Effects of beta-alanine supplementation on performance and muscle fatigue in athletes and non-athletes of different sports: a systematic review

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Abstract

Background: Beta-alanine (BA) is a non-essential amino acid that can be synthesized in the liver and obtained from diet, particularly from white and red meat. Increased availability of BA via dietary supplement, may improve performance of athletes. The aim of this study was to conduct a review of the use of BA supplementation as an ergogenic aid to improve performance and fatigue resistance in athletes and non-athletes. **Methods:** In this systematic review, a search in PubMed and Bireme databases was performed for the terms "beta-alanine", "beta-alanine and exercise", "carnosine" or "carnosine and exercise" in the titles or abstracts. We included randomized, clinical trials published between 2005 and 2015. **Results**: Twenty-three studies were selected. Most of them included physically active individuals. The mean intervention period was 5.2 ± 1.8 weeks, and mean BA dose was 4.8 ± 1.3g / day. The main outcome measures were blood lactate, pH, perceived exertion, power and physical working capacity at fatigue threshold. After BA supplementation, no statistically significant difference was observed in total work, exercise performance time, oxygen consumption and time to exhaustion. **Conclusion**: BA supplementation seems to improve perceived exertion and biochemical parameters related to muscle fatigue and less evidence was found for improvement in performance.

Keywords: beta-alanine; carnosine; muscle fatigue; athletic performance; oxygen consumption.

Introduction

Dietary supplements have been used as ergogenic aid in an attempt to increase energy, enhance recovery and modulate body composition[1], aiming at meeting energy needs and improving performance[2,3].

Beta-alanine (BA) is a non-essential amino acid that can be synthesized in the liver and obtained from diet, particularly from white meat (poultry and fish) and red meat[4]. Endogenous synthesis of BA derives from degradation of the pyrimidines thymine, cytosine and uracil and its transport to skeletal muscle is sodium- and chloride- dependent[5]. The entry of BA to the cells may be affected by similar structure compounds (glycine, taurine, gamma-aminobutyric acid) that compete for the same transporter[6]. It is in the skeletal muscle that BA plays its most important role, as an intermediate and limiting factor for carnosine synthesis. Carnosine is a dipeptide, responsible for reducing fatigue and buffering muscle acidosis[7,8,9].

The synthesis of carnosine in the skeletal muscle using histidine and BA is ATP-dependent and is catalyzed by carnosine synthase[9]. This process depends on the availability of BA, from the transport of the amino acid into muscle fibers, BA dietary intake, hepatic synthesis and carnosine synthase activity[10]. Carnosine may also be obtained directly from diet, particularly from meat and fish, although its bioavailability is affected by cooking[11]. In the digestive process, carnosine is mostly converted into BA and L-histidine by the enzyme carnosinase found in jejunal mucosa. For this reason, circulating blood levels of carnosine are relatively insignificant[12]. The content of carnosine in the muscle is also influenced by muscle contraction, and increases with muscle tension[13].

Physiologically, increased availability of BA via dietary supplement, combined with training, may improve performance of athletes who perform high-intensity

exercises, by increasing muscle buffering capacity[14-17]. Several doses and evaluation protocols of BA have been tested in different sports, and the timing of supplementation seems to range usually between 4 to 10 weeks and doses are distributed throughout the day, making the effect of BA supplementation on exercise still controversial[9,15,18]. The use of BA as an efficient ergogenic aid cannot be thoroughly recommended due to differences in studied populations, study protocols and BA dosages. Therefore, the aim of this study was to conduct a review of the use of BA supplementation as an ergogenic aid to improve performance and fatigue resistance in athletes and non-athletes.

Methods

This systematic review was performed using a predetermined protocol, which had been stablished according to the Cochrane Handbook recommendations[19]. The results are presented following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA Statement) criteria.

