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Original article

Effect of branched-chain amino acid intake with different leucine concentrations on the total number of repetitions performed during resistance exercise

Efeito da ingestão de aminoácidos de cadeia ramificada com diferentes concentrações de leucina sobre o número total de repetições realizadas durante o exercício resistido

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ABSTRACT

Introduction: the supplementation of branched chain amino acids (BCAA) has been widely used and studied during long-term activities, however, it presents a limited number of studies elucidating the effect of this supplementation during resistance training (RT). **Objective:** to evaluate the influence of BCAA intake, containing different concentrations of leucine, on the total number of repetitions performed during this practice. **Methods:** eight participants (4 men and 4 women; age: 20 to 35 years), with experience in RT between 3 and 18 months, performed 10 series with a load corresponding to 80% of 1RM, after ingestion of 0.4 g/kg of BCAA body weight diluted in 250 ml water, with two different leucine concentrations: 4: 1: 1 (3 g leucine, 750 mg isoleucine and 750 mg valine) and 6: 1: 1 (4.5 g leucine, 750 mg isoleucine and 750 mg valine), in addition to the control treatment (CON), characterized by the ingestion of 250 ml water containing a non-caloric dietary compound. **Results:** it was observed that the total number of repetitions performed in the 10 series was significantly higher for the 6: 1: 1 treatment (70.0 ± 9.5) when compared to the CON treatment (59.8 ± 9.9), different from the 4: 1: 1 treatment (66.8 ± 7.3), which presented a statistically similar result. **Conclusion:** the concentration of the leucine amino acid, related to the supplemented BCAA dose, is significant to obtain the ergogenic effects promoted by this supplement during the practice of resistance exercise.

Keywords: physical exercise; muscle fatigue; nutritional supplements.

RESUMO

Introdução: a suplementação de aminoácidos de cadeia ramificada (BCAA) tem sido amplamente utilizada e estudada durante as atividades de longa duração, no entanto, apresenta um número restrito de estudos elucidando o efeito desta suplementação durante o treinamento resistido (TR). **Objetivo:** avaliar a influência da ingestão de BCAA, contendo diferentes concentrações de leucina, sobre o número total de repetições realizadas durante essa prática. **Métodos:** oito participantes (4 homens e 4 mulheres; idade: 20 a 35 anos), com experiência no TR entre 3 e 18 meses, realizaram 10 séries com carga referente a 80% de 1RM, após a ingestão de 0,4 g/kg de peso corporal de BCAA diluídos em 250 ml água, com duas diferentes concentrações de leucina: 4:1:1 (3 g leucina, 750 mg isoleucina e 750 mg valina) e 6:1:1 (4,5 g leucina, 750 mg isoleucina e 750 mg valina), além do tratamento controle (CON), caracterizado pela ingestão de 250 ml água contendo um composto dietético não calórico. **Resultados:** observou-se que o número total de repetições realizadas nas 10 séries foi significativamente maior para o tratamento 6:1:1 (70,0 ± 9,5) quando comparado ao tratamento CON (59,8 ± 9,9), diferente do tratamento 4:1:1 (66,8 ± 7,3) que apresentou resultado estatisticamente semelhante. **Conclusão:** a concentração do aminoácido leucina, relacionada à dose de BCAA suplementada, é significativa para obtenção dos efeitos ergogênicos promovidos por este suplemento durante a prática do exercício resistido.

Palavras-chave: exercício físico; fadiga muscular; suplementos nutricionais.

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Introduction

Currently, due to the growing number of scientific researches reporting the benefits of regular physical exercise, the number of practitioners has increased substantially [1].

Concerning the places used for this practice, due to the social character, the facilities, and amenities provided, the gyms have been gaining, mainly through resistance training (RT), new followers every day [2].

Among the objectives pursued by these practitioners, there is an improvement in health (in general), in physical fitness, and in the aesthetic standard of the body, in addition to, in many cases, an evolutionary physical rehabilitation [3]. It should be noted that related to the objectives mentioned before, the increase in muscle trophism (muscle hypertrophy) is one of the most frequent morphophysiological adaptations in practitioners of physical exercises. There are several molecular mechanisms associated with the muscle hypertrophy process [4]. Some of them are even optimized from the supplementation of specific nutrients [5].

