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ORIGINAL ARTICLE

Incremental effects of 28 days of beta-alanine supplementation on high-intensity cycling performance and blood lactate in masters female cyclists

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Abstract Within the aging population, there exists a subset of individuals termed masters athletes (MA). As masters-level competition increases in popularity, MA must find methods to enhance individual athletic performance. Longitudinal beta-alanine (BA) supplementation is suggested to enhance physical capability during exercise; however, these effects have not been evaluated in MA. To examine the longitudinal effects of BA on time to exhaustion (TTE), total work completed (TWC), and lactate clearance in female MA cyclists. Twenty-two female MA (age = 53.3 ± 1.0) participated in this double-blind design. Subjects were randomly assigned to BA ($n = 11$; 800 mg BA + 8 g dextrose) or placebo (PLA; $n = 11$; 8 g dextrose) groups and supplemented 4 doses/day over 28 days. Every 7 days, subjects completed a cycling TTE at 120 % VO_{2max}, and TWC was calculated. Blood lactate was measured at baseline, immediate post, and 20-min post each TTE. No significant differences existed between groups for any variable at baseline ($p > 0.05$). After 28 days supplementation, BA had greater TTE (23 vs 1 % change) and TWC (21 vs 2 % change) than PLA ($p < 0.05$). Following the 20-min TTE recovery, lactate was 24 % lower in BA compared to PLA (4.35 vs. 5.76 mmol/L, respectively). No differences existed for variables during intermittent weeks. 28 days of BA supplementation increased cycling performance via an enhanced time to exhaustion and total work completed with associated lactate clearance during passive rest in female MA.

Keywords Ergogenic aid · Exercise · Women · Sport nutrition · Carnosine

Introduction

Older adults can gain extensive health benefits from regular physical activity; however, certain populations of aging adults, termed masters athletes (MA), are not simply content with maintaining physical health and strive for high levels of achievement (Hodge et al. 2008). In fact, many of these individuals undergo rigorous training regimens in order to compete in local and internationally organized athletic events (Rosenbloom and Bahns 2006). When referring to MA competition, the inaugural United States National Senior Games included 2500 athletes, but this number has since increased over 450 % to more than 12,000 participants in 2013 (National Senior Games Association 2013). As the number of MA continues to increase, so does the degree of competition (Tanaka and Seals 2008) requiring these individuals to continually find methods to further increase performance.

The use of ergogenic aids is becoming increasingly popular among MA (Kavanagh and Shephard 1977; Striegel et al. 2005); however, to date, there are no data indicating

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their individual effectiveness on masters-level athletic performance. One particular supplement increasing in popularity as an ergogenic aid is beta-alanine (BA), which is suggested to be effective for increasing high-intensity exercise performance (Derave et al. 2007; Hill et al. 2007). BA is a non-essential amino acid physiologically functioning as the precursor to carnosine (Culbertson et al. 2010; Smith et al. 2009), which increases the buffering capacity of H^+ (Derave et al. 2010; Eudy et al. 2013; Sale et al. 2010). This increased buffering capacity delays fatigue, ultimately resulting in enhanced exercise performance and more specifically increased power output (Hobson et al. 2012; Kern and Robinson 2011).

Baseline levels of intramuscular carnosine vary amongst specific populations, indicating certain individuals may experience enhanced effects from exogenous BA supplementation. When comparing intramuscular carnosine levels between males and females, a 3.5–1.0 ratio is observed, respectively, (Everaert et al. 2011) and females require lower levels of BA supplementation to obtain the same relative carnosine increases compared to males (Stegen et al. 2014). In females, 28 days of BA supplementation is documented to increase time to exhaustion (TTE; Stout et al. 2006b) and decrease feelings of perceived exertion (Smith et al. 2012); however, these findings have only been evaluated in younger women and cannot be extrapolated to older, female populations.

Independent of gender, carnosine levels also decrease with age (Everaert et al. 2011). Taken together with the fact that carnosine loading is further augmented in trained muscles (Bex et al. 2014), this indicates trained, older individuals (i.e., MA) may be more sensitive to BA supplementation. Currently, the only data evaluating BA supplementation in older adults have been collected in untrained (albeit healthy) individuals, and evaluated measures of functional fitness (del Favero et al. 2012; McCormack et al. 2013; Stout et al. 2008); however, MA are more concerned with increasing athletic performance as opposed to maintaining general functional fitness. As a result, when evaluating BA supplementation, it is important to extend the body of knowledge to include the effects on performance measures in this population.

