The Effect of Beta-Alanine Supplementation on Isokinetic Force and Cycling Performance in Highly Trained Cyclists

Samuel T. Howe, Phillip M. Bellinger, Matthew W. Driller, Cecilia M. Shing, and James W. Fell

Beta-alanine may benefit short-duration, high-intensity exercise performance. The aim of this randomized double-blind placebo-controlled study was to examine the effects of beta-alanine supplementation on aspects of muscular performance in highly trained cyclists. Sixteen highly trained cyclists (mean ± SD; age = 24 ± 7 yr; mass = 70 ± 7 kg; VO2max = 67 ± 4 ml·kg–1·min–1) supplemented with either beta-alanine (n = 8, 65 mg·kg–1·BM) or a placebo (n = 8; dextrose monohydrate) over 4 weeks. Pre- and postsupplementation cyclists performed a 4-minute maximal cycling test to measure average power and 30 reciprocal maximal isokinetic knee contractions at a fixed angular velocity of 180°·sec–1 to measure average power/repetition, total work done (TWD), and fatigue index (%). Blood pH, lactate (La–) and bicarbonate (HCO3–) concentrations were measured pre- and postisokinetic testing at baseline and following the supplementation period. Beta-alanine supplementation was 44% likely to increase average power output during the 4-minute cycling time trial when compared with the placebo, although this was not statistically significant (p = .25). Isokinetic average power/repetition was significantly increased post beta-alanine supplementation compared with placebo (beta-alanine: 6.8 ± 9.9 W, placebo: –4.3 ± 9.5 W, p = .04, 85% likely benefit), while fatigue index was significantly reduced (p = .03, 95% likely benefit). TWD was 89% likely to be improved following beta-alanine supplementation; however, this was not statistically significant (p = .09). There were no significant differences in blood pH, lactate, and HCO3– between groups (p > .05). Four weeks of beta-alanine supplementation resulted in worthwhile changes in time-trial performance and short-duration muscular force production in highly trained cyclists.

Keywords: carnosine, time-trial, ergogenic, supplement, bicarbonate, lactate

While the exact role of acidosis in causing fatigue is still relatively contentious (Allen, Lamb, & Westerblad, 2008; Cairns, 2006), there is evidence to support that a reduction in muscle pH may exacerbate fatigue either directly or indirectly (Fitts, 1994; Messonnier, Kristensen, Juel, & Denis, 2007). The first line of defense against muscle acidemia is intracellular buffers including phosphates, proteins, peptides, and amino acids (Abe, 2000). Carnosine is an important intracellular buffer that is synthesized in skeletal muscle from the amino acids L-histidine and beta-alanine. Beta-alanine is thought to be the rate-limiting precursor of endogenous carnosine production (Dunnett & Harris, 1999; Harris et al., 2006; Hill et al., 2007) as L-histidine is present in higher concentrations in muscle and plasma relative to its Km for carnosine synthase compared with beta-alanine (Bakardjiev & Bauer, 1994; Horinishi, Grillo, & Margolis, 1978). Supplementation with beta-alanine has been reported to increase skeletal muscle carnosine concentration (Baguet, Bourgois, Vanhee, Achten, & Derave, 2010; Derave et al., 2007; Harris et al., 2006). Therefore, if muscle buffering capacity can be enhanced via beta-alanine, then performance in short duration, high-intensity exercise may be improved (Derave et al., 2007; Hollidge-Horvat, Parolin, Wong, Jones, & Heigenhauser, 2000). Furthermore, there have been suggestions that carnosine exerts its ergogenic effects via altering calcium handling and sensitivity (Dutka & Lamb, 2004; Dutka, Lamboley, McKenna, Murphy, & Lamb, 2012) as well as through its antioxidative potential and vasodilatory effects (Ririe, Roberts, Shouse, & Zaloga, 2000), although evidence to support these potential ergogenic mechanisms in vivo is still limited.