In any case, whatever the intended objective, progression will only be achieved if the scientific principles of physical training are obeyed. Among these, the overload principle stands out, understood as the basis for the progress of any capacity that we want to improve [2,6].

The overload will be modified by manipulating the volume and/or intensity of the exercise, being inversely related to fatigue, whether central or peripheral [1,2,6].

Central fatigue can be defined as the state in which the cognitive actions that depend on the increase in the effort are interrupted, implying a reduction in the activity of the central nervous system (CNS), generating the decrease of motor units involved in the effort or their firing frequency and, as a consequence, loss of performance [7].

On the other hand, peripheral fatigue is related to neuromuscular events that can understand the inefficiency of the action potential through the sarcolemma, variations in the excitation and contraction process, decrease in high-energy phosphates in the intramuscular region, and the muscle metabolites accumulation [8,9].

As for resistance exercise, the fatigue experienced during the training session is related to complications that occur mainly at the neuromuscular level [10].

Neuromuscular fatigue can be considered as the loss of muscle's ability to generate strength or maintain performance during physical exercise [11,12]. This phenomenon has been widely studied in recent years, suggesting that this event is part of a complex and integrated response between the CNS, peripheral nervous system (PNS), neuromuscular junction, and muscle cells [13,14].

As a result of the above, branched-chain amino acids (BCAA) have become popular in the routine of nutritional supplementation, recommended as ergogenic resources in exercises with aerobic metabolic predominance and strength exercises.

Therefore, BCAAs have been increasingly used as a non-pharmacological strategy in reducing the fatigue experienced during physical exercise, as well as in promoting muscle protein anabolism [15,16].

The concentration of amino acids in the plasma is maintained steadily after ingestion. However, this concentration may change in metabolic conditions in which catabolism prevails. High-intensity or long-term exercises, for example, can be considered catabolic factors that alter the concentration of circulating amino acids in the plasma [17-19].

When the body is placed in situations of very intense or bulky efforts, these stimuli can cause the degradation of body proteins, especially those that form the muscular structure. Based on this principle, the use of BCAA, as an ergogenic resource, would serve as a strategy to minimize these catabolic effects that promote, among other consequences, the decline in physical performance [20-24].

BCAAs, after ingestion, are primarily oxidized in the muscle, i.e., the uptake and activation of the metabolic pathways of these amino acids favor muscle anabolism. Karlsson *et al.* [25] showed that the intake of 7.5 grams of BCAA promoted a 100% increase in the concentration of amino acids in the plasma, allowing a higher anabolic response to the placebo group.

Although most studies indicate that BCAAs can be ingested before, during, or even after an acute training session, it is essential to note that there is still a contradiction related to a possible performance gain. Studies that analyzed this type of intervention at times presented positive results, and at other times did not point out a significant change in physical performance [26].

Another point to be highlighted is that leucine, among BCAAs, has a higher performance, both from an anabolic point of view [27] and reducing fatigue [28]. It appears that the large variation in the amount of leucine used, as seen with BCAA supplementation, has generated ambiguous results.

Therefore, the present study's objective was to evaluate the influence of resisted pre-training intake of BCAA, containing different concentrations of leucine, on the total number of repetitions performed during this practice.

Methods

Eight healthy adult individuals (4 men and 4 women), aged between 20 and 35, were selected for the study. As an inclusion criterion, individuals should be regularly practicing RT between 3 and 18 months. On the other hand, the anabolic hormones use, food supplements, or anti-inflammatory drugs were considered exclusion criteria to compose this study's sample.

This research followed the rules for the tests' application on human beings under Resolution 466/12 of the Ministry of Health. It was approved by the Ethics Committee of the Faculty of Medical and Health Sciences of PUC/SP (01985418.9.0000.5373). The present study had the Physical Conditioning-room of the Academia Molhação -

Acqua e Fitness gym (São Roque/SP) as a research field. All participants signed the Informed Consent Form (ICF).