We included clinical trials and randomized clinical trials (RCTs) in English, published in the last 10 years, about the possible effects of BA and carnosine on fatigue and physical performance in humans. The search was conducted using the PubMed and Bireme databases for the terms “beta-alanine”, “beta-alanine and exercise”, “carnosine” or “carnosine and exercise” in the title or abstract from January to May 2015. The outcomes of interest were decrease in muscle fatigue and/or increase in performance; muscle carnosine content was not considered as outcome of interest. Unpublished studies, scientific abstracts (either published or unpublished), dissertations and thesis were not included. We considered, as intervention, the exclusive use of BA or carnosine in at least one of the groups, in order to evaluate their isolated effects. The articles were

analyzed in an independent, blinded fashion, by two of the authors of this manuscript (PBZ and FDA), and disagreements were resolved by a third reviewer (CGS).

Results

In the initial search for the selected terms, 241 articles were identified, and 23 were included in the final review (Figure 1). The results of these articles are summarized in Table I.

The impact factor of the journals in which the articles were published varied from 2.075 to 3.983, 61% of them was higher than 2.4. The articles were published between 2006 and 2014, most of them between 2012 and 2013. The mean sample size was 28.9 ±13.96 individuals, and the mean period of intervention was 5.2 ± 1.8 weeks. The main intervention was BA (mean dose 4.8±1.3g), followed by maltodextrin (12 studies), dextrose (8 studies), rice flour (2 studies) and glucose (1 study). Fifty-two percent of the studies were conducted with athletes, especially cyclists, rowers and football players, and 48% with non-athletes (mostly physically active persons).

For a better understanding of the results, they will be presented by outcome of interest.

Decrease in muscle fatigue

The variables were subdivided into biochemical and subjective variables, as follows:

Blood lactate concentration (HLa) and pH

Sixteen studies investigated blood lactate concentration (HLa) and/or pH[20-35]. Mean age of participants was 23.9±3.4 years, and sample size varied between 14 and 41 subjects. Intervention period varied from 28 days to 10 weeks, and a wide variety of doses were administered, from fixed doses of 2-6.7 g/day to individual doses of 65 mg/kg of body weight. Glucose[30], rice flour[24,28], dextrose[20,27,34] and maltodextrin[21-23,25,26,29,31-33,35] were used as placebo (PL). In three studies[20,25,34], the authors also investigated the effect of BA combined with sodium bicarbonate in comparison with PL.

Among all these studies, significant differences between BA and PL were reported in only 2 studies[29,32], with a decrease in pH and increase in HLa in the group receiving BA. In the first study[29] elevated acidosis (pH around 7.2) was detected at the sixth minute of cycling exercise at an intensity of 50%. Although there was no significant interaction effect between pH absolute values, a significant difference in exercise-induced acidosis was found between BA and PL groups ($p=0.031$). In the BA group, pH decreased 0.015 units as compared with baseline values, whereas in the PL group, a 0.012 unit decrease was observed in the same period. In the other study[32] the authors reported an increase in the lactate/proton concentration ratio following BA supplementation in comparison with placebo.

Subjective assessments of exertion and fatigue

Only three articles conducted subjective assessments of perceived exertion and muscle fatigue[20,21,36]. The number of participants varied from 26 to 40, with mean age of 24.0 ± 2.8 years. The intervention period varied from 3 to 4 weeks; the BA doses from 4.5 to 6.4 g, and the placebos used in these studies were dextrose[20] or maltodextrin[21,36].

In two studies[20,36] BA supplementation achieved significant differences in the outcomes between the study groups. In one of the studies[20] the combination of sodium bicarbonate and BA resulted in lower ratings of perceived exertion after exercise (p=0.05), and this effect was not achieved either by BA or sodium bicarbonate alone. In the second study[36] subjective feeling of fatigue, expressed as mean daily rate, was significantly lower in the BA (3.96 ± 0.80) than PL (4.55 ± 0.83) group. In the third study[21] subjective fatigue was not different between BA and maltodextrin group.

Improvement in performance

Due to their wide variety, the variables used for assessing performance improvement were divided into the following subsections:

Total work done

Five studies calculated the total work done[20,25,34,36,40]. Sample size varied from 14 to 40, with mean age of 26 ± 1.7 years. Intervention period varied between 3 and 4 weeks, and BA doses between 4.5 and 6.4 g. BA effects were compared with those of PL – maltodextrin[25,36] or dextrose[20,34,40]. In none of the studies was there a significantly difference in total work done between the group receiving BA and the group receiving PL.