Beta-alanine supplementation for 4 weeks or more at 4.0–6.4 g·day–1 has been shown to elevate intramuscular carnosine concentration by 30–80% in a dose dependent fashion (Baguet et al., 2010a; Derave et al., 2007; Harris et al., 2006; Hill et al., 2007; Kendrick et al., 2008; Kendrick et al., 2009) with intramuscular carnosine concentration associated with performance improvements in short duration, high-intensity exercise (Baguet et al., 2010a; Hill et al., 2007; Van Thienen et al., 2009). The relationship between intramuscular carnosine concentration and athletic performance was demonstrated by Baguet and colleagues (Baguet et al., 2010a) who reported a strong positive correlation between
baseline carnosine concentration and 100-, 500-, 2,000-, and 6,000-m rowing performance in 17 elite male rowers. However, significant increases in carnosine content of the soleus and gastrocnemius (45% and 28%, respectively) after supplementing with beta-alanine for 7 weeks, did not significantly improve 2,000-m rowing performance ($p = .07$). Similarly, Derave et al. (2007) found that 4 weeks of beta-alanine supplementation (4.8 g·day$^{-1}$) in track and field athletes significantly increased carnosine concentrations of both the soleus (+47%) and gastrocnemius (+37%) but did not significantly improve 400-m sprint performance compared with the placebo group ($p = .98$), despite a significant ($p < .05$) improvement in knee extension torque in an isokinetic test.

To date the ergogenic effect of beta-alanine supplementation on performance in highly trained cyclists is relatively unknown with the exception of two recent studies (Bellinger, Howe, Shing, & Fell, 2012; Van Thienen et al., 2009). One of these studies reported a 37% likelihood of improvement in average cycling time-trial power following 4 weeks of beta-alanine supplementation (Bellinger et al., 2012). The other found a small but significant effect on 30 s sprint performance following a 110 min simulated cycle racing but no benefit on 10-min time-trial performance following a simulated cycle race (Van Thienen et al., 2009).

The aim of this study was to examine the effect of beta-alanine supplementation on muscular performance variables in highly trained cyclists. Specifically, we investigated the effects of supplementation on a 4-minute maximal cycling performance test and a shorter isokinetic knee-extension protocol. We hypothesized that 4 weeks of beta-alanine supplementation would improve both maximal cycling and knee-extension performance in highly trained cyclists.

**Methods**

**Participants**

Sixteen highly trained male cyclists volunteered to complete the randomized, double-blind, placebo controlled study mean ± SD; placebo: age = 22 ± 5yr, height = 1.79 ± 0.07m, mass = 71.1 ± 7.5kg, VO$_{2\text{max}}$ = 67.3 ± 5.5mL·kg$^{-1}$·min$^{-1}$; beta-alanine: age = 26 ± 8 yr, height = 176 ± 0.07m, mass = 69.1 ± 7.3kg, VO$_{2\text{max}}$ = 67.5 ± 6.4mL·kg$^{-1}$·min$^{-1}$. There were no significant differences ($p > .05$) between the groups at baseline for any of the physical characteristics. Entrance criteria included: training for >10h per week, aged between 18–40 years and VO$_{2\text{max}}$ of ≥ 60mL·kg$^{-1}$·min$^{-1}$. All cyclists completed a Sports Medicine Australia pre-exercise screening questionnaire. This study has been approved by the Institutional Human Research Ethics Committee and has therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. All persons gave their informed consent before their inclusion in the study and details that might disclose the identity of the subjects under study have been omitted.

**Participant Requirements**

Before the performance trials, cyclists were asked to maintain their normal diet, abstain from strenuous exercise, consume alcohol, nonprescription drugs, and other potentially ergogenic supplements including caffeine, to communicate the use of any prescription medications and, via the completion of a prescribed diet diary, to record their diet 24h before the baseline performance trial and replicate for all subsequent trials. None of the cyclists were taking any other ergogenic aids in the 2 months leading up to the study. All participants were naive to beta-alanine supplementation before commencement of the study.

**Procedures**

**Design**

Cyclists supplemented orally with either beta-alanine (Balance 100% unflavored pure beta-alanine; Vitaco Health, Auckland, New Zealand, n = 8) or a placebo (dextrose monohydrate, n = 8) for 28 days. The beta-alanine used was produced by a certified manufacturing facility (New Zealand Food Safety Authority) with regular audits conducted by Medsafe New Zealand to retain its food and therapeutic licenses with raw materials meticulously batch tested to identify and quantify the active ingredients of the material to ensure against contamination. A cross-over design was not implemented due to the stable nature of carnosine in skeletal muscle, with a lengthy washout period following beta-alanine supplementation that has been reported to be up to 15 weeks before carnosine concentration is returned to baseline after a 5- to 6-week beta-alanine supplementation protocol (Baguet et al., 2009).

