation of more precise results.

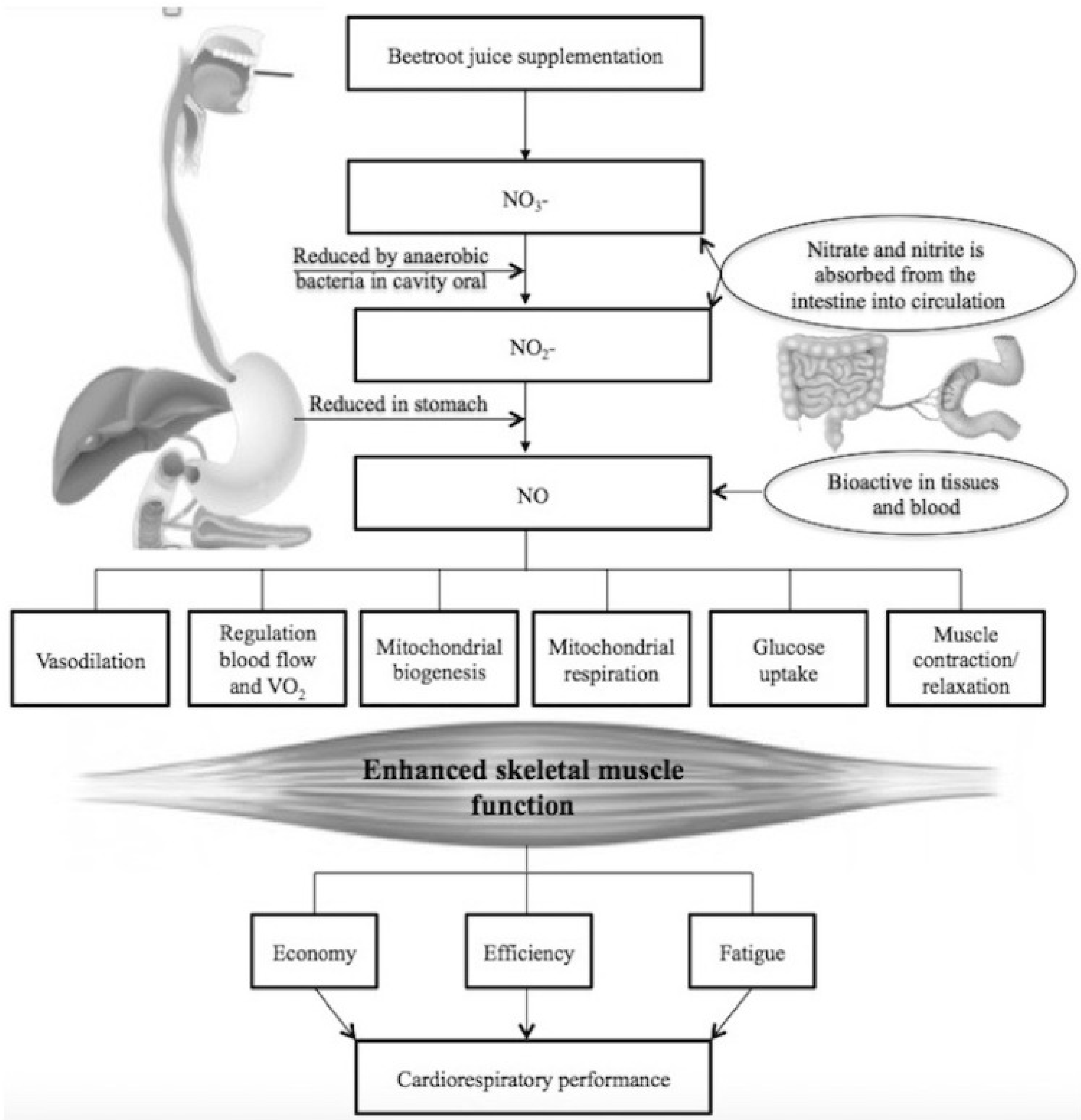

Figure 3.1: Illustration showing the endogic conversion of nitric oxide as a result of oral beetroot juice intake. Retrieved from Dominguez et al [12].

Conclusion

It is clear that consumption of beetroot juice has some positive effect on the performance of recreational distance running athletes. Consumption of beetroot juice both in a short time interval preceding a performance (2-5 hours), or longer-term supplementation in the week preceding, is shown to improve the athlete's running economy, time to exhaustion, and cardiorespiratory performance at the $VO_{2\ MAX}$intensity level [12].

However, through the work of Boorsma [9] and Balsalobre et al [7], it is clear that beetroot juice has a much weaker effect on elite runners. Elite runners seem not to benefit from beetroot juice suppelementation with respect to in VO_2, $VO_{2\ MAX}$, running economy, or timed performance over set distances. Some improvement has been observed to likely occur in RPE, muscle oxygen saturation, and time to exhaustion[7].

The results observed in elite male runners agree with prior findings in similar studies for elite flatwater kayakers[14] and cyclists[13]: beetroot juice supplementation has no clear performance benefit for elite athletes.

It is recommended that future research investigate the cause for beetroot juice's diminished effectiveness in elite runners. Boorsma did find that a small fraction of athletes did show some statistically significant performance improvement, suggesting that there may be some variance among athletes. De Castro posits that elite athletes may have a higher production of NO through the endogenous pathway, leading to a reduced effectiveness of NO production via dietary nitrate[15, 13].

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