Power

Eleven studies evaluated the effect of BA supplementation on power[20,24,27,30,33-37,40,41]. The sample size varied from 14 to 55 individuals, with mean age of 24.6 ± 3.5 years. Intervention period varied from 3 to 8 weeks, and the dose of BA from 1.5 to 6.7g. The placebos used in these studies were rice flour[24], glucose[30], maltodextrin[33,35,36]

or dextrose[20,27,34,37,40,41]. In one study[41] the authors also investigated the combination of BA and creatinine on power.

BA supplementation resulted in significantly different effects, compared with placebo, in only one study[35]. The authors reported increased peak power output by 11.4% (95% confidence interval of 7.8 – 14.9%, p=0.0001) and mean power output by 5.0% during the final sprint (95% confidence interval of 7.8 – 14.9%, p=0.0001) after the intervention.

In the study by de Salles Painelli et al. (2014)[40] peak power output was significantly higher in the non-trained, BA-supplemented group (p=0.004), and a tendency for increased values in the trained, BA-supplemented group (p=0.08) compared with before supplementation. In this study, BA supplementation also increased mean power output in bout 4 for the non-trained, BA-supplemented group (p=0.004), and in bouts 1, 2 and 4 for the trained, BA-supplemented group ($p \leq 0.05$), compared with before supplementation.

In another study[41] power output associated with lactate threshold (Watts) was significantly greater in the BA group after supplementation (130.0 ± 43.1W) compared with before supplementation (142.5 ± 42.7W), and in the BA-CR group (136.9 ± 37.9 and 125.6 ± 36.7W in the post- and pre-supplementation conditions, respectively). The effects of BA supplementation in these studies, although not statistically significant, were considered effective by the authors.

Performance time

Seven studies evaluated the effect of BA supplementation on exercise (running, cycling, rowing, swimming) performance time[21,22,26,30-32,34]. The number of participants varied from 14 to 41, with mean age of 24.3 ± 3.6 years. The period of intervention

varied from 28 days to 10 weeks, and the BA dose ranged from 6.7 g to 3.8 g. The effects of BA were compared with those of glucose[30], dextrose[34] or maltodextrin[21,22,26,31,32] with no significant difference between the amino acid and PL.

Oxygen (O_2) consumption

Eight studies evaluated O_2 consumption[21,28,29,33,35,37,39,41]. The sample size varied from 14 to 55 individuals, with mean age of 24 ± 3.7 years. Intervention period varied between 28 days and 8 weeks, and the BA dose between 1.4 and 6.4 g. The PL used in these studies were rice flour[28], dextrose[37,41] or maltodextrin[21,29,33,35,39]. No difference was found between BA and PL groups.

In the study by Gross et al. (2014)[33], BA supplementation increased maximal oxygen consumption (VO2 max) compared with pre-supplementation period. In another study[41] VO2 (L/min) associated with ventilatory and lactate threshold (1.74 ± 0.4 and 2.02 ± 0.50 L/min, respectively) and peak VO2 associated with ventilatory threshold (64.7 ± 10.5 %) were significantly higher in the group supplemented with BA and creatinine as compared with pre-supplementation period (1.84 ± 0.44 L/min, 2.18 ± 0.42 L/min and 69.8 ± 11.4%, respectively). In these studies, although not statistically significant, the effect of BA supplementation was considered effective by the authors.

Time to exhaustion (TTE)

Five studies evaluated the time to exhaustion (TTE)[25,28,35,39,41]. These studies involved 20-55 participants, aged 24.3 ±2.6 years. The intervention protocol varied from 28 days to 8 weeks. The BA dose ranged from 3.25 to 6.4g, and the placebos used were rice flour[28], dextrose[41] or maltodextrin[25,35,39] . No statistically significant difference in the TTE was observed between BA and PL groups.

In the study by Sale et. al., (2011)[25], TTE significantly increased by 12.1% after BA supplementation, and by 16.2% after BA combined with sodium bicarbonate supplementation, compared with before supplementation. Stout et. al., (2007)[39] also reported a significant increase in TTE (seconds) in the group supplemented with BA (1117.55 ± 118.98) compared to baseline (1146.73±110.27). In these studies, although not statistically significant, the effect of BA supplementation was considered effective by the authors.

