The Effect of Beetroot Juice on Cycling Performance, a Meta-Analysis

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Introduction

Throughout history, nutritional renaissances emerge in different regions of the world in response to societal needs. In recent years, western populations have become more health conscious, investing more effort into understanding the impact of nutrition on our daily lives. An prime example of this phenomenon is the "super food" craze that attracts young and mature adults alike. From supplements, to vegetables, to juice cleanses, more and more people are seeking out foods that have developed a healthy reputation.

A current member of the "super food" category is the beetroot, which is a vegetable that is known to be high in nitrates. Despite a distinct bitter flavor, beetroot has become a popular nutritional ingredient, believed to have many nutritional benefits. Apart from being a purported treatment for high blood pressure, beetroot is also believed to be exceptionally beneficial to athletic performance.

Due to the immense cardiovascular requirements of cycling, it has long been theorized that performance can be drastically enhanced through the use of both legal and illegal substances. Despite a long history of the use of illegal substances by professional cyclists, very little scientific information is commonly available regarding the performance benefits of regular food items.

At the intersection of superfoods and athleticism lies a fundamental question of whether athletes can exhibit a significant increase in performance from including specific food items in their diet. In this meta-analysis, we will focus specifically on the effects of beetroot juice on the mean power output(watts) and VO_2(L/min) consumption of a cyclist, through the analysis of experimental results summarized from several published articles.

Study Selection

As more eyes focus on the potential health benefits of specific food items, there are myriad studies, systematic reviews, and meta-analyses regarding the effect of beetroot, and other nitrate-rich foods, on human health. For the purpose of this analysis, we must narrow the scope of available studies to target only those that specifically test the effect of beetroot juice on cycling performance.

The initial selection of studies began with a search of the PubMed and Google Scholar databases for the keywords "beetroot" and "cycling". Studies were only considered for selection if the primary outcome of interest was an increase in a cycling performance under normal conditions, and the only factor under study was the administration of beetroot juice. Several articles targeting the desired effect in a subset of COPD (chronic obstructive pulmonary disease) patients, or as a tool for heat acclimation were excluded from consideration. Additional articles were excluded as they studied the effect of beetroot juice on the physical musculature of the cyclist, and not the outcome of a performance. In total, 8 studies, measuring at least power output, oxygen uptake, or both, were retained for the analysis.

Literature Review

All of the 8 studies retained for analysis were conducted under very similar experimental conditions. Each study administered identical beetroot juice treatments(Beet It Sports, James White Drinks, Ipswich, UK) in either 70ml, 140ml, or 500ml doses. Additionally, 6 of the 8 studies performed their testing using identical electronically braked cycle ergometers (Lode Excalibur Sport, Groningen, the Netherlands). Each study featured a randomized, blinded, placebo-controlled, crossover design

with similar pre-study procedures in order to minimize the presence of any dietary confounders. Of the 8 articles, 6 report experimental results under sea-level oxygenation conditions, while 1 article reports effects under simulated altitude conditions, and 1 reported results under both conditions.

The oldest study in the pool was performed by Lansley et al. in 2011, and examined the effect of a single 500ml dose of beetroot juice on cycling performance over a 4km and 16.1km time trial(TT)[9]. This study involved the participation of 9 male, non-elite, cyclists, having each participant perform both time time trials under treatment and placebo conditions. In this study, participants were required to perform familiarization sessions over each TT distance, until the difference in times was below 1%. In addition to recording blood pressure and blood plasma [NO2-], Lansley et al. also measured VO2 and power output(PO). While the results for VO2 were not reported, the article concluded a significant increase in PO for both 4km and 16.1km TT distances.

In 2012, Cermak et al. performed a similar study with 20 trained male cyclists, testing the effect of a 140ml dose of beetroot juice on performance in a 1 hour TT[4]. This study recruited cyclists that had been performing consistent cycling training($>$ 3x/week), and instructed participants to standardize their activity and dietary schedule for the 48 hours prior to each test. This study recorded plasma nitrite concentration, heart rate, and power output throughout each test, and concluded no significant increase in power output after ingesting the beetroot juice treatment.

Again in 2012, Cermak, Gibala, and van Loon aimed to further study the effect of beetroot juice by testing 12 male cyclists over the duration of a 10km TT[3]. This study administered a 140ml dose of beetroot juice treatment, but subjects were given this treatment daily, for 6 days prior to each TT effort. This study measured the treatment effect against time, power output, and VO_2 consumption. Contrary to their prior study, Cermak, Gibala, and van Loon concluded that the beetroot juice had a significant effect, hereby increasing the PO and decreasing the VO_2 consumptions over the 10km TT.