**Supplementation and Familiarization**

Supplements were provided in capsule form relative to the cyclists’ bodyweight (65mg·kg$^{-1}$ of body mass per day or quantity matched placebo) administered in four even daily doses following meals. The average total beta-alanine consumed was 127.4g (~4.5 g·day$^{-1}$ for 4 weeks), which is at the lower end of the spectrum for daily doses following meals. The average total beta-alanine consumed was 127.4g (~4.5 g·day$^{-1}$ for 4 weeks), which is at the lower end of the spectrum for total dose in recent literature. However, to our knowledge all studies to date that have measured muscle carnosine following beta-alanine supplementation have reported a significant increase (> 40%) using approximately 3–6g·day$^{-1}$ over 4–8 weeks (Baguet et al., 2009; Derave et al., 2007; Harris et al., 2006; Hill et al., 2007; Kendrick et al., 2008). Similarly, the expected increase in muscle carnosine concentration of the current study, based upon the relationship between the total ingested beta-alanine and increase in muscle carnosine as established by Stellingwerff et al. (2012) would be ~37%. Consequently the current study implemented a dose likely to increase muscle carnosine and minimize the likelihood of side effects that may jeopardize the blinding process.
Cyclists visited the exercise testing laboratories on six separate occasions; the first two visits were separated by at least 24 hr and included a VO_{2max} test and a familiarization trial of both the isokinetic and cycling performance tests. The latter four involved the pre- and post-supplementation isokinetic and cycling performance tests in a randomized order. During the 28-day supplementation period cyclists also completed two standardized high-intensity interval training (HIT) sessions each week. Cyclists were requested to report any side effects and to return the supplementation packaging following the supplementation period to monitor side effects and compliance.

**VO_{2max} Test**

Cyclists completed a maximal ramp exercise test on an electromagnetically braked cycle ergometer (Lode, Excalibur Sport, Groningen, Netherlands) to determine VO_{2max} (Laursen, Shing, Peake, Coombes, & Jenkins, 2002). Heart rate was recorded every minute using heart rate monitors (s610, Polar Electro, Oy, Finland) and rating of perceived exertion (RPE; Borg, 1982) was recorded every two minutes. These variables along with peak power output and VO_{2max} were determined to prescribe HIT sessions. Expired air was analyzed using a calibrated gas analyzer (Parvomedics Trueone 2400, Utah, USA).

**Warm-Up Protocol**

Before all performance tests cyclists completed a progressive three-step warm-up protocol relative to the cyclists’ bodyweight on a friction-braked cycle ergometer (Ergomedic 828E, Monark-crescent, Varberg, Sweden). Each 3-minute stage required a pedaling cadence of 80rpm to approximate 2.0W·kg^{-1}, 2.5W·kg^{-1} and 3.0W·kg^{-1}. Post warm-up, cyclists were given three minutes to allow for any mental or other preparation before the test commenced and this period was monitored and recorded to allow for replication in subsequent trials.

**Cycling Time Trial**

Cyclists completed the 4-minute maximal test on three separate occasions. The first of which was a familiarization trial to minimize any potential learning influence on the subsequent tests conducted pre- and post-supplementation (Hopkins, 2000). Cyclists completed the 4-minute test on a modified, air-braked, front access cycle ergometer (Repco Cycle Company, Canberra, Australia). The cycle ergometer was connected to a custom-made power evaluation system (PES Version 2.0, School of Human Life Sciences, Launceston, Australia) that allowed for the measurement of average power (W) over the four minutes. A 4-minute time-trial has been shown to have low coefficient of variation demonstrated by a strong intraclass retest correlation ($r = .98$, 95% CL: 0.92–0.99; Nimmerichter, Williams, Bachl, & Eston, 2010). It has also been strongly associated with maximal aerobic power ($p < .001$) and as such considered a suitable measure of cycling performance (Nimmerichter et al., 2010).

Dynamic calibration of the air-braked cycle ergometer was conducted before the study via the use of a previously described protocol (Maxwell et al., 1998). Heart rate was measured continuously and respiratory variables were measured and recorded at 30s intervals. Cyclists were instructed to perform maximally throughout the 4-minute test and constant strong verbal encouragement was given.