Physical working capacity at fatigue threshold

Two studies[38,39] involving 22 and 55 volunteers, respectively, with mean age of 25.9 ± 2 years examined the effects of BA supplementation on the fatigue using the physical working capacity at fatigue threshold. The intervention period was 4 weeks in both studies, the dose of BA ranged from 3.9 to 5.6 g, and the placebos were dextrose[38] and maltodextrin[39].

In the first study[38] the authors also evaluated the effects of BA and creatine supplementation in comparison with PL. There was a significant effect of BA supplementation on physical working capacity at fatigue threshold. When adjusted for pre-test values, post-test values (in Watts) were higher in the BA group (170.0 ± 15.9 *vs* 198.8 ± 19.9) compared with PL group (215.8 ± 19.0 *vs* 211.2 ± 23.7). The group supplemented with BA and creatinine also showed higher values compared with the PL group (190.7 ± 18.6 *vs* 214.3 ± 17.1). In the other study[39] a statistically significant difference was observed after BA supplementation (113.64 ± 12.45 Watts) compared with pre-supplementation values (130.00 ± 12.99 Watts). Similarly to the previous outcomes, although the difference between BA and PL groups was not statistically

significant, the effect of BA supplementation compared to pre-supplementation conditions was considered as effective by the authors.

Discussion

This review aimed to describe the result of clinical trials using BA supplementation as an ergogenic aid to improve performance and fatigue resistance in athletes and non-athletes. Few of the outcomes studied showed a significant difference between the intervention (BA supplementation) and the PL groups. There was, however, an important effect of BA supplementation in the intra-group comparison, *i.e.* post-supplementation *vs* pre-supplementation condition.

A higher number of the variables studied in the articles were more related to improvement of performance than to decrease of muscle fatigue. In addition, the studies were heterogeneous in terms of the dose of BA, period of intervention, and protocol of exercise, which makes the comparison of results difficult.

Controversial findings have been found with respect to blood HLa and pH. While some studies using either BA or BA plus sodium bicarbonate supplementation showed significantly increased values post-exercise, others showed a decrease in HLa concentrations and pH. The increase in HLa concentrations after sodium bicarbonate ingestion in the post-exercise period has been reported[43]. The mechanisms proposed for this response include higher lactate production caused by inhibition of glycolytic enzymes involved in the conversion of this intermediate into acetyl coenzyme[20]. On the other hand, the decrease in acidosis reported by some of the studies included in this systematic review may be explained by the increase in muscle carnosine, which acts as a physiological buffer, in response to BA supplementation[44].

Regarding the decrease in muscle fatigue, indicated by a reduction in subjective fatigue in response to the intervention, the supplementation of BA, either alone or combined with sodium bicarbonate, seems to decrease perceived exertion due to the buffering role of both compounds. In addition, the training status may affect the response to BA supplementation. For example, high-intensity, long-term training, *per se*, may increase muscle carnosine concentrations and hence, in this condition, the effect of BA supplementation on this dipeptide levels may be blunted[45].

According to a recent review of BA supplementation by the International Society of Sports Nutrition (ISSN), the intervention improves high-intensity, short-duration (60-240 seconds) exercise performance[46,47] and appears to be safe. Besides, the physiological role of carnosine on the regulation of calcium sensitivity of the contractile apparatus and calcium sarcoplasmic reticulum release is well known[48]. Therefore, the effect of BA supplementation in improving high-intensity exercise performance may be associated with an increase in muscle carnosine levels, and consequently, higher calcium sensitivity of the contractile apparatus and strength production, in addition to a reduction in muscle fatigue[44,49]. Also, we identified in this review that the positive effects of BA supplementation were mainly related to single doses of BA (4.5g or 6.4g/day), with the intervention period varied between 3 and 6 weeks, and all studies with significant results were conducted exclusively on men, practitioners of judo, jiu-jitsu, football, and cycling.