A 2013 study performed by Muggeridge et al. aimed to study the effect of beetroot juice on cycling performance in simulated altitude conditions[11]. A trial involving 9 non-elite male cyclists we performed, with each participant receiving only a single 70ml dose of the treatment 2.5 hrs prior to a 15 minute test of submaximal exercise, as well as a 16.1km TT. The results of this study suggested a both a significant increase in PO and decrease in VO_2 consumption under altitude conditions.

Kelly et al., performed a trial in 2013 to study the effect of beetroot juice on the power-duration relationship of cycling efforts[8]. Specifically, they aimed to test the hypothesis that nitrate supplementation could positively effect the relationship between the power capacity of a cyclist over given time durations. Enlisting 9 active male cyclists, Kelly et al. administered 500ml of treatment for between 7 and 12 days, while performing the supplemented tests. Heart rate, blood pressure, blood plasma, and VO_2 consumptions were recorded, and participants were monitored throughout periods at 60%, 70%, 80%, and 100% of maximal effort. Although there appeared to be a small decrease in VO_2 consumption at easier efforts, the composite effect across all effort levels was negative and non-significant.

In 2014, a study performed by Kelly et al. aimed to test the effect of a single 140ml dose of beetroot juice on VO_2 consumption on 12 cyclists in both normoxia and hypoxia[7]. All participants were evaluated under both oxygenation conditions for 2 five minute bouts of moderate(80% of gas exchange threshold(GET)) exercise, and a single bout of severe intensity(combination of GET and VO_2-peak) exercise to exhaustion. Combined effects for both intensity tests conclude no significant effect of treatment on VO_2 consumption under normoxia or hypoxia.

A 2015 study performed by Betteridge et al. performed testing on 8 active male cyclists using a single 140ml dose of beetroot juice supplement[2]. Participants performed a preliminary effort to assess VO_2-peak, and then were reassessed after receiving the treatment for the duration of 1 hour at 65% of VO_2-peak. Between 15-30 minutes and 45-60 minutes of the testing period, blood samples were recorded, as well as VO_2 and VCO measurements. Contrary to other studies, Betteridge et al. measured a non-significant increase in the VO_2 consumption of participants after receiving the beetroot treatment.

Another study published in 2015 by Bailey et al. explored the effect of beetroot juice supplementation by measuring cycling performance in time-to-exhaustion efforts at difference cadence specifications(35rpm and 115rpm)[1]. This study administered 140ml of treatment to 7 healthy male cyclists over 9 days of treatment, and monitored VO_2 consumption, blood pressure, blood plasma, and blood lactate. The resulting tests concluded a significant decrease in VO_2 consumption for high cadence(115 rpm) exercise, but no significant effect at low(35rpm) exercise.

Method

As all studies collected for this analysis used randomized,crossover designs, all patients were measured after receiving both placebo and control treatment. Each article indicates either a brief period of baseline testing or familiarization with the experimental protocol, which does not contribute towards treatment evaluation, and is not used in formulating conclusions. While the duration and intensity of each testing interval differs between studies, they all measure key performance indicators throughout the testing intervals while under placebo and treatment conditions. In the articles, the primary conclusion for each study is drawn from comparing the mean key performance indicators between each group, and evaluating whether the difference between groups is statistically significant. For this analysis, we will use the difference between the mean values of the placebo and treatment groups as the effect size.

In order to compare results across studies, standardized effect sizes were calculated for each article, using Cohen's *d*. For articles that presented results based on multiple performance tests or different outcomes, standardized effects were calculated for each outcome, and then a composite effect was calculated using a combination of the original outcome effects. Composite effects were only computed for outcomes with the same measurement(e.g., power, VO_2).

Table 1: Summary of mean effect size from each study used in the meta-analysis

Author	Sample	Condition	Dose	Frequency	Effect	Effect Size (s.e.)
Lansley(2011)	9	Normal	500ml/day	1 day	PO	0.2974 (0.2247)
Cermak(2012)a	20	Normal	140ml/day	1 day	PO	-0.4286 (0.1023)
Cermak(2012)b	12	Normal	140ml/day	6 day	PO	0.5 (0.1719)
Cermak(2012)b	12	Normal	140ml/day	6 day	VO_2	1.3621 (0.2054)
Muggeridge(2013)	9	Altitude	70ml/day	1 day	PO	1.3333 (0.2716)
Muggeridge(2013)	9	Altitude	70ml/day	1 day	VO_2	1.8399 (0.3163)
Kelly(2013)	9	Normal	500ml/day	7-12 days	VO_2	-0.0617 (0.0693)
Kelly(2014)	12	Normal	140ml/day	1 day	VO_2	0.0227(0.1671)
Kelly(2014)	12	Altitude	140ml/day	1 day	VO_2	0.2872(0.1687)
Betteridge(2015)	8	Normal	140ml/day	1 day	VO_2	-0.2054 (0.2514)
Bailey(2015)	7	Normal	140ml/day	9 days	VO_2	0.1296 (0.2877)

The effects of interest for each study are either power output in watts(PO) or oxygen consumption in ml/min(VO_2). A positive effect for PO indicates that the subject produced more power after ingesting beetroot juice, as compared to the placebo. A positive effect for VO_2 indicates that the subject consumed less oxygen after ingesting the beetroot juice, as compared to the placebo.

