



THE NUTRITION **X**-CHANGE

3 BETA-ALANINE

A LOOK AT THE EFFECTS OF BETA ALANINE SUPPLEMENTATION AND ITS BENEFITS TO ATHLETES

BY EIMEAR DOLAN,
JOSEPH MATTHEWS,
BRYAN SAUNDERS

Beta-Alanine

EIMEAR DOLAN, JOSEPH MATTHEWS, BRYAN SAUNDERS

Practical Implications

- Carnosine is a dipeptide formed by two amino acids, beta-alanine and L-histidine, and plays an important role in protecting against pH changes in skeletal muscle.
- High-intensity exercise leads to a reduction in muscle pH (or increased acidity) due to hydrogen ion accumulation. Acidosis negatively impacts performance via a range of mechanisms, including reducing the capacity for muscle contraction and slowing the rate of ATP regeneration.
- Beta-alanine supplementation increases skeletal muscle carnosine content, and with it, the buffering capacity of the muscle (i.e. its capacity to regulate pH).
- Beta-alanine supplementation improves exercise performance, with its greatest effect in sustained, high-intensity efforts lasting between 30 seconds and 10 minutes.
- At least 4 weeks supplementation of between 3.2 – 6.4 g·day⁻¹ is necessary to elicit performance benefits.
- Shortly after taking beta-alanine, some people may feel a prickling or 'pins and needles' type sensation on the skin—this is called paresthesia. It is believed to be harmless, although it can be uncomfortable.
- Paresthesia depends on the amount of free beta-alanine in blood, so splitting the dose (e.g., 3 or 4 doses throughout the day instead of all at once) can reduce or prevent this sensation.
- Beta-alanine supplementation increases the capacity for high-intensity work – although this is only useful if the extra capacity for training is used through performing maximum effort training; taking beta-alanine while engaging only in submaximal training is unlikely to be effective.
- As with all supplements, individual response to beta-alanine varies, and it is always recommended that you trial new supplements in the off-season and monitor your own response.

Background

Beta-alanine (BA) is a widely used sport supplement that enhances high-intensity exercise capacity, and is one of 5 performance supplements supported by the International Olympic Committee for use in sport (the others being creatine, sodium bicarbonate, caffeine, and nitrates) [1]. This article addresses some key questions related to BA supplementation, which may help guide decision making when it comes to whether or not you wish to supplement with BA, along with how to get the most from it.

What is it?

BA is a non-proteogenic amino acid, meaning it is not involved in muscle protein synthesis. The performance enhancing effects of beta-alanine supplementation occur due to its ability to increase muscle carnosine content. Carnosine is a dipeptide made up of two connected amino acids, i.e., beta-alanine and L-histidine [2,3]. It is abundant in skeletal muscle, where it contributes to a wide range of cellular processes, and from a sports performance context, the most important of these is muscle buffering. The role of a buffer is to prevent changes in the pH (acidity/alkalinity) of the environment

by regulating the number of free hydrogen ions in that system (which thereby dictates the pH of the system). Human muscle naturally has a pH of approximately 7.1, but this can reduce to as low as 6.1 following high-intensity, exhaustive exercise [4], meaning that the internal environment is more acidic during and following high-intensity exercise. The reason for this is that sustained high-intensity exercise requires more energy (provided by ATP regeneration) than the capacity of the cell to supply it aerobically, and so the muscle must use energy from anaerobic metabolism. The anaerobic system provides ATP at a faster rate than aerobic sources, enabling the muscles to continue contracting at a high intensity. However, it also results in an accumulation of hydrogen ions, leading to a state of metabolic acidosis. Intramuscular acidosis impacts muscle contraction via a host of mechanisms, and ultimately leads to muscle fatigue and a reduction in the ability to maintain power output [5].

Because of the detrimental effect that acidosis has on performance (and other physiological functions), the body has evolved a range of mechanisms to combat it. One of these is the presence of intracellular buffers found in the skeletal muscle, such as carnosine. Intracellular buffers bind excess

hydrogen ions, thus reducing their accumulation in the cell and consequently preventing or delaying the development of acidosis. The greater the internal buffering capacity of the muscle, the greater its capacity to regulate pH and to sustain high-intensity efforts. As intramuscular carnosine is an important buffer, higher contents are desirable for athletes who regularly undertake high-intensity efforts. Indeed, higher carnosine contents have been recorded in athletes who regularly undertake high intensity training, including sprinters, rowers and bodybuilders [6,7]. Research shows, however, that most people have large capacity to increase their muscle carnosine content [8], and BA supplementation is an evidence based way to achieve this. In 2006, Professor Roger Harris and colleagues identified that BA availability dictates the amount of muscle carnosine, and by supplementing with BA individuals can substantially increase muscle carnosine content [9]. A large number of studies have since confirmed that BA supplementation increases muscle carnosine content in virtually everyone who takes it, which may in turn lead to better pH regulation and an enhanced ability to withstand metabolic acidosis during high intensity exercise. An overview of how BA supplementation may enhance

exercise performance is described in Figure 1.