The results of BA supplementation are controversial, with some studies finding significant effects while others reporting no effects. This may be explained by evidence on the capacity of BA absorption and utilization by the skeletal muscle, which varies individually. It is speculated that the response to BA supplementation would be similar to that of creatine supplementation, whose response depends on pre-existing levels of

muscular creatine levels, and approximately 20% of individuals are non-responsive[50]. This would explain, in part, the controversial results on the ergogenic effects of BA supplementation.

Also despite of the absence of significant difference in muscle fatigue and performance in some of the studies evaluated in our review, it should be remembered the low sample size combined with the discrete magnitude of supplementation effects on performance, could result in low statistical power in many studies[51]. Therefore, although the performance improvement was not statistically significant in these studies, the relevance of this effect in a competitive situation should not be neglected.

In studies that showed an improvement in performance, the period of intervention varied between 4 and 8 weeks, and a mean BA dose of 4.4g (3.2 – 6.4g) per day was used, lower than those used in the studies evaluating the effect of BA on muscle fatigue. The mostly used methods for BA supplementation were dose increment or dose decrease. Only one study was carried out with women. The sport studied was cycling, and the other studies were conducted with physically active volunteers.

The inconsistent findings around the studies in this review may be related to (a) supplementation period, (b) dosage, (c) type of exercise training, (d) participants' training status, (e) sample size, (f) methodological problems of the RCTs. In light of this, the most prominent effects of BA were modulation of muscle acid-base balance and decrease in perceived exertion.

Conclusion

Current evidence indicates that BA supplementation leads to improvements in perceived exertion and biochemical parameters related to muscle fatigue, particularly in protocols using 4.5 - 6.4g per day of BA for 4 weeks. In addition, BA seems to improve

exercise performance, especially in non-athletes. The heterogeneity of protocols and scarcity of data on women suggest the need for further studies.

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Legends of figures and tables

Figure 1. Flowchart of the literature search.

Table I. Effects of beta-alanine supplementation on performance and muscle fatigue.