At least 28 days of BA supplementation is documented to increase high-intensity exercise performance in younger males (Hoffman et al. 2008) and females (Smith et al. 2012), along with untrained older adults (del Favero et al. 2012; McCormack et al. 2013; Stout et al. 2008). With regard to carnosine increases, trained muscle responds more efficiently to BA supplementation (Bex et al. 2014) and females experience greater relative increases compared to males (Stegen et al. 2014). Combined with the fact that carnosine levels naturally decrease with advancing age (Everaert et al. 2011), trained, master-level females may have an unparalleled physiological advantage when it comes to the benefits from exogenous BA supplementation and positive results may be observed sooner than the traditional 28-day loading period (Stout et al. 2006b). Therefore, the purpose of this study was to examine the longitudinal effects of BA supplementation on TTE, total work completed (TWC), and post-exercise lactate clearance rates in female MA cyclists.

Materials and methods

Subjects

Based on previous literature, 22 subjects (11 per group) are appropriate to attain a minimal statistical power of at least 0.80 (Stout et al. 2006b). All subjects were female MA cyclists from the Midwestern United States. MA were classified as competitive masters cyclists based on requirements set forth by USA Cycling and World Masters Cycling. These requirements necessitated that MA were (a) $\geq$30 years old, (b) not classified as an elite cyclist or competitors in an elite event based on Union Cycliste Internationale (UCI) standards, and (c) not previously a team member of a registered team disciplined by the UCI. For the purposes of this study, MA must also have had at least 2-year competitive cycling experience and cycle a minimum of 3 days per week (Halson et al. 2002). Since carnosine levels significantly decrease by 47 years (Everaert et al. 2011), this was used as the age cutoff for our subjects. Participants were recruited via email, flyers, and visits to local cycling clubs and organizations. Informed consent was obtained from all participants included in the study. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Experimental design

This double blind, randomized study consisted of a 28-day supplement intervention using BA as the experimental group and dextrose as the placebo (PLA) group. Each participant reported to the Human Performance Laboratory on the University campus for all visits. Participants completed baseline testing on two separate days. Day one consisted of signing an informed consent and completion of a health history questionnaire to ensure all participants met inclusion criteria. Height and mass measurements were assessed using a stadiometer and weight beam eye-level scale, respectively (Detecto, Webb City, MO). Body fat, lean mass analysis (dual-energy X-ray absorptiometry; DXA),

and determination of aerobic capacity (VO_{2peak}) were also assessed on the initial visit. Day two consisted of the baseline TTE where subjects cycled at 120 % of their initial VO_{2peak} values. During the supplementation period, participants ingested the assigned supplementation (PLA = 8 g dextrose; BA = 800 mg + 8 g dextrose) 4 times per day throughout the 28-day intervention. During the 28-day intervention, TTE was re-evaluated at 7-, 14-, 21-, and 28-day intervals before reassessment of VO_{2peak} and DXA measurements post-supplementation. Testing protocols were completed in the same order for all participants and at least 24 h were allotted between the VO_{2peak} and TTE sessions at baseline and 28-day time points.

To ensure, changes during each testing trial were not based on training or detraining effects, participants completed exercise logs at baseline and were instructed to maintain the same training intensity throughout the study. At the completion of the investigation, each subject confirmed maintenance of consistent exercise patterns similar to baseline. Pre- and post-VO_{2peak} measures were also compared to ensure maintenance of training status. Food logs were analyzed via diet analysis software (Nutritionist Pro, Redmond WA) and distributed to all participants at baseline, 2 week, and final testing intervals to be completed on two non-consecutive weekdays and one weekend day (Smith et al. 2009). To account for dietary consumption on testing days, participants fasted 3 h prior to each trial (Stout et al. 2006b). All participants had never ingested supplementary BA and were instructed to refrain from vigorous exercise, alcohol, and caffeine 24 h preceding each trial. Subjects wore the same attire for all trials and wore clothes/shoes in which they normally cycled.