The overall standardized effect, after computing composite scores, are listed in Table 1. Although each article reported measurements for more than power output or VO_2 consumption, these are the most common measures for assessing the cardiovascular output of interest. Other measures were not included in the composite effect calculations, as the correlation between physiological responses is unknown.

After computing overall effect scores for either VO_2 consumption or power output for each article, the effects can be analyzed using either a fixed or random effects model. Such a model will allow us to better understand the data we have collected, as well as formulate a conclusion regarding the possible effect of the beetroot juice treatment.

Results

Testing for homogeneity between the aggregated effects attempts to determine whether the studies all effectively measure the same construct. The Q-test is a common measure for testing homogeneity, and can be used to determine whether a fixed or random effects model would be appropriate for the analysis. Based on a p-value of 0.01, we will proceed with the analysis of VO_2 consumption effect using a random effects model. Figure 1 presents a forest plot of the VO_2 effects for each study, as well as respective confidence intervals for each. In addition, Figure 1 also presents the results of fitted random effects models for overall VO_2 effects, as well as subgroups for normal and altitude conditions.

Confidence intervals for each fitted random effects model indicate whether the total effect size is significantly different from zero. Despite two studies reporting effect sizes of 1.36(Cermak et

al. 2012b) and 1.02(Muggeridge et al.2013), the confidence interval for the overall effect of VO_2 consumption(-0.11, 0.97) includes zero, which indicates that beetroot juice has no significant effect on VO_2 consumption during cycling. Additionally, as shown in the subgroup effect analysis for both normal and altitude conditions, these confidence intervals also include zero, concluding that beetroot juice does not effect VO_2 consumption regardless of elevation conditions.

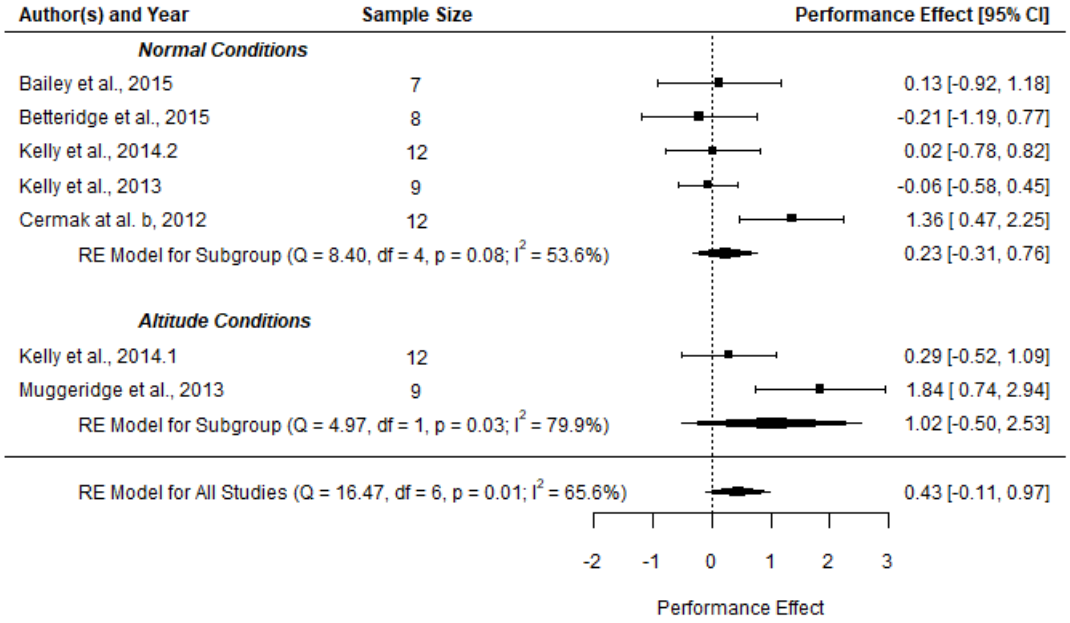

Figure 1: Forest plot of the reported effects sizes of beetroot juice on VO_2 consumption.

As in the analysis of VO_2 consumption effects, an initial test of homogeneity within power output effects suggests the use of a random effects model(p=0.03). Output corresponding to a similar analysis is presented in the forest plot of power output effects in Figure 2. As shown in this plot, the confidence interval for the estimated total effect size of beetroot juice on power output(-0.36, 1.07) also includes zero as a possible value. This indicates that beetroot juice has zero effect on power output when cycling, without accounting for elevation conditions. However, confidence intervals for the estimated effect for each subgroup indicate that beetroot juice may have zero effect under normal conditions, but may have a performance increasing effect when cycling at altitude.