Figure 1. Flowchart of the literature search

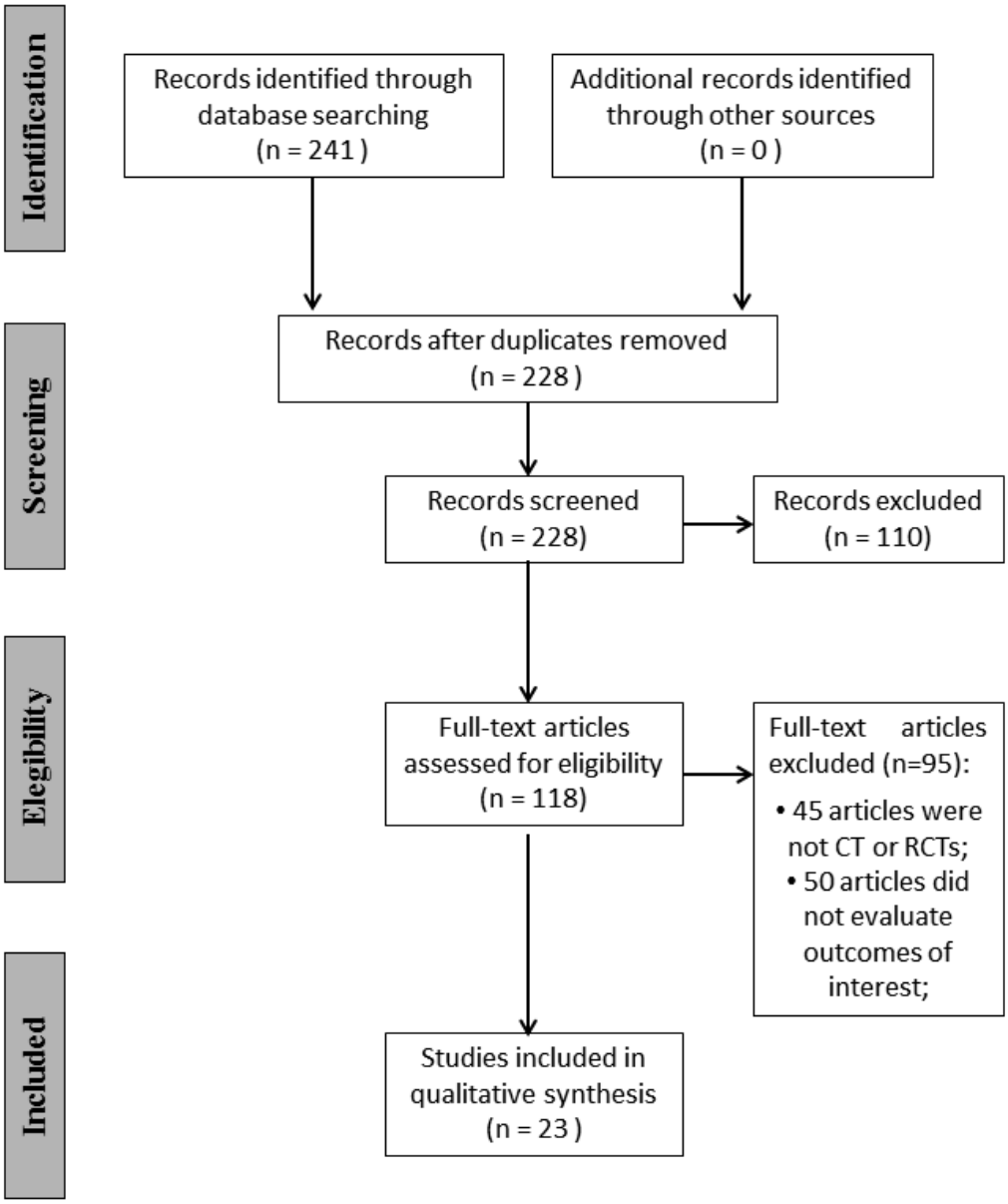

Table I. Effects of beta-alanine supplementation on performance and muscle fatigue.

Authors and year	Study type and sample	Intervention	Follow-up period	Outcome measures	Results
Tobias, et al., 2013 (20)	RCT with judo (n=19) and jiu-jitsu (n=21) male competitors	BA supplementation (6.4g/day) or PL (dextrose 6.4g/day) for 4 weeks. In the last week of supplementation, the athletes also received SB (500 mg/kg of body mass) or PL (calcium carbonate, 500 mg/kg of body mass). Hence, 4 study groups were formed: PL-PL, BA-PL, PL-SB and BA-SB	4 weeks	HLa, rate of perceived exertion, total work done, peak and mean power.	HLA: significantly higher after BA-PL, PL-SB and BA-SB supplementation Rate of perceived exertion: significantly lower in BA-SB group Total work done, peak and mean power: significantly higher after BA-PL, PL-SB and BA-BS supplementation
Saunders et al., 2012 (21)	Double-blind, RCT with male elite (n=20) and non-elite (n=20) game players.	BA supplementation (6.4g/day) or PL (maltodextrin 6.4g/day)	4 weeks	HLa, perceived exertion, sprint performance (time) and VO_2 max	There was no statistically significant difference between groups
Chung et al., 2012 (22)	Double blind, RCT with swimmers of both sexes (n = 41)	BA supplementation (4.8g/day for 4 weeks, 3.2g/day for 6 weeks) or PL (maltodextrin 4.8g/day for 4 weeks and 3.2 g/day for 6 weeks)	10 weeks	HLa, pH, SB concentrations and training performance (time).	There was no statistically significant difference between groups
Smith-Ryan et al., 2012 (23)	Double blind, RCT with physically active individuals (n= 15) of both sexes	BA supplementation (4.8g/day) or PL (maltodextrin 4.8g/day)	28 days	HLa, time to exhaustion and velocity	HLa and velocity: no statistically significant difference Time to exhaustion: significantly greater after supplementation (compared with pre-supplementation value) in men
Sweeney et al., 2010 (24)	Double blind, RCT with college men (n=19)	BA or PL (rice flour) supplementation (4g/day in the first week, and 6 g per day over the next 4 weeks)	5 weeks	HLa, horizontal power (peak and mean), percentage of fatigue	HLa, horizontal power (peak), percentage of fatigue: no statistically significant difference. HLa, horizontal power (mean): significantly lower in BA and PL groups (compared with pre-supplementation values)
Sale et al., 2011 (25)	Randomized, cross-over clinical trial with physically active men	BA supplementation (6.4g/day) or PL (maltodextrin 6.4g/day), using a crossover design with 2	4 weeks	HLa, PH, BS concentration, work done and TTE.	HLa: significantly higher in all groups (pre-supplementation *vs.* post-supplementation)