Supplementation protocol

After the familiarization trial, subjects were randomly assigned to either the PLA or BA groups. The BA provided for this investigation was 3rd party lab tested for supplement purity and authenticity (Powder City, York, PA). To maintain a double-blind design, a separate investigator completed subject supplement assignments. Conditions included PLA [8 g dextrose (NOW Foods, Bloomingdale IL) per dose] or BA (800 mg BA + 8 g dextrose per dose) and subjects consumed their respective supplement doses four times per day. Individual doses of 800 mg BA were used to circumvent the potential onset of paresthesia occurring (Kendrick et al. 2008, 2009). Any subject experiencing supplement-related side effects throughout the study was documented appropriately as to not affect final analyses. Participants were instructed to consume supplement doses in 16 oz of water (Stout et al. 2006a).

Aerobic capacity testing protocol (VO_{2peak})

At the initial and final testing trials, all participants performed a graded exercise test (GXT) on a Velotron Dynafit Pro cycle electronically braked cycle ergometer (Racer Mate, Seattle, WA) to determine VO_{2peak}. Prior to testing, seat and handlebar preferences were established for each individual and recorded for use in all future testing sessions. Subjects warmed-up at 50 W for 5 min at a self-selected cadence. Upon completion of the warm-up, the resistance increased 25 W in 2 min intervals until the participant could no longer maintain 60 revolutions per minute (RPM). VO_{2peak} was measured using breath-by-breath analysis and analyzed via open-circuit spirometry (PARVO Medics, Sandy, UT). The highest 15 s VO_{2peak} value recorded was used as the peak measurement provided it met at least two of the following criteria: (a) a plateau in heart rate or heart rate is within 10 % of the age-predicted maximum, (b) a plateau in VO_{2peak} (an increase of no more than 150 mL min^{-1}), and/or (c) an RER value >1.15 (Smith et al. 2009). Test retest reliability (ICC = 0.98) and coefficient of variation (5.18 %) for this protocol have been previously demonstrated (Smith et al. 2009).

Time to exhaustion (TTE), total work completed (TWC), and lactate measurements

TTE trials were completed at baseline, 7, 14, 21, and 28 days of supplementation. Prior to TTE testing, the predetermined seat height and handlebar settings were adjusted for each participant. After completing the same warm-up as used for the GXT, subjects completed a TTE at 120 % of their previously recorded VO_{2peak} (Simmonds et al. 2010; Weber and Schneider 2001). TTE was defined as the amount of time (s) participants could maintain intensity above 40 RPM pedaling cadence (Astorino et al. 2000; Vivodtzev et al. 2011). Reliability and coefficient of variation for TTE protocol have been reported as ICC = 0.71 and 3.8 %, respectively (Smith et al. 2009). Lactate measurements were taken from the fingertip (Tobias et al. 2013) and analyzed immediately at rest, directly after TTE cessation, and after a 20-min seated recovery period (Accutrend Lactate Monitor, Indianapolis, IN). TWC was calculated by multiplying time (s) during the TTE test and the power output (W), divided by 1000 to get the final product in kilojoules (Smith et al. 2009).

Blinding efficacy and side effects

Upon completion of the supplementation intervention, subjects were asked which supplement they believed they had consumed. Subjects were also asked if they experienced

Table 1 Subject demographic data

	PLA	BA	*p* value
Age (years)	53 ± 1	54 ± 2	0.463
Height (cm)	162.33 ± 2.50	163.00 ± 2.08	0.839
Mass (kg)	68.70 ± 5.64	64.01 ± 2.82	0.466
Body fat (%)	32.97 ± 2.70	28.05 ± 3.88	0.309
Time cycling (year)	5.86 ± 2.20	7.20 ± 2.12	0.667
Distance cycled/week (km)	135.18 ± 7.88	144.76 ± 15.03	0.579

All data are expressed as mean ± se

No differences existed between groups for any variables. Significance level was set at $\alpha < 0.05$

BA beta-alanine, *PLA* placebo

any side effects throughout the course of the study related to the supplement ingested.