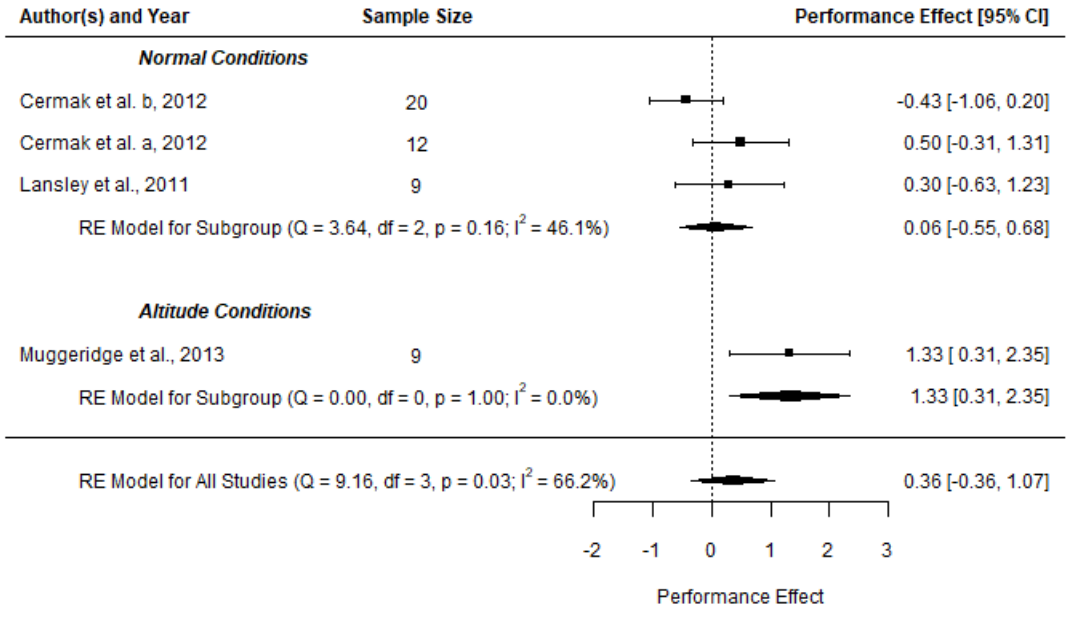

Figure 2: Forest plot of the reported effects sizes of beetroot juice on power output.

Limitations

There are significant limitations in performing a meta-analysis with so few studies to sample from. Ideally, a meta-analysis should be exhaustive, including results from both published and unpublished sources, and should not be limited to a certain language or population. This meta-analysis includes both publication and language bias, as only published articles, written in English, were collected.

In addition to the biases involved in the collection of articles for analysis, there could be definite bias in the mechanisms used to evaluate cycling performance in a number of the studies. Despite, detailed experimental protocols, the wide range of test intensities and durations over which the participants were evaluated in each study inserts tremendous risk into the act of comparing results across studies. In addition to the difficulties associated with using small sample sizes to measure treatment effects that can be generalized to larger populations, all but one study used exclusively male participants.

Conclusion

In summary, the results from published studies aiming to measure the effect of consuming beetroot juice in order to enhance cycling performance tend to be mixed. This is highlighted no better than by the contradictory effects identified by Cermak et al. in two separate 2012 studies[3, 4], as shown in Table 1. However, each year more studies are being published on the relationships between dietary intake an health and fitness improvements, which can only help to improve our understanding.

In conclusion, the aggregation of published research results, and subsequent random effects modelling, indicate that ingesting beetroot juice does not significantly improve cycling performance. In addition, the 95% confidence interval for the estimated effect within each subgroup for both VO_2 consumption and power output are displayed in Table 2. As evident by the respective confidence intervals, beetroot juice appears to have no significant effect on VO_2 consumption when cycling, regardless of altitude conditions. Additionally, based on findings reported in 3 articles, beetroot juice has no significant effect on power output when cycling at normal altitude. However, this meta analysis is unsuitable for assessing the effect on power output when cycling at altitude, as only one published study was available, which concluded a significant increase in power output.

Table 2: Summary of total effect sizes for the effect of beetroot juice on VO_2 and power output during cycling

Outcome	Condition	Studies	Effect Size	95% Confidence Interval	Conclusion
VO_2	Normal	5	0.23	[-0.31 , 0.76]	No effect
VO_2	Altitude	2	1.02	[-0.50 , 2.53]	No effect
PO	Normal	3	0.06	[-0.55 , 0.65]	No effect
PO	Altitude	1	1.3333	[0.31 , 2.35]	Effect

Subgroup effect estimates were computed through the use of a random effects model.

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