The supplement used by all subjects in the sample was the Amino BCAA (Recover my clinical line) in two different concentrations, enabling two experimental treatments: BCAA 4:1:1 (intake of branched-chain amino acids containing 3 g of leucine, 750 mg of isoleucine, and 750 mg of valine per 6 g of the product), and BCAA 6:1:1 (intake of branched-chain amino acids containing 4.5 g of leucine, 750 mg of isoleucine and 750 mg of valine per 6 g of the product). It is noteworthy that the dose used in the present study was 0.4 g BCAA/kg of body weight diluted in 250 ml of water, similar to that used by Ratames *et al.* [29] in an experimental study already published.

Regarding the control treatment (CON), the sample subjects ingested 1.6 g of a non-caloric dietary compound FIT® (substance considered placebo, with a similar appearance and taste to the product used in the experimental phase, containing 0.36 mg of aspartame, 0.53 mg of acesulfame potassium and 23 mg of sodium), diluted in the same 250 ml of water used in the experimental treatments.

The administration of supplements in the experimental and control treatments was carried out at random, 30 minutes before each RT session, separated by an interval of 7 (seven) days, during which the participants were allowed to continue only their training routine for lower limbs.

The one maximum repetition (1RM) test was used to determine the load to be applied for the bench press exercise in the supine position, according to methods previously described by Kraemer and Fry [30]. The test started with a warm-up, consisted of performing 2 sets of 5 to 10 repetitions of the straight supine movement, using 40-60% of the predicted load for 1RM, respecting an interval of 2 minutes between sets. Subsequently, after a 5-minute pause, between 2 and 4 attempts were made to determine the load equivalent to 1RM. Rest periods between attempts were 2 to 5 minutes [30].

On the days of the evaluation sessions, the individuals were submitted to 10 sets of the bench press exercise in the supine position, using a load corresponding to 80% of 1RM. The exercise started from the supine position with the torso leaning on the bench, knees flexed, with the feet resting on the ground, elbows with moderate flexion, shoulders adduced horizontally. The hands were positioned on the bar in a position equivalent to twice the biacromial distance. In the concentric phase, the shoulders' horizontal adduction and elbow extension were performed, and subsequently, during the eccentric phase, the return to the initial position occurred.

During the performance of the sets, individuals were encouraged to perform as many repetitions as possible. The foot movement, loss of hip contact with the bench, upper limbs incoordination during the movement's concentric phase, or muscle failure were adopted as criteria for interrupting the sets.

To bring the evaluation sessions protocol closer to the reality experienced in the daily life of the gyms, the recovery time between these sessions sets was established at 1'30'' in the first three sets, at 1'45'' between the 4th and 6th sets, and 2' in the remaining four sets.

The individuals underwent 3 evaluation sessions, one after the intake of dietary juice (CON) and the other two after the intake of BCAAs with concentrations of 4:1:1 and 6:1:1. As already shown, the order of the sessions (BCAA or CON) was carried out at random.

The workload was demonstrated from the following sums, in each evaluation session, for further comparison and analysis of the data: 1) the number of total repetitions (performed in the 10 sets); 2) the number of repetitions performed in the first 5 sets; 3) the number of repetitions performed in the last 5 sets.

The results of the different sessions were expressed as means and standard deviations. The data normality was verified by the *Kolmogorov–Smirnov's test*. To compare the individuals' means in the sessions with different supplements, the variance analysis for parametric data was used (one-way ANOVA). To indicate possible differences, *Tukey's posthoc test* was used. For all cases of analysis, a significance level of $p < 0.05$ was adopted. The indication of the sample number was based on the studies by Ratames *et al.* [29], Kraemer *et al.* [31], Sharp and Pearson [32], and Van Dusseldorp *et al.* [33].

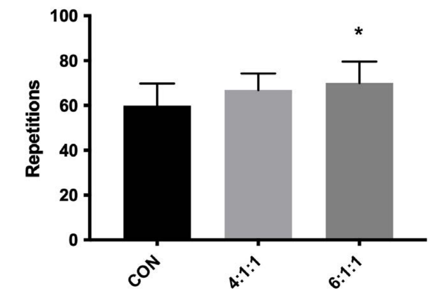
The statistical analysis was performed with the aid of the *GraphPad Prism* 8.0 *software*.

Results

Currently, the number of RT practitioners has been increasing significantly, and, in association, the search for improving physical fitness and performance has also grown exponentially. In this context, the BCAA supplementation strategy has been increasingly used for optimizing the performance during the resisted exercise execution. However, the studies presented are controversial regarding the use of this resource [24,26].