Statistical analyses

Statistical Analysis System (SAS) version 9.4 (Cary, IN) was used to analyze all data. Repeated measure analysis of variance (ANOVA) was used to evaluate food logs at the pre-, mid-, and post-time points. *T* tests evaluated initial TTE, TWC, and lactate values between groups to ensure no significant differences existed at baseline. To assess the effects of supplementation on TTE, TWC, and lactate levels between groups, investigators utilized a 2 (group) × 5 (time; baseline, 7, 14, 21, and 28 days) between-within repeated measures ANOVA for each variable. Additionally, separate 2 (group) × 3 (time; pre, immediately post, and 20 min post) repeated measures ANOVA was used to examine any differences in lactate levels between groups within each week's trial. An alpha level of $p < 0.05$ defined significance for the repeated measures model. For statistically significant *F* scores, simple main effects were analyzed with one-way factorial ANOVAs for each time point. Fisher's exact test evaluated the subject's ability to determine supplement ingestion throughout the study. All data are reported as mean ± se.

Results

There were no initial significant differences ($p > 0.05$) between groups for demographic variables (Table 1) or aerobic capacity (i.e., VO_{2peak}; Table 2). Similar values for aerobic capacity from pre- to post-testing also confirmed that the subjects were performing at 120 % of VO_{2peak} for each TTE evaluation. When examining weekly dietary logs between BA and PLA, no significant differences were observed for overall total kilocalorie intake or individual macronutrient (carbohydrate, fat, protein) breakdowns within or between groups at the pre-, mid-, or post-time points (Table 3).

Time to exhaustion

No initial significant differences existed between groups at the pre-testing time point ($F = 2.30$, $p = 0.15$). Repeated measures ANOVA revealed a significant interaction between groups throughout the 28-day intervention ($p = 0.002$). Follow-up univariate analysis indicated that by the 28th day, BA significantly ($F = 5.71$, $p = 0.03$) increased TTE (23 %) compared to PLA (1 %) when compared to baseline values; however, no differences were observed during any of the intermittent weeks (Fig. 1a).

Total work completed

Similar results were observed for TWC ($p = 0.001$) in reference to performance increases (Fig. 1b). No initial significant differences were observed between groups ($F = 0.22$, $p = 0.65$) and BA did not elicit increases in TWC before 28 days. However, at the 28th day, TWC was significantly greater ($F = 5.65$, $p = 0.03$) in BA compared to PLA (21 vs. 2 %, respectively) when compared to baseline values.

Lactate

No significant differences existed between groups for blood lactate levels at the rest, immediate post, or 20-min rest intervals at pre-testing (all $p > 0.05$). Repeated measures ANOVA revealed lactate measures taken at rest ($p = 0.96$) and immediately after completion of the TTE test ($p = 0.13$) were not significantly different between BA and PLA over the course of the intervention. However, a significant group by time interaction ($p = 0.01$) was observed between groups for lactate levels after the 20-min rest interval (Fig. 2). Univariate analyses indicated that lactate was 24 % lower ($F = 4.70$, $p = 0.04$) for BA when compared to PLA by the 28th day (4.35 vs. 5.76 mmol/L, respectively), although there was a trend for significance by the 21st day ($F = 4.12$, $p = 0.056$).

Blinding efficacy and side effects

Fisher's exact test indicated the subjects were unable to accurately assess which supplement they had consumed based on a 2 (supplement guess) × 2 (accuracy) analysis ($p = 0.31$). Accurate guesses for the BA and PLA groups were recorded as 23 and 32 %, respectively. Only one subject reported feelings of paresthesia throughout the course of the intervention. All analyses were run without and with the subject experiencing side effects during the trials. No

Table 2 Aerobic capacity between groups

	Pre		*p* value	Post		*p* value
	BA	PLA		BA	PLA	
VO_{2PEAK} (L/min)	2.28 ± 0.65	2.31 ± 0.49	0.903	2.45 ± 0.45	2.28 ± 0.47	0.411
VO_{2PEAK} (mL/kg/min)	39.13 ± 8.46	36.51 ± 8.27	0.472	39.82 ± 8.88	36.15 ± 7.84	0.316
Metabolic equivalent of task	10.69 ± 2.54	10.44 ± 2.36	0.810	11.33 ± 2.44	10.31 ± 2.25	0.321

