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**Section:** Original Investigation

**Article Title:** Effects of Acute Carnosine and  $\beta$ -Alanine on Isometric Force and Jumping Performance

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**Journal:** *International Journal of Sports Physiology and Performance*

**Acceptance Date:** August 1, 2015

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**DOI:** <http://dx.doi.org/10.1123/ijsp.2014-0507>

## **Effects of acute carnosine and $\beta$ -alanine on isometric force and jumping performance**

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**Running head:** Muscle performance with carnosine

**Abstract word count: 250**

**Text only word count: 3470**

**n. of figures: 2**

**n. of tables: 3**

## Abstract

**Purpose:** To assess the effects of acute L-carnosine and  $\beta$ -alanine (Carn-BA) supplementation on isometric and dynamic tasks. **Methods:** Twelve healthy participants performed knee extensors maximal voluntary contractions (MVC) and countermovement jumps (CMJ) before and after a fatiguing protocol (45s continuous CMJ). Isometric and dynamic tests were performed four hours after Carn-BA (2g of L-carnosine and 2g of  $\beta$ -alanine) or placebo (PLA) ingestion, in random order. After the fatiguing protocol, blood lactate concentration ( $[La^-]$ ), general and muscular rate of perceived exertion (RPE), and muscular pain (after 24h and 48h from the end of the fatiguing protocol) were assessed. **Results:** During the fatiguing protocol, significant decreases in jump height, and increases in contact time were found in both groups from the 15<sup>th</sup> second onwards to the end of the fatiguing protocol. Average contact time and jump height were respectively lower (-7%;  $P=0.018$ ) and higher (+6%;  $P=0.025$ ) in Carn-BA compared to PLA. After the fatiguing protocol, MVC decreased in both PLA and Carn-BA, but it was higher in Carn-BA compared to PLA (+15%,  $P=0.012$ ), while CMJ did not change. Moreover, general RPE was lower and muscle pain at 24h was higher in Carn-BA compared to PLA, whereas muscular RPE and  $[La^-]$  did not differ between conditions. **Conclusions:** Ingesting Carn-BA prior to exercise induced positive effects on MVC and CMJ after the fatiguing protocol and improved CMJ performance during the 45s continuous jumping effort, even when acutely supplemented. Furthermore, Carn-BA reduced the general RPE and increased muscular pain 24 h after the fatiguing task.

**Keywords:** countermovement jump, maximum voluntary contraction, EMG, RPE, muscular pain

## Introduction

Muscle performance decreases progressively during exercise because of central and peripheral fatigue.<sup>1</sup> It's becoming very popular among recreational and competitive athletes the ingestion of different types of legal ergogenic aids to counteract the effects of fatigue.<sup>2,3</sup> Although controversial,<sup>4,5</sup> chronic supplementation with carnosine together with  $\beta$ -alanine (Carn-BA), the rate-limiting precursor in carnosine synthesis,<sup>6</sup> has been recently proposed to increase skeletal muscle carnosine levels,<sup>6-8</sup> which can improve muscle contractility and reduce muscle fatigue.<sup>8,9</sup> Among several hypotheses, Carn-BA effects have been suggested to rely on its buffering action in the muscle<sup>10</sup> or on its role as a diffusible  $\text{Ca}^{2+}/\text{H}^{+}$  exchanger, which would increase cross-bridge formation and force output.<sup>11</sup>

Four weeks of L-carnosine or  $\beta$ -alanine supplementation has been shown to increase muscle carnosine levels up to about 66 % and 64 %, respectively.<sup>12</sup> An amelioration of muscle contractility and exercise performance have been associated to these carnosine increased levels.  
6, 8, 13, 14

While the consequences of chronic Carn-BA supplementation have been already extensively investigated, little is known about the effects of acute Carn-BA administration. Gardner et al.<sup>15</sup> argued that carnosine could be already available inside the muscle fibres few hours after ingestion. Therefore, acute Carn-BA supplementation may be similarly effective in increasing muscle performance. Consequently, athletes could benefit from its ingestion immediately, avoid the nuisance of chronic supplementation, simplify consumption procedures, and reduce the associated costs. Bellinger and coworkers found that acute ingestion of  $\beta$ -alanine was not associated with improved cycling time trial performance.<sup>16</sup> However, the effects of acute supplementation on high intensity anaerobic tasks yet have to be assessed.