To investigate the BCAA efficiency on the practitioners' performance, the present study simulated the volume of training used in gyms (between 9 and 12 sets per muscle group) and assessed the number of repetitions performed during the execution of 10 sets performed with 80% of 1RM.

As main results, it is possible to observe in Figure 1 that it occurred, related to the sum of the total number of repetitions of the straight supine movement in the 10 sets performed, a significant difference between the treatment with BCAA 6:1:1 and the CON treatment ($p < 0.05$).



*Statistical difference ($p < 0.01$) concerning the CON

Figure 1 - Average of the sum of the total number of repetitions performed during the 10 sets in the treatments CON (59.8 ± 9.9), BCAA 4:1:1 (66.8 ± 7.3), and BCAA 6:1:1 (70.0 ± 9.5)

Other interesting answers were found when the results referring to the first 5 and the last 5 sets performed were analyzed separately. The average of the sum of the total number of repetitions performed in the first 5 sets did not show any significant difference between treatments (Figure 2).

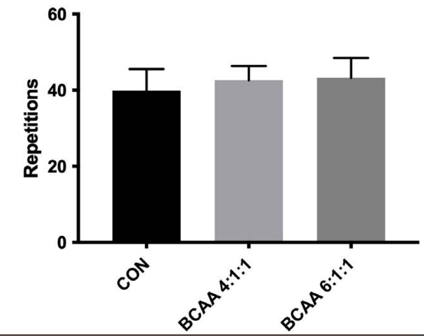
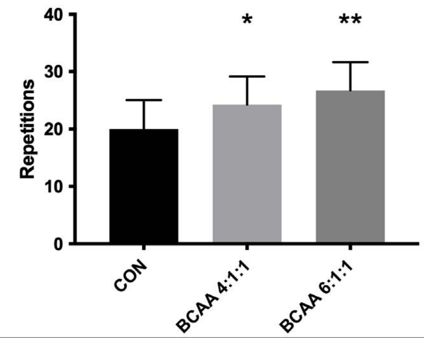


Figure 2 - Average of the sum of the total number of repetitions performed in the first 5 sets of treatments CON (39.8 ± 5.6), BCAA 4:1:1 (42.6 ± 3.7), and BCAA 6:1:1 (43.2 ± 5.2)

However, when analyzing the average sum of the total number of repetitions performed in the last 5 sets in the different treatments (Figure 3), a significantly higher result was observed in the treatments with BCAA supplementation when compared to the CON treatment. It was also observed that the treatment related to the ingestion of a higher concentration of leucine (BCAA 6:1:1) provided a higher statistical difference ($p < 0.02$) about the treatment related to a lower concentration of leucine ($p < 0.03$) when compared to the CON treatment.



*Statistical difference ($p < 0.03$) concerning the CON; **Statistical difference ($p < 0.02$) concerning the CON

Figure 3 - Average of the sum of the total number of repetitions performed in the last 5 series of treatments CON (20.0 ± 5.0), BCAA 4:1:1 (24.2 ± 4.8), and BCAA 6: 1: 1 (26.7 ± 4.8)

Discussion

Regarding BCAA supplementation, most studies show concern for analyzing the effects of these amino acids on muscle anabolism and catabolism [25]. Relating the effects of BCAAs with performance and muscle fatigue, some studies have been found, although, generally, methodologically designed using exercises with a predominance of aerobic metabolism [34]. Seeking to propose another scenario, the present study was conceived using the relationship between BCAA supplementation vs. resistance training vs. muscle fatigue.

It was observed, in the present study, that the pre-RT supplementation with 0.4 g BCAA/kg in a concentration of 6:1:1 (leucine, isoleucine, and valine, respectively) resulted in a higher sum of repetitions performed during the execution of 10 sets in the bench press exercise on the horizontal bench when compared to the CON treatment. However, it is noteworthy that several studies that analyzed the effects of BCAA supplementation on performance during the performance of RT showed a lot of contradiction in the results [26].