**High-Intensity Interval Training**

The inclusion of the HIT sessions was done to limit the likelihood that some of the athletes might adopt more sprint-type training in their current regimes to prepare for the second performance test, thereby reducing the potential between cyclist variability due to training. The training session comprised of 8 × 2.5 min intervals at an intensity that approximated 90% VO_{2max}, interspersed with 3-minute recovery periods, during which cyclists exercised at approximately 40% VO_{2max}. Heart rate, power output, and RPE values corresponding to ~90 and 40% VO_{2max} were provided to the cyclists for the prescription of the intervals. Cyclists were asked to keep a record of all training sessions completed during the 4-week supplementation period, noting the activity, duration, and RPE. The RPE was measured using the category ratio (CR10) Borg scale (Borg, 1982) and multiplied by duration of each training session in minutes to provide a session-load RPE (Foster et al., 2001).

**Isokinetic Performance Test**

Isokinetic testing was performed on a Cybex 340: Extremity testing and rehabilitation system (Stoughton MA, USA), calibrated to the manufacturer’s guidelines before all trials. Cyclists were placed in an upright-seated position and fastened to the seat via shoulder, pelvic and thigh straps to reduce contribution of irrelevant body movements and positioned according to Newman and colleagues (Newman, Tarpenning, & Marino, 2004). After the standardized warm-up as mentioned previously, the athletes completed ten submaximal reciprocal concentric extension/flexion repetitions with cyclists instructed to slowly increase intensity until approaching a maximum effort, followed by a 1-minute passive recovery before the performance test. During this period, cyclists were instructed to attempt maximal force from the first repetition. The isokinetic test consisted of 30 reciprocal maximal knee extension/flexion contractions at a fixed angular velocity of 180°·s^{-1}. The test velocity of 180°·s^{-1} was used due to comparative literature finding 180°·s^{-1} is attained relatively early in the range of motion, hence acceleration time, which doesn’t contribute to measurable total work, is limited (Scibelli, Brown, Whitehurst, Bryant, & Buchalter, 1993). The pre- and post-supplementation performance trials were performed at the same time of day (±2h) to control for circadian rhythm. The performance variables measured were average power/repetition (W), total work done (J) peak torque (N·m^{1}) and fatigue index (%). Fatigue
index (%) was calculated via deducting the minimum power output from the maximum to find the change, then dividing the change by the maximum power output and multiplying by 100. Feedback concerning the number of repetitions completed was given at 10, 15, 20, 25, and the last repetition.

**Blood Sampling and Analysis**

Preceding the warm-up and directly after isokinetic testing, 80μL of blood was taken from the fingertip into a preheparinized capillary tube and analyzed for pH (H⁺), lactate (La⁻) and bicarbonate (HCO₃⁻) concentrations using a calibrated handheld i-STAT blood-gas analyzer (i-STAT, Princeton, USA). The analyzer was calibrated before each test with known controls and according to manufacturer’s recommendations. The reliability of the i-STAT blood-gas analyzer has been described previously with strong intraclass correlation coefficients observed (0.77–0.95) over a range of blood variables during rest and exercise (Dascombe, Reaburn, Sirotic, & Coutts, 2007).

**Statistical Analysis**

Changes in performance variables were determined via the change in test scores pre- to post-supplementation for each participant. Independent t tests were used to compare differences in change score between beta-alanine and placebo supplemented groups. The absolute difference between groups (effect statistic) was used to assess magnitudes of effects and provide the likelihood of the true effects being practically beneficial, trivial, and harmful by dividing the changes by the appropriate between-participant deviation (Hopkins, 2000). Independent t-tests were used to compare any differences between the two groups in training volume/intensity during the 28-day supplementation period. Values are presented as means ± SD unless otherwise stated and significance was assumed at p < .05.

**Results**

The between group difference for the absolute increase in 4-min cycling average power was not statistically significantly (p = .25; Table 1). Supplementation with beta-alanine was 44% likely to improve cycling performance, with a 1% likelihood of a harmful effect. Beta-alanine supplementation significantly improved average power/repetition following supplementation when compared with placebo (p = .04; Figure 1). Supplementation also significantly reduced fatigue index compared with placebo (p = .03), however no significant difference was observed for peak torque (p = .76; Table 2). Total work done (TWD) was 89% likely to be improved following beta-alanine supplementation, however this was not statistically significant (p = .09). The isokinetic knee extensor performance variables and associated magnitude-