Therefore, this study aimed at assessing the effects of acute Carn-BA supplementation on maximum isometric strength and repeated vertical jumps. Should a higher isometric and

jumping performance in Carn-BA compared to PLA be retrieved after a fatiguing protocol, then Carn-BA effects may be claimed to be present also after its acute supplementation. The effects of acute Carn-BA ingestion on rate of perceived effort and muscular pain after a fatiguing protocol were also assessed.

## **Methods**

### *Participants*

Twelve healthy, physically active, male participants (age  $23 \pm 2$  years; stature  $1.79 \pm 0.09$  m; body mass  $75.8 \pm 9.8$  kg; mean  $\pm$  standard deviation, SD) volunteered for the study. They were all without any form of neuromuscular and skeletal diseases. The participants were naive to the purpose of the experiments. After full explanation of the experimental design and procedures, each participant gave written informed consent before engaging in the experiments. The study was approved by the local Ethics Committee and was conducted in accordance with the principles of the 1964 Declaration of Helsinki.

### *Experimental design*

The study has a double blind, randomized, counterbalanced placebo design. All participants reported to the laboratory on three different occasions. The first visit served for familiarization purpose, during which participants were accurately instructed with the experimental setup and procedures. In the two following visits, each participant performed static and dynamic tests with (Carn-BA) or without (placebo-PLA) supplement ingestion, in randomized order.

Carn-BA supplementation involved tablets with a total amount of 2 g of L-carnosine and 2 g of  $\beta$ -alanine, plus excipients. According to the main formulator of the product (Velleja Research, Piacenza, Italy), the carnosine and  $\beta$ -alanine combination was proposed to maximize the carnosine content within the muscle cells.<sup>10, 17</sup> Placebo tablets contained only excipients.

Carn-BA and PLA tablets were both manufactured by Procemsa Farmaceutici (Nichelino, Turin, Italy). The purity of the supplement was tested independently from the formulator of the product, with the aim to exclude the presence of performance-enhancing compounds such as anabolic agents or stimulants.

Visits 2 and 3 were separated by at least two weeks, according to the reported time for carnosine washout.<sup>18</sup> During this period, participants were asked not to change their usual training program and nutrition. The Carn-BA or PLA supplementation was carried out in double-blind fashion and was administered four hours before tests. Some evidences, indeed, indicates that carnosine becomes available and ready to exert its function inside the muscle fibres just after few hours from ingestion.<sup>19</sup>

During visits 2 and 3, after maximum voluntary contraction (MVC) assessment of the knee extensor muscles of the dominant limb, maximum countermovement jump (CMJ) performance was evaluated. Then, a fatiguing protocol consisting of 45 s of continuous CMJ jumps was administered. After the fatiguing protocol, one MVC and one CMJ were performed again to assess the effects of fatigue.

Participants were asked not to engage in physical activity over 24 hours prior to the experiments. All tests were carried out in a climate-controlled laboratory (constant temperature of  $21 \pm 1$  °C and relative humidity of  $50 \pm 5$  %), approximately at the same hour of the day.

### *Experimental procedures*

Initially all participants completed a standardized warm-up which consisted of 10 min of running at a slow pace, two sets of five isometric submaximal contractions and three trials of vertical jumps.

MVC assessment. After the warm-up, participants completed three trials of maximal isometric effort with the dominant leg knee extensors, each lasting 3 s, with 4 min of rest in

between. The highest value obtained was considered as the maximum voluntary contraction (MVC).

During tests, participants seated on a knee-extensor ergometer with the knee joint at 90 degrees. The load cell attached to the ergometer was connected to a carbon shin pad positioned on the dominant leg of the participant by an inextensible steel wire. The position of the subject on the ergometer and the placement of the shin pad on the leg was carefully standardized. To isolate the knee extensor muscles contribution to the force output, limiting accessory muscles involvement, participants were also secured to the ergometer with Velcro straps at the chest. After the fatiguing protocol, a single MVC determination was immediately repeated.