	(n=20)	days of rest between trials, creating four study groups: PL-PL, BA-PL, PL-SB, BA-SB.			pH: significantly higher in the PL-SB and BA-SB groups (compared with pre-supplementation period) BS concentration: significantly lower in all groups (post-supplementation *vs.* pre-supplementation) Work done and TTE: significantly higher in the BA-PL and BA-SB groups (post-supplementation *vs.* pre-supplementation)
Baguet et al., 2010 (26)	RCT with rowers (n=18) of both sexes	BA supplementation (5g/day) or PL (maltodextrin 5g/day)	7 weeks	HLa and performance (time)	There was no statistically significant difference between the groups
Kern & Robinson, 2011 (27)	Double blind, RCT with football players (n=15) and physically active individuals (n=22)	BA supplementation (4g/day) or PL (dextrose 4g/day)	8 weeks	HLa and anaerobic power	There was no statistically significant difference between the groups
Jagim et al., 2013 (28)	Double blind, RCT with physically active men (n=21)	BA supplementation or PL (rice flour) (4g/day in the first week and 6g/day in the following weeks)	5 weeks	HLa, TTE and VO_2 max	There was no statistically significant difference between the groups
Baguet et al., 2009 (29)	Double blind, RCT with male physical education students (n=14)	BA or PL (maltodextrin) supplementation (2.4g/day in the first 2 days, 3.6g/day in the next 2 days, and 4.8g/day until the end of the study)	4 weeks	HLa, pH, SB concentration, kinetics of pulmonary oxygen consumption	pH: different between BA and PL groups HLa, SB concentration, kinetics of pulmonary oxygen consumption: no statistically significant difference
Ducker, Dawson & Wallman, 2013 (30)	RCT with male rowers (n=16)	BA supplementation (6.7g/day) or PL (glucose, 10g/day)	28 days	HLa, pH, mean power, split power and race time	HLa and mean power: no statistically significant difference pH, split power and race time: significantly higher in the BA group (post-supplementation *vs*. pre-supplementation values)
Derave et al., 2007 (31)	Double blind, RCT with male athletics athletes (n=15)	BA supplementation or PL (maltodextrin) (2.4g/day in the first 4 days, 3.6g/day in the following 4 days, and 4.8g/day until the end of the study)	4-5 weeks	HLa and running time	HLa: significantly higher in both groups (post-supplementation *vs.* pre-supplementation value) Running time: significantly lower in both groups (post-supplementation *vs.* pre-supplementation value).

Chung et al., 2013 (32)	RCT with male cyclists (n=28)	BA supplementation or PL (maltodextrin) (6.4g/day)	6 weeks	HLa, pH, SB concentrations and time trial performance	HLa: significantly higher in the BA group pH, SB concentrations, time trial performance: there was no statistically significant difference
Gross et al., 2014 (33)	Double blind, RCT with physically active men (n=17)	BA supplementation or PL (maltodextrin) (3.2g/day in the first 38 days)	38 days	HLa, pH, peak power, power at ventilatory threshold and VO_2 max	HLa and VO_2 max: significantly higher in the BA group (post- supplementation *vs.* pre-supplementation values). pH, peak power, and power at ventilatory threshold: there was no statistically significant difference
Bellinger et al., 2012 (34)	Double blind, RCT with male cyclists (n=14)	BA supplementation (65 mg/kg of body mass, PL (dextrose 65 mg/kg of body mass), BA+PL, PL+BS (0.3 mg/kg of body mass) or BA+SB	28 days	pH, total work done, mean power and 4-min cycling time trial performance	pH: significantly lower in PL-BS and BA-SB groups (post- supplementation *vs.* pre-supplementation values). Total work done and mean power: significantly higher in the PL-SB and BA-SB (post- supplementation *vs.* pre-supplementation values). 4-min cycling time trial performance: no statistically significant difference
Thienen et al., 2009 (35)	Double blind, RCT with male cyclists (n=21)	BA supplementation or PL (maltodextrin) (2g/day in the first two weeks, 3g/day in the third and fourth week and 4g/day until the end of the study)	8 weeks	HLa, power, peak VO_2 and TTE	HLA and peak VO_2: no statistically significant difference Power: significantly increased during the final sprint after the time trial after BA supplementation TTE: significantly higher in both groups (post-supplementation *vs*. pre-supplementation)
Hoffman et al., 2007 (36)	RCT with football players (n=26)	BA supplementation or PL (maltodextrin) (4.5g/day)	3 weeks	Fatigue rate, subjective sensation of fatigue, total work done, peak and mean power	Subjective sensation of fatigue: significantly lower in the BA group Fatigue rate, total work done, peak and mean power: no statistically significant difference
Walter et al.,	Double blind, RCT	BA+PL supplementation (1.5g+	8 weeks	Power at the ventilatory threshold and	Power at the ventilatory threshold and VO_2