| Table 1  Four-Minute Cycling Time-Trial Average Power (W) Pre and Post Supplementation. The Magnitude-Based Inferences Predict the Percentage Chance or Likelihood That the True Effect of the Intervention (e.g. Beta-Alanine Supplementation) will be Positive, trivial, or Negative When Compared with the Placebo |
|-------------------|-----------------|---|-----------------|-----------------|-----------------|-----------------|
| Beta-Alanine | Placebo | Magnitude-Based Inferences |
| Pre | Post | Δ | Pre | Post | Δ | p | Positive | Trivial | Negative |
| 394 ± 43 | 401 ± 43 | 6.5 ± 7.3 | 421 ± 48 | 422 ± 47 | 1.2 ± 9.7 | 0.25 | 44% | 55% | 1% |

Note. Performance variables presented as mean ± SD
based inferences are reported in Table 2. There were no significant differences in the change in blood variables between groups pre- to postsupplementation (Table 3).

There were no significant differences in the training intensity and load between the groups during the 28 day supplementation period: RPE (beta-alanine: 6.8 ± 0.55, placebo: 6.8 ± 0.76, p = .97), average training hours per week (beta-alanine: 12.1 ± 2.2h, placebo: 12.8 ± 2.3h, p = .55), and total amount of training performed as identified by the session-RPE method (beta-alanine: 19759 ± 4386, placebo: 20998 ± 5257, p = .63) were not significantly different.

Of the eight cyclists supplementing with beta-alanine, two reported side effects indicative of paraesthesia (also known as flushing, causing uncomfortable sharp tingling sensations).

**Discussion**

The primary findings of the current study were that in highly trained cyclists, four weeks of beta-alanine supplementation resulted in worthwhile changes in time-trial performance and short-duration muscular force. Supplementation with beta-alanine increased average power during a four minute cycling time-trial by 1.7%. In addition, knee extension dynamic power output improved by 3.2%.

In trained athletes beta-alanine supplementation has been associated with improvements in isokinetic performance, (Derave et al., 2007) while in active, healthy students no improvement additional to training alone has been reported (Kendrick et al., 2008). In the current study average power output and fatigue index over 30 maximal isokinetic repetitions were significantly improved following four weeks of beta-alanine supplementation. Derave and colleagues (Derave et al., 2007) reported an increase in isokinetic average knee extension peak torque during the fourth and fifth sets of a 5 × 30 contraction protocol at 180°·s⁻¹ in track and field athletes following a similar supplementation protocol to the current study that elevated muscle carnosine content. The athletes in both the placebo and beta-alanine group improved average peak torque in the first and second sets of the isokinetic knee extension test protocol postsupplementation (Derave et al., 2007) which may have been due to the fact that athletes were preparing for the competition season during the course of the study. In addition, the beta-alanine group also significantly increased power in the remaining sets. The current study showed a performance enhancing effect of beta-alanine during a single bout of 30 contractions at 180°·s⁻¹, while there was no significant improvement in the placebo group. The lack of improvement in the placebo group in the current study is testament to the cyclists’ training status given four weeks of HIT did not improve isokinetic power output or four minute cycling performance.

Knee extension peak torque was not significantly improved following b-alanine supplementation. This find-

**Table 2** Knee Extension Performance Measures During 30 Isokinetic Contractions Pre and Post Supplementation. The Magnitude-Based Inferences Predict the Percentage Chance or Likelihood that the True Effect of the Intervention (e.g. Beta-Alanine Supplementation) will be Positive, Trivial, or Negative When Compared with the Placebo Condition

<table>
<thead>
<tr>
<th>Knee Extension</th>
<th>Beta-Alanine</th>
<th>Placebo</th>
<th>Magnitude-Based Inferences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Δ Pre to Post (90% CI)</td>
<td>Δ Pre to Post (90% CI)</td>
<td>p</td>
</tr>
<tr>
<td>Average Power/Rep (W)</td>
<td>6.8 (0.1-13.4)</td>
<td>−4.3 (−10.6–2.1)</td>
<td>.04*</td>
</tr>
<tr>
<td>Peak Torque (N·m⁻¹)</td>
<td>4.0 (1.5-6.5)</td>
<td>3.0 (−0.9–6.9)</td>
<td>.76</td>
</tr>
<tr>
<td>Fatigue Index (%)</td>
<td>2.0 (−5.0–2.2)</td>
<td>13.7 (1.3–7.0)</td>
<td>.03*</td>
</tr>
<tr>
<td>Work Done (N·m⁻¹)</td>
<td>183 (−8-375)</td>
<td>−104 (−341–133)</td>
<td>.09</td>
</tr>
</tbody>
</table>

*Note. Performance variables presented as mean ± SD. Pre: week before supplementation; Post: after 4 weeks of supplementation. Significance was set at p < .05.