Fujita *et al.* [35] evaluated the effects of BCAA intake, containing 1 g leucine at a dose of 0.35 g BCAA/kg of body weight, on biochemical markers after performing 10 sets of 10RM in the leg extension exercise, not observing changes in the fatigue. In another study, Sharp and Pearson [32] also found no difference in performance among the group supplemented with BCAA (supplementation twice a day, with the following concentration: leucine: 1800 mg; isoleucine: 750 mg; valine: 750 mg) and the control group.

A probable explanation for the result found in the present study lies in the dose used in BCAA treatments. After reviewing the literature on the effects of BCAA supplementation on performance during RT, it was observed that the study by Ratames *et al.* [29], whose objective was to verify the influence of BCAA supplementation (with a dose of 0.4 g BCAA/kg of body weight) on performance during RT, demonstrated an increase in performance in the bench press and barbell squat exercises.

To verify BCAA supplementation influence on the training volume, the sum of the repetitions number, performed during the first 5 and 5 last sets, was analyzed separately. Regarding the sum of the first 5 sets, it was observed that the CON treatment obtained an average of repetitions like the two treatments with BCAA. On the other hand, when analyzing the sum of the number of repetitions performed during the last 5 sets, the results indicate that both BCAA treatments performed a higher number of repetitions when compared to the CON treatment, although the BCAA 6:1:1 treatment presented a higher difference ($p < 0.02$) than the BCAA treatment 4:1:1 ($p < 0.03$) in these comparisons. This can be explained because the factors related to muscle fatigue do not impair performance until a specific volume of training is performed [17-19,36].

A possible explanation for the increase in the number of repetitions performed, especially during the last 5 sets, is the fact that BCAAs can be metabolized and converted into Acetyl-coenzyme A (Acetyl-CoA) groups; being sent subsequently to the Tricarboxylic Acid Cycle (TCA cycle) [37]. In this way, the BCAA could complement the release of energy necessary for the quantitatively more adequate resynthesis of Adenosine Triphosphate (ATP) at that exact moment of the exercise. As described by Gastin [38], during recovery intervals, a part of the resynthesized ATP is cleaved to provide energy for the reconstruction of Creatine Phosphate (CP). Therefore, we can raise the hypothesis that the increase in the supply of Acetyl-CoA to TCA cycle, originating from BCAA, could also increase the rate of resynthesis of ATP between the sets performed, accelerating the resynthesis of CP stocks and allowing the individual, consequently, a greater work capacity in the subsequent sets.

Another fact that deserves attention is that the greater resynthesis of CP between the sets would result in greater participation of this energetic substrate in the execution of the subsequent sets and, according to Robergs, Ghiasvand & Parker [39], the cleavage of the CP would assist in the buffering of H+ protons released during ATP hydrolysis, thereby reducing the chance of intracellular pH imbalance (metabolic acidosis), minimizing muscle fatigue.

It is worth mentioning that the present study used a sample number of 8 individuals, which could limit, in part, the results and conclusions presented here. However, the sample number of the experimental group of other studies carried out with the same intention [29,31-33], that is, evaluating the effects of supplementation with BCAA, was like the one used here.

Conclusion

This study aimed to evaluate the influence of BCAA intake, containing different concentrations of leucine, on the total number of repetitions performed in resistance training.

Based on the results obtained, it is concluded that BCAA supplementation, with a 6:1:1 concentration, is associated with an increase in the total number of repetitions performed when compared to the control treatment, emphasizing that, in the second half of the training session (last 5 sets), this increase, about the control group, was also observed in the treatment with the concentration 4:1:1. Therefore, BCAA supplementation, especially with a higher leucine concentration, seems to have a relevant effect in reducing muscle fatigue during the resistance training practice, optimizing performance, especially concerning the training volume-dependent (number of sets performed).

However, it is worth noting that this group of authors understands the need for further studies to elucidate this topic, including using different doses of BCAA with other concentrations of the amino acid leucine in populations with diverse levels of physical fitness and age group.

Potential conflict of interest
No conflicts of interest with relevant potential for this article was reported.

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There were no external sources of funding for this study.

Authors' contributions
Research conception and design: Machado OAS, Haddad RN. **Obtaining data:** Haddad RN, Machado OAS. **Analysis and interpretation of data:** Machado OAS, Lima WP. **Statistical analysis:** Machado OAS. **Obtaining financing:** Machado OAS, Gianolla F. **Manuscript writing:** Haddad RN, Machado OAS, Lima WP, Machado GAC, Gianolla F. **Critical review of the manuscript for important intellectual content:** Lima WP, Machado GAC, Machado OAS.