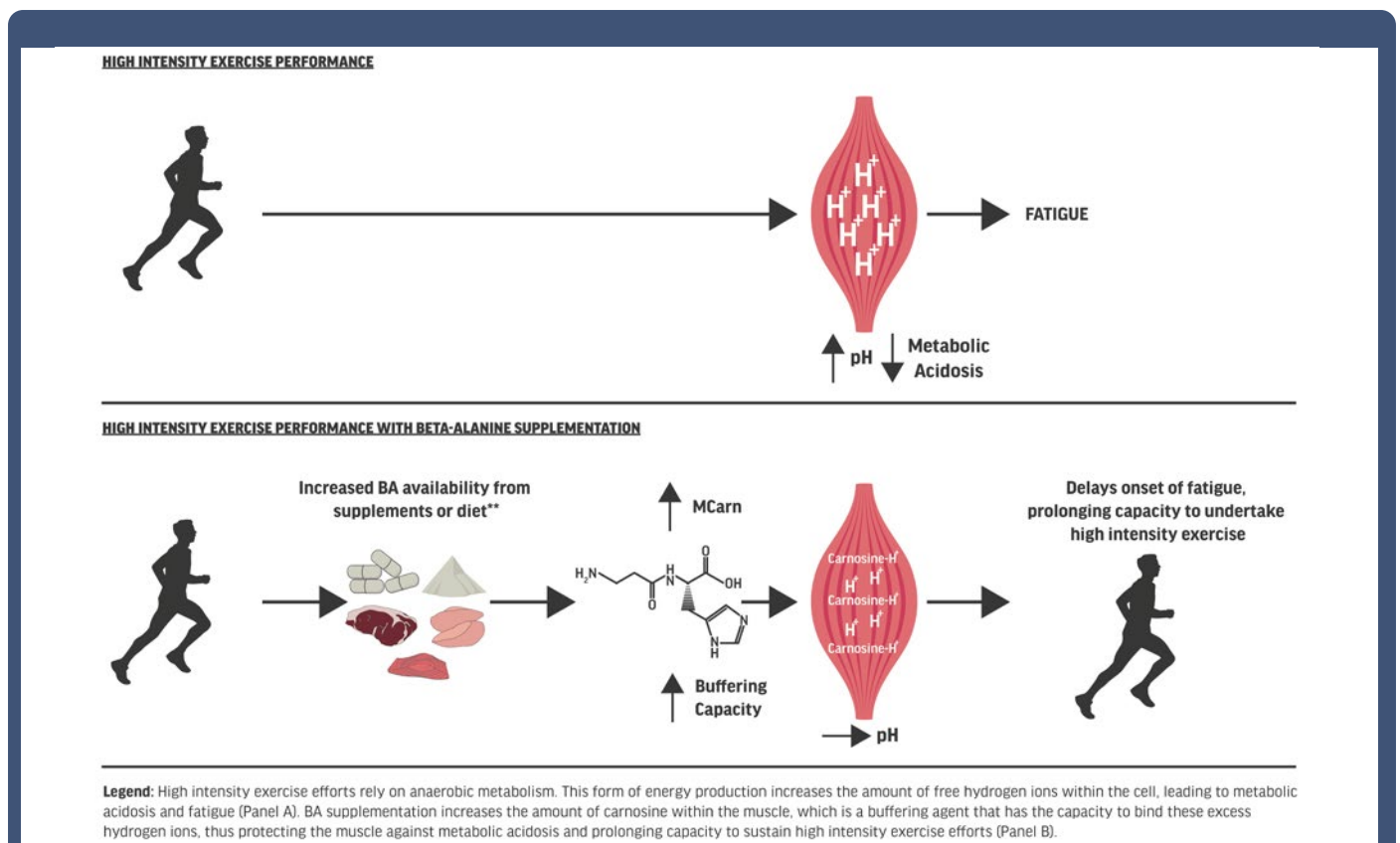


Figure 1 .The Influence of BA Supplementation on High-Intensity Exercise Performance.

Why should you take it?