CMJ. Before the fatiguing protocol and three minutes after the last MVC assessment, participants performed three single CMJ on a force platform (4 Jump, Kiestler, Zurich, CH), with a recovery time of 3 min between trials. Participants squatted down until the knees were bent at 90°. The knee angle was measured by an electrogoniometer (Biopac System Inc., Goleta, CA, USA) and the full knee extension was assumed to be 0°. Operators firmly encouraged the participants to jump as high as possible. After the fatiguing protocol and after MVC reassessment, one CMJ was repeated in the same way as before. Each selected jump was analyzed using a custom-built software (Labview 7.1, National Instruments, Austin, TX, USA) that detected automatically different hallmarks (eccentric and concentric phase onsets, leaving and landing instants), and measured the variables of interest. The landing instant was detected as the instant at which ground reaction force exceeded 50 N. During each jump selected for the analysis, the following parameters were calculated: peak force (pF), contact time, and jump height.

Force and EMG signals. During MVC and jump tests, force output and electromyographic (EMG) signal from the *vastus lateralis* and *vastus medialis* muscles were recorded. The force output of the knee extensor muscles was recorded using a previously

calibrated load-cell (mod. SM-2000N, Interface, Scottsdale, UK). The force signal was filtered (bandwidth 2–64 Hz) and stored on a personal computer after A/D conversion (mod. UM150, Biopac System, Goleta, USA) with a sampling frequency of 2048 Hz. The EMG probe was positioned on the belly of the muscle, with the electrodes (4 silver bars with 1 mm diameter and 1 cm length, 1 cm interelectrode distance) perpendicular to the fibers major axis. The skin area under the EMG electrodes was shaved, gently abraded with fine sand paper and carefully cleaned with ethyl alcohol and conductive gel, to achieve an inter-electrode impedance below 2000  $\Omega$ . EMG was amplified (gain of 1000; mod. ASE16, LiSin, Turin, Italy; input impedance: 60 M $\Omega$ ; common-mode rejection ratio: >90 dB), filtered (bandwidth 10–500 Hz) and stored on a personal computer after A/D conversion (mod. UM150, Biopac System, Goleta, USA) at a sampling rate of 2048 Hz.

To avoid interference of transient phenomena, only the middle 2 s of the MVC test, where force signal remained steady, were analysed. From the EMG signal, time domain analysis allowed the calculation of the root mean square (RMS) during MVC and CMJ. EMG RMS values during CMJ were selected from the best jump, based on the following criteria: (a) the correct execution of the movement, determined by electrogoniometer (knee joint angle reaching 90°) and operator’s visual inspection, and (b) the maximal vertical height achieved. To account for daily variations, CMJ EMG RMS values were normalized to the highest EMG signal collected during MVC maneuver.

Blood lactate concentration ( $[La^-]$ ). Arterialized blood samples (5  $\mu$ l) were collected from the ear lobe before tests and at minute 1, 3 and 6 of recovery after the fatiguing protocol. Samples were immediately analysed using a portable system (Lactate Pro LT-1710, Arkay, Japan) to determine  $[La^-]$ .

Fatiguing protocol. After 5 minutes of recovery from pre-fatigue tests, participants performed 45 s of continuous CMJ, during which they verbally encouraged to jump with a



maximum frequency and height, always reaching a knee angle of 90° at the end of the eccentric phase of the movement. Again, the knee angle was monitored by an electrogoniometer, with the full knee extension assumed to be 0°.

Scales and surveys. The general and muscular RPE were measured immediately after the fatiguing protocol using the Borg scale (category ratio, CR-10<sup>20</sup>) to determine the perceptual level of effort. In addition to the information provided during the familiarization visit, the same instructions were repeated to the participants at the beginning of the experimental sessions. RPE scale was visible to the participants throughout the entire fatiguing protocol. Immediately after, participants were requested to give a rating of their general and muscular (lower limbs) perceived exertion. After being specifically instructed, participants were asked to classify their muscular pain at the lower limbs 24 h and 48 h after the end of the fatiguing protocol on a visual analogic scale (VAS<sub>24h</sub> and VAS<sub>48h</sub>, respectively). In particular, individuals were instructed to make a vertical mark on a 10 cm horizontal line, with the left edge of the line representing “no pain at all”, and the right edge of the line representing the “worst pain imaginable”.<sup>21</sup>