References

1. Fisher J, Steele J, Stewart B, Dave S. Evidence-based resistance training recommendations. Med Sport 2011;15:147-62. doi: 10.2478/v10036-011-0025-x

2. American College of Sports Medicine. Progression models in resistance training for healthy adults. Med Sci Sports Exerc 2009;41(3):687-708. doi: 10.1249/MSS.0b013e3181915670

3. Santarem JM. Musculação em todas as idades: comece a praticar antes que o seu médico recomende. Barueri: Manole; 2012.

4. Lima WP. Mecanismos moleculares associados à hipertrofia e hipotrofia muscular: relação com a prática do exercício físico. Rev Bras Fisiol Exerc 2017;16(2):95-113. doi: 10.33233/rbfe.v16i2

5. Lane MT, Herda TJ, Fry AC, Cooper MA, Andre MJ, Gallagher PM. Endocrine responses and acute mTOR pathway phosphorylation to resistance exercise with leucine and whey. Biol Sport 2017;34(2):197-203. oi: 10.5114/biolsport.2017.65339

6. Davies T, Orr R, Halaki M, Hackett D. Effect of training leading to repetition failure on muscular strength: a systematic review and meta-analysis. Sports Med 2016;46(4):487-502. doi: 10.1007/s40279-015-0451-3

7. Morgan RM, Parry AM, Arida RM, Matthews PM, Davies B, Castell ELM. Effects of elevated plasma tryptophan on brain activation associated with the Stroop task. Psychopharmacology 2006;190(3):383-89. doi: 10.1007/s00213-006-0609-7

8. Allen DG, Lamb GD, Westerblad H. Skeletal muscle fatigue: cellular mechanisms. Physiol Rev 2008;88(1):287-332. doi: 10.1152/physrev.00015.2007

9. O'Leary TJ, Morris MG, Collett J, Howells K. Central and peripheral fatigue following non-exhaustive and exhaustive exercise of disparate metabolic demands. Scand J Med Sci Sports 2016;26(11):1287-1300. doi: 10.1111/sms.12582

10. Gibson H, Edwards RHT. Muscular exercise and fatigue. Sports Med 1985;2:120-32. doi: 10.2165/00007256-198502020-00004

11. Newsholme EA, Blomstrand E. The plasma level of some amino acids and physical and mental fatigue. Experientia 1996;52(5):413-15. doi: 10.1007/BF01919308

12. Jakeman PM. Amino acid metabolism, branched-chain amino acid feeding and brain monoamine function. Proc Nutr Soc 1998;57(1):35-41. doi: 10.1079/PNS19980007

13. Pires FO. Thomas Kuhn's Structure of Scientific Revolutions' applied to exercise science paradigm shifts: example including the Central Governor Model. J Sports Med 2012;47(11):721-2. doi: 10.1136/bjsports-2012-091333

14. Siegler JC, Marshal IP. The effect of metabolic alkalosis on central and peripheral mechanisms associated with exercise-induced muscle fatigue in humans. Exp Physiol 2015;100(5):519-30. doi: 10.1113/EP085054

15. Rogero MM, Tirapegui J. Aspectos atuais sobre aminoácidos de cadeia ramificada e exercício físico. Rev Bras Cienc Farm 2008;44(4):563-75. doi: 10.1590/S1516-93322008000400004

16. Pereira Junior M. Aspectos atuais sobre aminoácidos de cadeia ramificada e seu efeito ergogênico no desempenho físico humano. Revista Brasileira de Nutrição Esportiva [Internet] 2012;6(36):436-48. [cited 2021 Jan 10] Available from: http://www.rbne.com.br/index.php/rbne/article/view/333

17. Schaefer A, Piquard F, Geny B, Doutreleau S, Lampert E, Mettauer B, Lonsdorfer J. L-arginina reduces exercise-induced increase in plasma lactate and ammonia. Int J Sports Med 2002;23(6):403-7. doi: 10.1055/s-2002-33743