A large number of studies have been conducted to investigate the influence of BA supplementation on high-intensity exercise performance. The first of these was by Hill and colleagues [10] in 2007, which showed improved performance on a high intensity cycling test following 4 – 10 weeks of BA supplementation (3.2 – 6.4 g·day⁻¹). Since then, multiple other studies have examined how BA impacts performance on a wide range of exercise tests, and in order to collectively examine the evidence from these studies, our research group recently performed a large meta-analysis that statistically combined all available high-quality research on this topic [11]. We set strict criteria on which types of studies were included in the review, i.e., only those with robust double-blinded, placebo-controlled designs. We grouped results from 40 different studies, containing 65 different exercise protocols, and saw a small positive effect of BA supplementation on exercise performance. This small effect varied quite a lot, depending on the exercise test conducted, which makes sense given that exercise tests challenge the body in different ways, meaning that different supplements will differentially impact different forms of exercise. For example, the cause of fatigue in an endurance event (e.g. a 10 km run) is not the same cause of fatigue in a high-intensity sprint exercise (e.g., a 400 m sprint), and so collectively examining the effect of a supplement on all available exercise tests is not very informative. Accordingly, we subcategorized the tests into different types and durations, to more precisely identify the situations in which BA was likely to exert its greatest effect. The available evidence indicated that BA supplementation was most likely to enhance performance during capacity-based tests (i.e., those conducted to the point of exhaustion), lasting between 30 seconds and 10 minutes. These are precisely the type of tests likely to be influenced by a supplement that improves buffering capacity, because the length of the test dictates which energy system is primarily used (aerobic or anaerobic), and the extent of hydrogen ion accumulation. For example, longer lasting efforts (e.g., > 10 minutes) will be conducted at a lower intensity and will be largely fueled by aerobic metabolism. As such, they are unlikely to be limited by changes in pH. Similarly, hydrogen ions take some time to accumulate in the muscle, so very

short, high-intensity efforts (< 30 seconds) are also unlikely to be limited by changes in pH, meaning that these durations are also unlikely to be impacted by BA supplementation. In contrast, medium-length, high-intensity tests lasting 30 s to 10 min, that are conducted to the point of exhaustion are most likely to be limited by hydrogen ion accumulation and pH perturbations, and as such, are most amenable to BA supplementation. So, if your sport involves sustained, high-intensity efforts or repeated sprints, e.g., team sports such as football or rugby, or races such as 100 – 400 m swimming, 4-km cycling, 800 – 1500 m running and 2000 m rowing, then BA may be of benefit. It must be stressed, however, that BA can improve the capacity to undertake high-intensity exercise efforts, but this is only effective if the effort is maximal. Taking a supplement designed to enhance high-intensity exercise capacity makes little or no difference if training is sub-maximal.

How should you take it and are there any side-effects you need to worry about?

Beta-alanine is available in powder or capsule form and both are effective at increasing skeletal muscle carnosine content. It takes some time for intramuscular carnosine to increase, and currently, four weeks of supplementation of 3.2-6.4 g·day⁻¹ is the recommended supplementation strategy. The larger dose of 6.4 g·day⁻¹ can increase muscle carnosine more than 3.2 g·day⁻¹, and there is some evidence that this translates to greater improvements in performance. We do not know the maximum amount of carnosine that the muscle can store, however, recent research indicates that we have a large capacity to accumulate carnosine – far larger than is commonly observed with current dosing strategies [8]. Having said that, clear performance benefits have been observed with these commonly used protocols, meaning that maximizing carnosine content does not seem to be necessary to elicit performance gains. An important factor to consider is that once BA supplementation stops, muscle carnosine content slowly returns to baseline levels within ~10-15 weeks. To prevent this, it is important to maintain your preferred dose throughout training and competition, although some evidence indicates that a smaller “maintenance” dose (e.g., 1.2 g·day⁻¹) could allow for maintenance of elevated carnosine levels after the initial loading phase [12]. Supplementation of beta-alanine for up

ACTIVITIES MOST LIKELY TO BE ENHANCED BY BETA ALANINE SUPPLEMENTATION



Figure 2. Illustration of the types of sports / activities likely to be aided by beta-alanine supplementation. The examples of activities likely to be positively impacted BA supplementation are based on tests that have been directly investigated, but other high-intensity, sustained efforts of similar duration (e.g., as occur in other intermittent sports, or other track and field modalities) may also benefit. It should also be noted that athletes competing in the type of events unlikely to be impacted by BA supplementation (e.g., very short duration, or endurance type events) should consider the demands of training, as well as the event itself, to decide if BA supplementation may be of benefit.