### *Statistics*

Statistical analysis was performed with a commercially available software (SigmaStat, Systat Software Inc., USA). A sample size of 12 participants was selected to ensure a statistical power >0.80. The normal distribution of the sampling was checked by a Shapiro-Wilk test. A two-way (condition\*time) ANOVA for repeated measures was utilized to detect statistical differences during the R-CMJ test. A post-hoc Bonferroni test was applied when necessary to establish the location of the differences. The magnitude of the changes were assessed using effect size (ES) statistics with the Standard Error of ES Estimate and the ES lower and upper 95% confidence interval (CI). ES was classified as trivial for ES values < 0.2, small between 0.2-0.6, moderate between 0.6-1.2, large between 1.2-2.0, very large >2.0.<sup>22</sup> Statistical level

of significance was fixed at an  $\alpha$  level  $< 0.05$ . Unless otherwise stated, results are expressed as mean  $\pm$  SD.

## Results

None of the participants reported the occurrence of side effects following the acute ingestion of Carn-BA, neither during the testing period nor in the next hours or the day after.

### *MVC pre- and post-fatiguing protocol*

As shown in Table 1, MVC was not statistically different between conditions before the-fatiguing protocol ( $P=0.141$ ,  $ES=-0.78$ ,  $CI=-1.8 - 0.24$ ). After the fatiguing protocol, MVC decreased from baseline by  $\sim 19\%$  and  $12\%$ , in PLA and Carn-BA, respectively ( $P=0.001$ ,  $ES=2.23$ ,  $CI=0.99 - 3.48$  for PLA;  $P=0.001$ ,  $ES=2.17$ ,  $CI=0.93 - 3.40$  for Carn-BA). However, MVC after the fatiguing protocol was higher in Carn-BA compared to PLA ( $+15\%$ ,  $P=0.012$ ,  $ES=-1.62$ ,  $CI=-2.75 - -0.49$ ). During MVC, EMG RMS was higher in PLA in respect to Carn-BA, both before and after the fatiguing protocol ( $P=0.011$ ,  $ES=-0.11$ ,  $CI= -1.09 - 0.87$  before the fatiguing protocol;  $P=0.044$ ,  $ES=-0.23$ ,  $CI=-1.22 - 0.75$  after the fatiguing protocol). Moreover, EMG RMS values decreased with fatigue by  $22\%$  ( $P=0.006$ ,  $ES=1.01$ ,  $CI=-0.03 - 2.05$ ) and by  $20\%$  ( $P=0.003$ ,  $ES=0.74$ ,  $CI=-0.28 - 1.75$ ) in PLA and in Carn-BA, respectively.

### *CMJ pre- and post-fatiguing protocol*

During CMJ, no differences in EMG RMS between groups (PLA and Car-BA,  $P=0.212$  and  $P=0.195$  for before and after the fatiguing protocol, respectively) and conditions (before and after the fatiguing protocol,  $P=0.069$  and  $P=0.192$  for PLA and Car-BA, respectively) were retrieved.

Carn-BA did not improve CMJ height compared to PLA, neither before ( $P=0.652$ ) nor after ( $P=0.217$ ) the fatiguing protocol. Nevertheless, Carn-BA prevented CMJ pF reduction

with fatigue. In PLA, indeed, the fatiguing protocol decreased CMJ pF by  $\sim 6\%$  ( $P=0.017$ ,  $ES=0.48$ ,  $CI= -0.51 - 1.48$ ), while in Carn-BA it did not ( $P=0.107$ ).

### *Fatiguing protocol*

As indicated in Table 2, Carn-BA had positive effects on the overall performance during the fatiguing protocol. In Carn-BA, the mean contact time through the fatiguing protocol was lower than in PLA by  $\sim 7\%$  ( $P=0.018$ ,  $ES=0.42$ ,  $CI= -0.57 - 1.41$ ). The mean height of the jumps was higher in Carn-BA than in PLA by  $\sim 6\%$  ( $P=0.025$ ,  $ES=-0.37$ ,  $CI= -1.36 - 0.61$ ). During the fatiguing protocol, significant decreases in jump height ( $P<0.001$  and  $P<0.001$  in Carn-BA and PLA, respectively; Figure 1, panel A), and increases in contact time ( $P<0.001$  and  $P<0.001$  in Carn-BA and PLA, respectively; Figure 1, panel B) were found in both groups from the 15<sup>th</sup> second onwards to the end of the fatiguing protocol.