All data are expressed as mean ± se

No significant differences were observed over time between or within groups from the initial to post-testing trials. Significance level was set at $\alpha < 0.05$

BA beta-alanine, *PLA* placebo

Table 3 Dietary intake values between supplementation groups

	BA	PLA
PRE		
Total kilocalories	1802.10 ± 508.05	2189.71 ± 477.38
Carbohydrates (g)	182.82 ± 61.78	249.30 ± 68.30
Fats (g)	69.38 ± 22.17	79.96 ± 24.58
Protein (g)	90.15 ± 26.60	96.96 ± 27.09
MID		
Total kilocalories	1752.11 ± 344.96	1889.01 ± 532.35
Carbohydrates (g)	175.70 ± 57.15	224.19 ± 93.20
Fats (g)	75.41 ± 22.71	66.78 ± 23.97
Protein (g)	87.96 ± 25.34	85.59 ± 18.37
POST		
Total kilocalories	1770.83 ± 549.49	1897.91 ± 617.02
Carbohydrates (g)	187.20 ± 58.91	227.81 ± 89.80
Fats (g)	69.08 ± 23.88	68.66 ± 31.05
Protein (g)	100.31 ± 28.52	88.52 ± 27.12

All data are expressed as mean ± se

No differences were observed for dietary intake between groups or over time. Significance level was set at $\alpha < 0.05$

BA beta-alanine, *PLA* placebo, *PRE* pre-testing, *MID* 2 week time point, *POST* 4 week time point

changes were detected for any of the analyses and as a result, the subject was included in the final statistical models. One subject was forced to drop out due to repeated headaches, which she believed was related to the supplement she was ingesting. At the completion of the study, it was established that she was in the PLA group and her data have not been included in the final analyses.

Discussion

These are the first data evaluating the efficacy of BA supplementation on exercise performance in MA, independent of gender. The purpose of this study was to examine the longitudinal effects of BA supplementation on TTE, TWC, and post-exercise lactate clearance rates in female MA cyclists. Overall results support previous literature suggesting that BA significantly increases performance during exercise lasting 60–240 s (Hobson et al. 2012). This is comparable to recent data demonstrating increases in cycling TWC in college-aged men after high-intensity training combined with BA supplementation (Smith et al. 2009). Similar positive results have been observed in females for submaximal cycling performance and TTE after 28-day supplementation periods (Stout et al. 2006b). However, these results were obtained in untrained younger subjects and it is important to understand if these effects are present among MA.

Exercise performance

The use of BA to increase intramuscular carnosine plays an important role during exercise (Sale et al. 2010) and as exercise intensity increases, carnosine becomes an integral component for improving performance (Hobson et al. 2012). Baseline levels of intramuscular carnosine vary between males and females (Everaert et al. 2011) and compared to males, females require lower levels of BA supplementation to obtain similar relative carnosine increases (Stegen et al. 2014). Taken together with the fact that carnosine loading is further augmented in trained muscles (Bex et al. 2014), trained females may be more sensitive to BA supplementation in reference to increasing intramuscular carnosine concentrations. Results from this investigation support this concept as female MA significantly increased TTE (23 %) and TWC (21 %) during cycling after 28 days of BA supplementation compared to age-matched controls. Previous literature has evaluated the effects of BA supplementation on cycling performance in males (Hill et al. 2007; Smith et al. 2009). Initial work concluded that exogenous ingestion of BA increased TWC 13 % after 4 weeks of supplementation and an additional 3 % increase after another 6 weeks (Hill et al. 2007). These performance increases were suggested to be the result of increased concentrations of the dipeptide carnosine at each time point