*Significant difference in the change from pre- to postsupplementation for beta-alanine vs. placebo.

**Table 3** Blood Variables Pre- and Postsisokinetic Test Both Pre and Post Beta-Alanine or Placebo Supplementation

<table>
<thead>
<tr>
<th></th>
<th>Beta-alanine</th>
<th>Placebo</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preexercise</td>
<td>Postexercise</td>
<td>Preexercise</td>
</tr>
<tr>
<td>pH</td>
<td>7.44 ± 0.03</td>
<td>7.35 ± 0.03</td>
<td>7.45 ± 0.03</td>
</tr>
<tr>
<td>[La]</td>
<td>1.3 ± 0.5</td>
<td>10.4 ± 2.2</td>
<td>1.5 ± 0.4</td>
</tr>
<tr>
<td>HCO₃</td>
<td>26.7 ± 1.2</td>
<td>18.9 ± 1.2</td>
<td>26.6 ± 1.4</td>
</tr>
</tbody>
</table>

*Note. Blood variables presented as mean ± SD; p value presented for comparison of pre- to post-exercise change, pre- to postsupplementation between groups.
ing is not surprising given that intramuscular carnosine is proposed to reduce perturbations in pH and in turn sustain power output, rather than improve peak power. Although not a beta-alanine supplementation study, Suzuki et al. (Suzuki, Ito, Mukai, Takahashi, & Takamatsu, 2002), reported no correlation between carnosine concentration and peak power in a 30s maximal cycling test but showed a significant correlation between carnosine concentration and mean power ($p < .001$). A reduction in fatigue index experienced by cyclists in the current study suggests that beta-alanine dampened the reduction in power output that is associated with acidosis which would have accounted for the increased mean power/repetition.

While buffering capacity is the primary role ascribed to carnosine there were no significant differences in the change in blood pH, $HCO_3^-$ and $La^-$ concentrations pre- to postsupplementation, despite improvements in isokinetic knee extension performance. Given the fact that the work performed during the performance tests in our study was not fixed, an equivalent degree of acidosis or lactate accumulation with increased work performed as seen in the beta-alanine condition could still be indicative of improved buffering capacity. A possible explanation is that the supposed elevated muscle carnosine content as a result of beta-alanine supplementation was effectively buffering $H^+$ within the muscle cell, limiting its release via the $La^+ / H^+$ cotransporter into the plasma and consequently attenuating the reduction in extracellular buffering mechanisms, namely $HCO_3^-$ (Messonnier, Kristensen, Juel, & Denis, 2007). Previous studies have used both clamped (Baguet, Koppo, Pottier, & Derave, 2010) and unclamped (Bellinger, et al., 2012) exercise protocols that have also measured lactate, pH and bicarbonate have shown little effect of beta-alanine on these blood analytes. Bellinger et al. reported no between group differences after a 4-min cycling time-trial, while Baguet et al. (2010b) reported a small significant reduction in pH change after 6 minutes of constant load cycling above the ventilatory threshold. The differing results of Baguet et al. (2010b) from that of Bellinger et al. (2012) and our study may have been due to the longer exercise duration (6 min), or the lower training status of their participants.

Increasing intramuscular buffering capacity enables the muscle to produce more $La^-$ and $H^+$ before levels potentially become deleterious to muscle function, thereby enhancing the production and maintenance of force (Sahlin & Henriksson, 1984). Alternatively, as several physiological roles have been ascribed to carnosine, explanations for the ergogenic response other than increased buffering capacity are plausible. Increased carnosine concentration has been found to aid excitation-contraction coupling in skeletal muscle via increasing calcium sensitivity of the contractile apparatus thereby increasing force production (Dutka & Lamb, 2004). However, this finding is equivocal at best as the physiological mechanism for how this may occur is still unclear. The antioxidative potential and vasodilatory actions of carnosine have also been proposed to be ergogenic (Ririe et al., 2000), although as mentioned previously, evidence to support these potential ergogenic mechanisms in vivo is limited to date.