Carn-BA did not affect  $[La^-]$  at the end of the fatiguing protocol ( $12.34 \pm 3.46$  and  $11.91 \pm 2.51$  mM in PLA and Carn-BA, respectively;  $P=0.256$ ).

ANOVA did not disclose significant differences in EMG RMS between Carn-BA and PLA during the fatiguing protocol, as shown in Figure 2.

### *Perceived exertion and pain*

The general and muscular RPE and the level of muscular pain at 24 and 48 h after the fatiguing protocol in PLA and Carn-BA are provided in Table 3. Immediately after the fatiguing protocol, less general effort was perceived in Carn-BA than in PLA ( $-6\%$ ;  $P=0.042$ ,  $ES=0.50$ ,  $CI= -0.49 - 1.50$ ). On the contrary, the muscular RPE measured at the end of the fatiguing protocol did not differ between PLA and Carn-BA ( $P=0.093$ ). VAS administered along the two days following the experiment unveiled higher levels of muscular pain in Carn-BA compared to PLA at 24 hours ( $+19\%$ ,  $P=0.039$ ,  $ES=-0.55$ ,  $CI= -1.55 - 0.44$ ), but similar values at 48 hours ( $P=0.472$ ).

## **Discussion**

The main finding of the present study was that Carn-BA acute supplementation was effective in ameliorating maximum static and dynamic tasks. With Carn-BA, the maximum isometric force dropped to a lesser extent after a 45-s fatiguing protocol. Moreover, jumps height was higher while contact time was lower throughout the fatiguing protocol, compared to PLA. Lastly, despite muscle pain indices at 24 hours were higher with Carn-BA, muscular RPE immediately at the end of the fatiguing protocol did not differ between conditions, and general RPE was lower in Carn-BA. These data suggest that Carn-BA had positive effects on static and dynamic performance during and after a high intensity fatiguing effort even when acutely administered.

### *Acute effects of Carn-BA on MVC and jump performance before the fatiguing protocol*

The influence of acute Carn-BA supplementation on the maximum isometric force and jump performance is a novel finding of this study. Our findings show a higher neuromuscular activation with Carn-BA, suggesting the occurrence of phenomena at central level neuromodulator.<sup>23</sup> However, they do not support the hypothesis of an acute effect of Carn-BA on unfatigued muscle performance. Even though MVC and CMJ pF showed higher values in Carn-BA with respect to PLA, the difference did not achieve statistical significance, suggesting that the tendency of Carn-BA to ameliorate maximum static and dynamic performance needs further investigation. In previous studies, the increase in muscle carnosine levels has been shown to induce positive effects on muscle performance in continuous or intermittent exercise.<sup>13, 24, 25</sup> These observations, though, were made only after chronic supplementation. No studies on the effects of Carn-BA on maximum isometric force output have been performed so far. Therefore, comparisons with previous findings cannot be made.

*Acute effects of Carn-BA on MVC and jump performance during and after the fatiguing protocol*

As expected, MVC decreased after the fatiguing protocol in both Carn-BA and PLA. However, the MVC post-fatigue value in Carn-BA was higher than in PLA, suggesting that muscle contractile properties were less affected by the fatiguing protocol with acute Carn-BA supplementation. Carn-BA effects on MVC were accompanied by similar effects on EMG activity. In particular, the neural drive was higher in Carn-BA as before fatigue, and neuromuscular activation dropped to a lesser extent after the fatiguing protocol, suggesting that after the fatiguing protocol Carn-BA effects were evident also at the force output level. Collectively, we cannot exclude that the higher MVC in Carn-BA after the fatiguing protocol could be attributed to phenomena occurring at central level neuromodulator.<sup>23</sup> This explanation, though, may require further investigation.