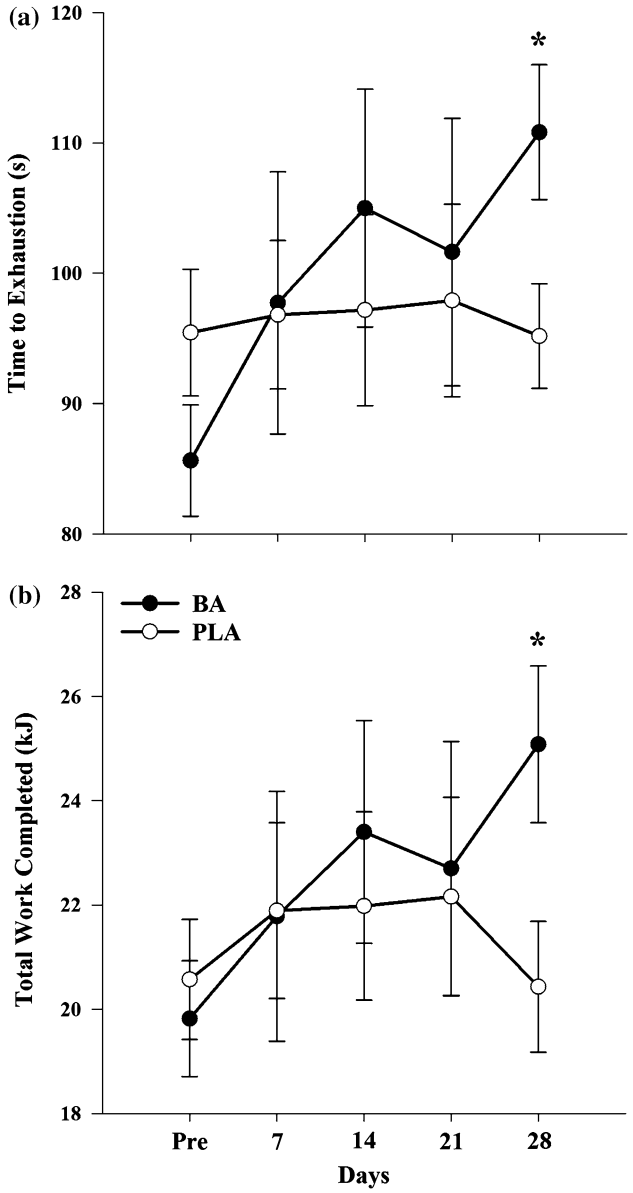

Fig. 1 **a** Time to exhaustion and **b** total work completed between beta-alanine (*BA*) and placebo (*PLA*) groups after 28 days of supplementation. *Asterisk* indicates a significant difference between BA and PLA ($p < 0.05$)

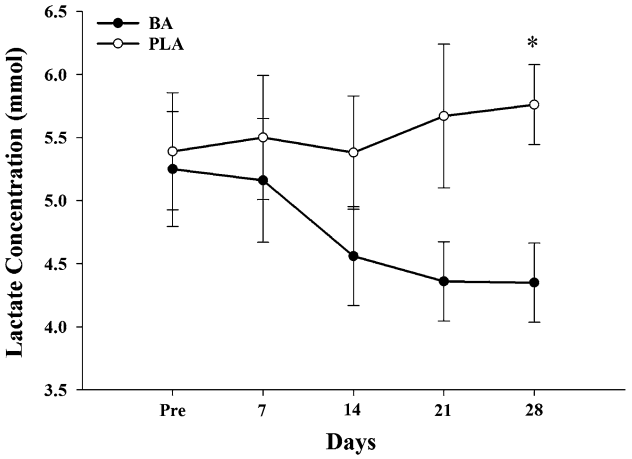

Fig. 2 Lactate rates 20 min after completion of time to exhaustion evaluation between beta-alanine (*BA*) and placebo (*PLA*) groups after 28 days of supplementation. *Asterisk* indicates a significant difference between BA and PLA ($p < 0.05$)

(59 and 80 % increases, respectively). More recently, Smith et al. (2009) evaluated the use of BA to increase cycling performance with similar findings. VO_{2peak}, TTE, and TWC all significantly increased after longitudinal supplementation, potentially due to the increased buffering capacity from increased carnosine concentrations. However, it is important to note that the results from Hill et al. (2007) and Smith et al. (2009) were collected only in younger, male subjects.