2010 (37)	with physically active women (n=44)	dextrose 15g/day) or PL (dextrose 16.5g/day)		VO_2 peak	peak: significantly higher in both groups (post-supplementation *vs*. pre-supplementation values)
Stout et al., 2006 (38)	Double blind, RCT with male volunteers (n=55)	BA supplementation (6.4g/day in the first 6 days, and 3.2g/day until the end of the study), PL (dextrose 34g), CR (5.25g) or BA + CR (1.6g+5.25g)	28 days	Physical working capacity at fatigue threshold	Physical working capacity at fatigue threshold: significantly higher in the BA and BA-CR groups
Stout et al., 2007 (39)	Double blind, RCT with female volunteers (n=22)	BA supplementation or PL (maltodextrin) (3.2g/day in the first week and 6.4g/day in following weeks)	4 weeks	VO_2 max, ventilatory threshold, TTE and physical working capacity at fatigue threshold	VO_2 max: there was no statistically significant difference Ventilatory threshold, TTE and physical working capacity at fatigue threshold: significantly higher in the BA group (post-supplementation *vs*. pre-supplementation)
Painelli et al., 2014 (40)	RCT with male trained and non-trained cyclists (n=40).	BA supplementation or PL (6.4g/day) in four experimental conditions: non-trained PL, non-trained BA, trained BA and trained BA	4 weeks	Total work done, peak and mean power, and performance	Total work done: significantly higher in non-trained-BA and trained-BA groups, and significantly lower in the non-trained-PL and trained-PL (post-supplementation *vs*. pre-supplementation values) Peak power: significantly higher in the non-trained-BA group (post-supplementation *vs*. pre-supplementation values) Mean power: significantly higher in the non-trained-BA and trained-BA groups (post-supplementation *vs*. pre-supplementation) Performance: there was no statistically significant difference
Zoeller et al., 2006 (41)	Double blind, RCT with male volunteers (n=55)	BA supplementation (6.4g/day in the first 6 days and 3.2 g/day until the end of the study), PL (dextrose 34g), CR (5.25g) or BA + CR (1.6g+5.25g)	28 days	Power output, VO_2, % peak VO_2, and VO_2 at ventilatory and lactate threshold, and TTE	Power output, VO_2, % peak VO_2, VO_2 at ventilatory and lactate threshold: significantly higher in the BA-CR group (post-supplementation *vs*. pre-supplementation) Power output at lactate threshold: significantly higher in the BA and BA-CR

					groups (post-supplementation *vs*. pre-supplementation) TTE: there was no statistically significant difference
Smith et al.., 2008 (42)	Double blind, RCT with male, physically active volunteers (n=46)	BA supplementation (6g/day in the first two weeks and 3g/day until the end of the study) or PL (dextrose 16.5g)	5 weeks	Efficiency of electrical activity (muscle function) and electromyographic fatigue threshold	Efficiency of electrical activity (muscle function) and electromyographic fatigue threshold: significantly improved in both groups (post-supplementation *vs*. pre-supplementation)

RCT – randomized clinical trial; BA – beta alanine; PL – placebo; SB – sodium bicarbonate; HLa – blood lactate concentration; CR – creatine; VO_2 – volume of oxygen consumed; TTE – time to exhaustion.