In addition to these Carn-BA positive effects on MVC, CMJ pF in Carn-BA did not drop after the fatiguing protocol as in PLA (see Table 1), even though CMJ height did not change with fatigue. A decrease in jump height would be reasonably expected after a fatiguing jumping exercise.<sup>26,27</sup> The discrepancy could be possibly explained by the higher number of jumps performed in the two cited studies compared to those in the present investigation. Moreover, the longer recovery time before performing the CMJ post-fatiguing protocol may have played a role. Indeed, in our study the CMJ measurement was accomplished after MVC assessment, as MVC was chosen as the main parameter to determine the presence of fatigue. Consequently, MVC test was performed immediately at the end of the fatiguing protocol. This experimental procedure delayed the CMJ test by about 6 minutes (for  $[La^-]$  determination during recovery), compared to less than 2 minutes from the end of the fatiguing protocol in the studies of King and coworkers<sup>26</sup> and Skurvydas and coworkers.<sup>27</sup> This period likely allowed

the participants to recover from fatigue, at least in part, before maximum jump performance reassessment.

The positive effects of acute Carn-BA supplementation had further support from the findings during the fatiguing protocol (Table 2), where Carn-BA condition highlighted a lower average contact time and a higher average jump height. Moreover, Carn-BA counteracted the fall in jump height and the rise in contact time after the first 15 seconds of the fatiguing protocol, as shown in Figure 1. Compared to PLA, the better jump performance with Carn-BA may be ascribed to the reported amelioration in buffering capacity and/or an increased  $\text{Ca}^{2+}$  unloading at the muscle level, where Carn-BA exerts its primary function.<sup>6-8, 11, 17</sup> Should the Carn-BA-induced increase in buffering capacity be the explanation,<sup>19</sup> muscle contractility may have been considerably preserved in Carn-BA compared to PLA, thus limiting the drop in jumping capacity. On the contrary, should the effect of Carn-BA on dynamic performance be based on higher  $\text{Ca}^{2+}$  unloading at the sarcomere level,<sup>11</sup> leading to an increase in cross-bridge formation and force output, this would anyway explain the present findings. Further studies, though, involving muscle biopsies before and after the same fatiguing protocol would be required to elucidate these or other explanations.

Noticeably, the different behavior in Carn-BA became evident after the first 10 seconds of the fatiguing protocol, leading to the hypothesis that the increased muscle carnosine content exerted an effect few seconds from the beginning of the fatiguing exercise.

#### *Acute effects of Carn-BA supplementation on RPE and pain*

RPE and pain surveys showed an interesting and unexpected finding supporting the beneficial effects of Carn-BA to improve the performance during and after a fatiguing exercise. Indeed, RPE at the end of the fatiguing protocol should have been similar in PLA and Carn-BA because of the exhaustive meaning of the fatiguing protocol and of the consequential intensity constraint asked to the participants (all-out continuous jumps). However, while this is

what occurred for the muscular RPE, this was not the case for general RPE (lower value in Carn-BA compared to PLA). A first explanation may come from the lower contact time in Carn-BA compared to PLA that may reflect a higher usage of the elastic component during the jumps, thus entailing a lower perception of effort. An alternative or complementary explanation could be ascribed to some effects that carnosine has been reported to induce on the central nervous system.<sup>23</sup> Carn-BA, indeed, can affect either the motor cortex or the generation of the effort sensation through the corollary discharge, inducing a positive effect on the general perception of effort.<sup>28</sup>

Compared to PLA, muscular pain was higher in Carn-BA after 24 hours from the fatiguing protocol, but not different at 48 hours. This finding may help to further understand the contribution of Carn-BA in improving muscle performance. Possibly, participants were able to push harder with Carn-BA and stress their muscles to a higher extent, reporting better jumps with the same muscular RPE as in PLA. However, they experienced more muscular pain the day after the fatiguing exercise may be due to a higher delayed muscular soreness induced by the greater effort in Carn-BA, returning to a level similar to PLA after 48 hours.

## **Conclusions**

Acute Carn-BA supplementation few hours prior to exercise improved muscle performance during and after a fatiguing effort of high-intensity. This acute supplementation induced positive effects on MVC and CMJ after the fatiguing protocol and improved CMJ performance during the 45 s continuous jumping effort. The increased muscular engagement was accompanied by a reduction in general RPE, and led to a higher level of muscular pain 24 h after the fatiguing protocol. As a practical application, in sports involving high intensity anaerobic efforts, athletes may take advantage of acute Carn-BA supplementation, which in the present investigation reported benefits similar to other protocols based on chronic

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*International Journal of Sports Physiology and Performance*  
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supplementation. Further studies on Carn-BA dose-response and on the effects of different diets on intracellular carnosine levels are required for a better understanding of the topic.