Cycling performance data involving females have suggested similar results as compared to males. After 28 days of BA supplementation, significant increases were observed for working capacity at the onset of fatigue (14 %), ventilatory threshold (13 %), and TTE (3 %) compared to subjects supplementing with a placebo (Stout et al. 2006a). Although the dipeptide was not measured directly, these results were suggested to be from increased carnosine concentrations, ultimately resulting in an enhanced buffering capacity. The increases in TTE and TWC in the current investigation are markedly higher compared to previous literature involving younger females and may be an indication that older, athletic females present an ideal population to benefit from longitudinal BA supplementation. However, it must be noted that this study utilized a TTE evaluation at 120 % of the subject's VO_{2peak}, while earlier studies used either the time exercised during a GXT (Stout et al. 2006a) or an intensity of 110 % VO_{2peak} (Smith et al. 2009). Therefore, it cannot necessarily be ascertained whether these elevated increases in TTE and TWC are a direct reflection of the population tested or if the type of evaluation also had an effect on performance outcomes. Further research needs to be conducted in female MA to determine overall efficacy of BA supplementation for athletic improvements in comparison to trained and untrained, younger female populations.

Lactate accumulation and clearance

Although in the current investigation BA supplementation increased various indices related to exercise performance in female MA cyclists, this was independent from changes in peak lactate accumulation immediately after TTE completion. Previous literature evaluating peak lactate accumulation are equivocal. Although numerous studies indicate BA has no effect on peak lactate accumulation (Baguet et al. 2010; Kern and Robinson 2011; Van Thienen et al. 2009),

other investigations have proposed otherwise (Ghiasvand et al. 2012; Tobias et al. 2013). However, regardless of peak lactate accumulation, it is important to note these investigations did not measure the effects on lactate clearance during recovery.

When investigating lactate clearance, studies involving BA supplementation have measured blood lactate up to 5 min after completion of high-intensity exercise (Sale et al. 2011; Tobias et al. 2013). Although Sale et al. (2011) observed no significant differences in lactate clearance when compared to subjects consuming a placebo, Tobias et al. (2013) determined that BA supplementation resulted in reduced levels of lactate clearance after 28 days of supplementation. As it can take an hour or more for blood lactate to return to baseline levels (Karlsson 1971), a 5-min recovery measure may not be adequate to determine the efficacy of BA on post-exercise lactate clearance. In the current study, blood lactate was 24 % lower in BA 20 min after completion of TTE compared to PLA. From a practical point of view, these findings translate into attractive implications for athletes during competitive races. During sanctioned competition, cyclists reach higher levels of exertion during elevated climbs or intermittent sprints when pulling a team. Throughout a longer-duration race (e.g., century rides), cyclists may be forced to endure multiple high-intensity bouts which go beyond steady-state exercise (Andez-Garcia et al. 2000; Rodriguez-Marroyo et al. 2009) leading to elevated lactate accumulation (Gladden 2004; Wasserman et al. 1986). As increased carnosine levels lead to increased buffering capacity, this may improve lactate clearance, ultimately leading to improved performance times.

Limitations

The results of this study are based on the premise that performance increases are directly related to increases in intramuscular carnosine concentrations; however, carnosine was not directly measured in this investigation. Several recent studies have indicated significant increases in carnosine concentrations based on at least 28 days of BA supplementation (Hill et al. 2007; Kendrick et al. 2009) and this study utilized dosing strategies previously reported to be sufficient for these increases to occur (Hobson et al. 2012). This indicates the increases in performance are related to elevated intramuscular carnosine levels; however, this cannot be confirmed based on this investigation. Other limitations included the inability to directly control dietary intake and exercise activity. Although subjects reported maintenance of regular training programs and no differences existed between groups for total kilocalorie or macronutrient intakes throughout the study, this is reliant on subject honesty and accurate recordings. Similar VO_{2peak} values pre- and post-supplementation also confirm training status was maintained throughout the study and that the increases in performance were a result of BA supplementation and not training.

Conclusion

These are the first data evaluating the ergogenic effects of BA on performance measures in female MA. The main findings of this study indicate 28 days of BA supplementation increases TTE and TWC in female MA with associated increases in rate of lactate clearance. However, there is much to be clarified as to the ergogenic role BA has on performance in this population. Although female MA have the potential to experience enhanced performance increases from BA supplementation, this needs to be clarified through comparisons to age-matched males and younger female, trained cyclists. Future investigations should directly evaluate carnosine concentrations amongst MA populations, allowing for comparisons to be made from basic and applied perspectives.

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Compliance with ethical standards

Conflict of interest The authors declare they have no conflicts of interest associated with this study.

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