to 24 weeks at a daily dose of 6.4 g appears safe in healthy individuals [13,14]. There are currently no data to show that continuing supplementation past 24 weeks would be harmful, although many individuals choose to either halt supplementation, or to reduce to a maintenance dose during the off-season, mainly due to the practical issues of continuing to consume large supplementation doses throughout the year. BA is available in many meats, fish and seafoods (see Table 1), however typical daily intake is estimated to be approximately 0.4 – 0.8 g·day⁻¹, meaning that quite large intakes of BA rich foods would be required to meet the current dosing recommendations (3.2 – 6.4g·day⁻¹ for 4 weeks) that are proven to increase muscle carnosine and to enhance high intensity exercise performance. Having said that, a high intake of BA rich foods may facilitate maintenance, or augmentation, of muscle carnosine levels during or following the recommended supplementation protocol.

Beta-alanine can cause an uncomfortable side-effect called “paraesthesia”, which has been described as a prickly or warm sensation on the surface of the skin, similar to pins and needles. This occurs within 30-60 minutes of taking an individual dose, and larger doses increase the incidence and intensity of paraesthesia. There is no evidence to suggest that paraesthesia is harmful, but many people consider it to be uncomfortable, and so wish to avoid it. To reduce the feelings of paraesthesia, it is recommended that athletes split their BA dose throughout the day, rather than taking one or two larger doses. A common approach is to consume 0.8-1.6 g of beta-alanine every 3-4 hours, although individuals may wish to practice their supplementation strategy to see if any side-effects are experienced. For those who continue to experience side effects, slow- or sustained-release tablets might alleviate symptoms, allowing for a higher individual dose. Interestingly, not all athletes dislike the feeling of paraesthesia, with some reporting that it increases their motivation to train and perform

Table 1: Food Sources of Beta Alanine

Food	BA (g/100g)
Beef	0.28
Pork	0.22
Chicken Breast	0.38
Trukey Breast	0.52
Mutton/Lamb	0.18
Trout	0.48
Prawns	0.75
Tuna	0.82
Horse	0.98

[15]. As such, individual strategies should depend on personal responses. If paresthesia is not an issue then taking a larger dose fewer times a day is fine.

Some supplements need to be taken at specific times to be effective. However, beta-alanine may be consumed at any time throughout the day, and taking it with a meal or around training does not seem to impact its effectiveness, nor to optimise gains. There is also no need to take beta-alanine exclusively as a pre-workout supplement because a single dose will not influence muscle carnosine. Instead, supplementing beta-alanine consistently for several weeks, will lead to sustained increases in muscle carnosine. Athletes aiming to reach peak conditioning for specific competitions should take the 4-week supplementation timeframe into consideration. Some data suggests that higher beta-alanine intakes of $12 \text{ g}\cdot\text{day}^{-1}$ for 2 weeks can accelerate increases in muscle carnosine content [16]. Those short on time might wish to consider this dosing strategy, but some caution should be taken due to the increased potential for paraesthesia at these high doses.

Summary:

Carnosine acts as a pH buffer in the muscle and delays the development of acidosis during high-intensity exercise. Beta-alanine is the rate-limiting step in muscle carnosine synthesis. As such, BA supplementation can enhance the capacity to undertake high-intensity exercise, and its performance enhancing effects are supported by a large body of evidence. It takes time, and a substantial amount of BA, to increase muscle carnosine content, so a chronic dosing protocol (e.g., $3.2 - 6.4 \text{ g}\cdot\text{day}^{-1}$ for 4 weeks) is necessary to benefit from its performance enhancing effects. Keep in mind that BA supplementation increases the body's capacity for high-intensity exercise efforts, but this is only beneficial when athletes are training to the best of their abilities. For maximum benefit, we recommend supplementing with BA alongside a well-structured training and nutrition program.

Author bios



Eimear Dolan

Eimear completed her undergraduate and postgraduate studies in sport and exercise science in Dublin City University, Ireland. She then worked as a Sports Nutrition lecturer in the Robert Gordon University, Scotland, before moving to Brazil to do a postdoctoral research project. Currently, she is a member of the Applied Physiology and Nutrition Research Group of the University of São Paulo, and leads a research program investigating how exercise and nutrition influence bone, which is funded by the Sao Paulo Research Foundation (FAPESP). Her research interests include pH regulation and high-intensity exercise performance (including the use of buffering supplements such as beta-alanine); the influence of low energy availability on health and performance, and bone metabolism.