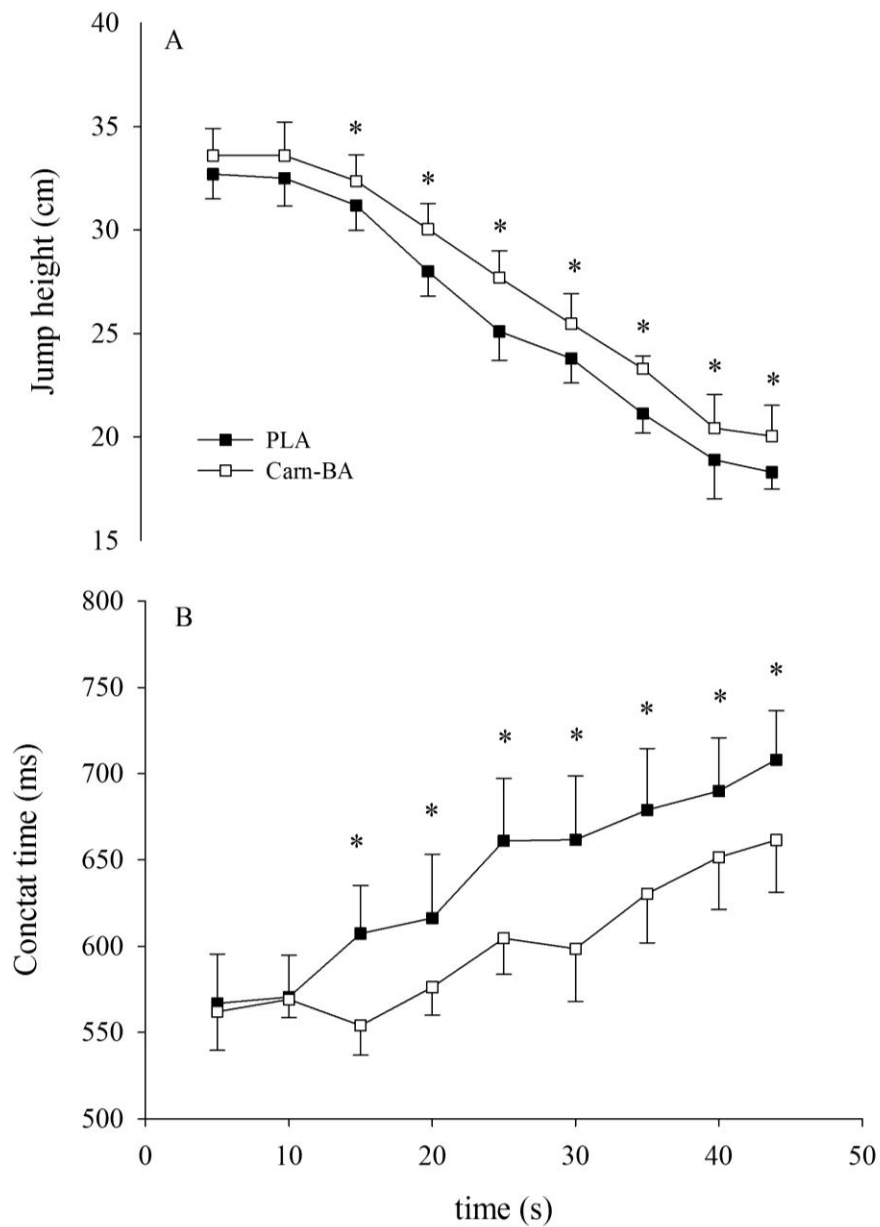


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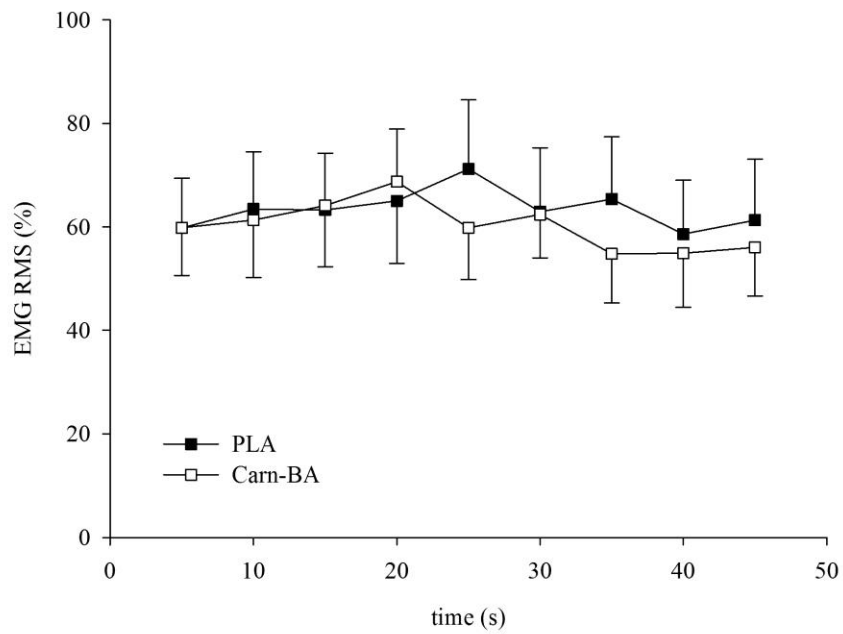
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**Figure 1:** Jump height (panel A) and contact time (panel B) during the 45-s fatiguing protocol with (Carn-BA) and without (PLA) supplementation. Error bars indicate standard error values. \* $P < 0.05$  between conditions.



**Figure 2:** EMG root mean square (RMS) values, normalized to the value obtained during MVC, throughout the 45-s fatiguing protocol with (Carn-BA) and without (PLA) supplementation. Error bars indicate standard error values.

**Table 1**

|                 | PLA           |                            | Carn-BA                    |                               |
|-----------------|---------------|----------------------------|----------------------------|-------------------------------|
|                 | before        | after                      | before                     | after                         |
| MVC (N)         | 687 (61)      | 553 (52) <sup>b</sup>      | 727 (31)                   | 637 (46) <sup>a, b</sup>      |
| EMG RMS (mV)    | 0.355 (0.079) | 0.278 (0.073) <sup>b</sup> | 0.372 (0.088) <sup>a</sup> | 0.298 (0.087) <sup>a, b</sup> |
| CMJ pF (N)      | 2041 (257)    | 1916 (216) <sup>b</sup>    | 2125 (224)                 | 2045 (171)                    |
| CMJ height (cm) | 32.3 (5.9)    | 33.4 (7.3)                 | 31.6 (7.3)                 | 33.2 (6.5)                    |