Skeletal muscle carnosine content was not measured in the current study which is recognized as a limitation. However, it is reasonable to assume from previous studies using a similar dosing protocol that have shown increases in muscle carnosine (Derave et al., 2007; Harris et al., 2006; Kendrick et al., 2009) that four weeks of beta-alanine supplementation in the current study most likely increased carnosine content in both Type I and Type II muscle fibers.

Average power output was 44% likely to increase during the four-minute cycling time-trial following supplementation when compared with the placebo, although this was not statistically significant ($p = .25$). To date there is a limited although growing body of research investigating supplementation in highly trained populations. In elite rowers, elevation of muscle carnosine due to beta-alanine supplementation had significant positive correlation with improvement in 2,000-m rowing performance ($p = .042, r = .498$; Baguet et al., 2010a). In support of this, 28 days of beta-alanine supplementation was associated with a mean improvement in 2,000-m rowing performance of 1.8 s (49% likely to be beneficial) in nationally competitive rowers (Ducker et al., 2013) and 2.9 s (96% likely to be beneficial) in club level rowers (Hobson et al., 2013), suggesting greater ergogenic potential in nonelite athletes.

In highly-trained cyclists, beta-alanine has a significant effect on mean 30s sprint power following 110min simulated cycle racing, but no benefit on 10min time-trial performance following the simulated cycle race (effect size 0.74 and 0.44, respectively; Van Thienen et al., 2009). Furthermore, supplementation did not significantly improve 4min cycling performance in highly trained cyclists; however, there was a small meaningful improvement in performance (Bellinger et al., 2012). In trained swimmers, two recent studies have presented conflicting findings with one showing beta-alanine supplementation significantly improved 200-m swimming performance ($p = .01$; Coelho et al. 2012; abstract only) while the other found that it had a minimal effect on swim times in a nonlaboratory controlled, real-world training and competition setting (Chung et al. 2012). It is apparent from the findings of these studies that have employed varied dosing regimens and exercise modes that the influence of beta-alanine on performance in highly trained populations is equivocal. The effect of b-alanine on exercise performance in untrained to moderately-trained individuals is larger than that in trained populations (Hobson, Saunders, Ball, Harris, & Sale, 2012); however, the current study shows supplementation in trained cyclists provides significant improvements in isokinetic knee extension performance and a meaningful improvement in four minute cycling performance.

Oral b-alanine doses larger than 800mg commonly result in unpleasant sensory symptoms (paraesthesia; Harris, et al., 2006) and there is evidence that delivering the supplement in smaller, more frequent doses, or as a slow release form, improves whole body retention and
is associated with sensory side-effects that cannot be differentiated from a placebo (Décombaz, Beaumont, Vuichoud, Bouisset, & Stellingwerff, 2012). While we attempted to enhance the blinding process and avoid side effects by delivering a beta-alanine dose specific to each individual’s body mass in four daily doses we recognize that a potential limitation of the current study is that two of the eight participants supplementing with beta-alanine reported mild symptoms of paraesthesia. The findings of the analysis were significant when carried out both with and without these two individuals ($\rho < .05$) suggesting that there was no impact of the potential reduced blinding on the results. Consequently, the authors did not feel that their inclusion compromised the studies’ blindings and conclusions and their data remained in the analysis.

In the current study there was a 1.7% increase in power output after beta-alanine supplementation during a 4-minute maximum effort on a cycle ergometer. According to Hopkins (Hopkins, 2004), a 1% change in endurance power output measured on an ergometer is equivalent to ~0.4% improvement in road-cycling time-trial time. Utilizing the current world record for the 4,000-m individual men’s track cycling pursuit of 4:10.5 s, this would equate to a 1.7 s reduction in time. At the highest level of competition even small improvements in performance can be the difference between success and failure, thus any legal training and/or nutritional strategies which may optimize performance should be explored. Future research should further investigate the mechanism for performance improvements and potential additive benefits of combining beta-alanine with a combination of other supplements. In addition, further research should be conducted into potential measures of performance such as the isokinetic test in the current study, which are less stressful for athletes than traditional maximal exercise testing and hence may be conducted on a more regular basis to monitor changes in sporting performance.

**Conclusion**

This study illustrates that 4 weeks of beta-alanine supplementation resulted in worthwhile changes in time-trial performance and short-duration muscular force production in highly trained cyclists.

**Acknowledgments**

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**References**