Joseph Matthews

Joseph is a Lecturer at Birmingham City University and a practicing Sports Nutritionist, with his applied work focusing on safe approaches to making weight for combat sport athletes, specifically in boxing, kickboxing, and mixed martial arts. He is also a PhD researcher in the Musculoskeletal Physiology Research Group at Nottingham Trent University, where his research focuses on the physiological roles of carnosine and beta-alanine in healthy and type 2 diabetic skeletal muscle.



Bryan Saunders

Bryan Saunders is a researcher and lecturer in sport and exercise science at the Faculty of Medicine of the University of São Paulo, Brazil. His main areas of research include nutritional supplementation to improve exercise performance, determination of the mechanisms through which these supplements act and what factors might moderate these effects. Bryan has applied sport science experience having provided performance analysis and physiology support to several UK-based football teams and currently works with elite cycling in Brazil.

References:

1. Maughan RJ, Burke LM, Dvorak J, Larson-Meyer DE, Peeling P, Phillips SM, et al. IOC consensus statement: Dietary supplements and the high-performance athlete. *Br J Sports Med.* 2018;52:439–55.
2. Sale C, Artioli GG, Gualano B, Saunders B, Hobson RM, Harris RC. Carnosine: From exercise performance to health. *Amino Acids.* 2013;44:1477–91.
3. Boldyrev A, Aldini G, Derave W. Physiology and pathophysiology of carnosine. *Physiol Rev.* 2013;93:1803–45.
4. Pan J, Hamm J, Hetherington H, Rothman D, Shulman R. Correlation of lactate and pH in human skeletal muscle after exercise by ¹H NMR. *Magnetic Reson Med.* 1991;20:57–65.
5. Robergs RA. Biochemistry of exercise-induced metabolic acidosis. *AJP Regul Integr Comp Physiol.* 2004;287:R502–16.
6. Parkhouse W, McKenzie D, Hochachka P, Ovalle W. Buffering capacity of deproteinized human vastus lateralis muscle. *J Appl Physiol.* 1985;58:14–7.
7. Tallon M, Harris R, Boobis L, Fallowfield J. The carnosine content of vastus lateralis is elevated in resistance-trained bodybuilders. *J Strength Cond Res.* 2005;19:725–9.
8. Rezende N, de Oliveira L, da Silva R, Eira Silva V, Nemezio K, Yamaguchi Y, et al. Human skeletal muscle has large capacity to increase carnosine content in response to beta-alanine supplementation. A systematic review with bayesian individual and aggregate data E-max model and meta-analysis. *Front Physiol.* 2020; 3389.
9. Harris R, Tallon M, Dunnett M, Boobis L, Coakley J, Kim H, et al. The absorption of orally supplied beta-alanine and its effect on muscle carnosine synthesis in human vastus lateralis. *Amino Acids.* 2006;30:279–89.
10. Hill C, Harris R, Kim H, Harris B, Sale C, Boobis L, et al. Influence of β -alanine supplementation on skeletal muscle carnosine concentrations and high intensity cycling capacity. *Amino Acids.* 2007;32:225–33.
11. Saunders B, Elliott-Sale K, Artioli G, Swinton P, Dolan E, Roschel H, et al. β -alanine supplementation to improve exercise capacity and performance: a systematic review and meta-analysis. *Br J Sports Med.* 2017;51:658–69.
12. Stegen S, Bex T, Vervaet C, Vanhee L, Achten E, Derave W. β -Alanine dose for maintaining moderately elevated muscle carnosine levels. *Med Sci Sports Exerc.* 2014;46:1426–32.
13. Saunders B, Franchi M, de Oliveira L, da Eira Silva V, da Silva R, de Salles Painelli V, et al. 24-Week β -alanine ingestion does not affect muscle taurine or clinical blood parameters in healthy males. *Eur J Nutr.* 2020;59:57–65.
14. Dolan E, Swinton P, Painelli V, Stephens Hemingway B, Mazzolani B, Infante Smaira F, et al. A systematic risk assessment and meta-analysis on the use of oral beta-alanine supplementation. *Adv Nutr.* 2019;10:452–63.
15. Bellinger PM, Minahan CL. Performance effects of acute β -alanine induced paresthesia in competitive cyclists. *Eur J Sport Sci.* 2016;16:88–95.
16. Church D, Hoffman J, Varanoske A, Wang R, Baker K, La Monica M, et al. Comparison of two β -alanine dosing protocols on muscle carnosine elevations. *J Am Coll Nutr.* 2017;36:608–16.