| EMG RMS (mV)    | 0.216 (0.119) | 0.210 (0.155)              | 0.220 (0.097)              | 0.204 (0.079)                 |

Static and dynamic tests results in the two conditions, before and after the fatiguing protocol. MVC, maximum voluntary contraction; EMG RMS, EMG root mean square (during both MVC and countermovement jump, CMJ); pF, force peak. Standard deviation values are given in parentheses. PLA, placebo; Carn-BA, carnosine with  $\beta$ -alanine supplementation. <sup>a</sup> $P < 0.05$  vs PLA; <sup>b</sup> $P < 0.05$  vs before.

**Table 2**

|                           | PLA           | Carn-BA       |
|---------------------------|---------------|---------------|
| Jumps (n.)                | 39.5 (4.0)    | 39.9 (3.8)    |
| Average contact time (ms) | 647.1 (111.9) | 604.7 (81.4)* |
| Average jumps height (cm) | 25.7 (3.1)    | 27.2 (3.8)*   |

Mean values along the 45 s rebound countermovement jump. Measurements' standard deviation is given in parentheses. \* $P < 0.05$  vs PLA.

**Table 3**

|                         | PLA       | Carn-BA    |
|-------------------------|-----------|------------|
| General RPE (au)        | 8.0 (0.8) | 7.5 (1.0)* |
| Muscular RPE (au)       | 7.5 (1.6) | 7.1 (1.5)  |
| VAS <sub>24h</sub> (cm) | 3.7 (1.1) | 4.4 (1.3)* |
| VAS <sub>48h</sub> (cm) | 2.2 (1.7) | 2.1 (0.7)  |

Rate of perceived exertion (RPE) and pain at the end and after 24 and 48 hours from the end of the fatiguing task. Standard deviation values are given in parentheses. VAS, visual analogic scale. \* $P < 0.05$  vs PLA.