18. Popovic PJ, Zeh HJ, Ochoa JB. Arginine and immunity. J Nutr 2007;137(6):1681-86. doi: 10.1093/jn/137.6.1681S

19. Manso Filho HC, Mckeever KH, Gordon ME, Manso HE, Legakos WS, Wu G. Developmental changes in the concentrations of glutamine and other amino acids in plasma and skeletal muscle of the standard bed foal. J Anim Sci 2009;87(8):2528-35. doi: 10.2527/jas.2009-1845

20. Hsueh CF, Wu HJ, Tsai TS, Wu CL, Chang CK. The effect of branched-chain amino acids, citrulline, and arginine on high-intensity interval performance in young swimmers. Nutrients 2018;10:1979. doi: 10.3390/nu10121979

21. Norton LE, Layman DK. Leucine regulates translation initiation of protein synthesis in skeletal muscle after exercise. J Nutr 2006;136(2):533S-37S. doi: 10.1093/jn/136.2.533S

22. Kimball SR, Jefferson LS. New functions for amino acids: effects on gene transcription and translation. Am J Clin Nutr 2006;83(2):500-7. doi: 10.1093/ajcn/83.2.500S

23. Blomstrand E, Eliasson J, Karlsson HK, Kohnke ER. Branched-chain amino acids active key enzymes in protein synthesis after physical exercise. J Nutr 2006;136(1):269-73. doi: 10.1093/jn/136.1.269S

24. Cruzat VF, Krause M, Newsholme EP. Amino acid supplementation and impact on immune function in the context of exercise. J Int Soc Sports Nutr 2014;11(1):1-13. doi: 10.1186/s12970-014-0061-8

25. Karlsson H, Nilsson PA, Nilsson J, Chibalin AV, Zierath JR, Blomstrand E. Branched chain amino acids increased p70s6k phosphorylation in human skeletal muscle after resistance training. Am J Physiol Endocrinol Metab 2004;287(1):E1-7. doi: 10.1152/ajpendo.00430.2003.

26. Lorenzeti F, Carnevali LC, Lima WP, Zanuto R. Nutrição e suplementação esportiva: aspectos metabólicos, fitoterápicos e da nutrigênomica. São Paulo: Phorte; 2015.

27. Joanisse S, Lim C, McKendry J, McLeod JC, Stokes T, Phillips SM. Recent advances in understanding resistance exercise training-induced skeletal muscle hypertrophy in humans. F1000 Research 2020;141(9):1-12. doi: 10.12688/f1000research.21588.1

28. Abumoh'd MF, Matalqah L, Al-Abdulla Z. Effects of oral branched-chain amino acids (BCAAs) intake on muscular and central fatigue during an incremental exercise. J Hum Kinet 2020;72:69-78. doi: 10.2478/hukin-2019-0099

29. Ratames NA, Kraemer WJ, Volek JS, Rubin MR, Gomez AL, French DN, *et al.* The effects of amino acid supplementation on muscular performance during resistance training overreaching. J Strength Cond Res 2003;17(2):250-8. doi: 10.1519/1533-4287(2003)017<0250:teoass>2.0.co;2

30. Kraemer WJ, Fry AC. Strength testing: development and evaluation of methodology. In: Maud PJ, Foster C. Physiological assessment of human fitness. Champaign, IL: Human Kinetics; 1995. p. 115-38.

31. Kraemer WJ, Ratamess NA, Volek JS, Hakkinen K, Rubin MR, French DN, *et al.* The effects of amino acid supplementation on hormonal responses to resistance training overreaching. Metabolism 2006;55(3):282-91. doi: 10.1016/j.metabol.2005.08.023

32. Sharp CP, Pearson DR. Amino acid supplements and recovery from high-intensity resistance training. J Strength Cond Res 2010;24(4):1125-30. doi: 10.1519/JSC.0b013e3181c7c655

33. Van Dusseldorp TA, Escobar K, Johnson KE, Stratton MT, Moriarty T, Cole N, *et al.* Effect of branched-chain amino acid supplementation on recovery following acute eccentric exercise. Nutrients 2018;10(10):1389-1404. doi: 10.3390/nu10101389

34. Davis JM, Anderson NL, Welsh RS. Serotonin and central nervous system fatigue: nutritional considerations. Am J Clin Nutr 2000;72(2):573S-8S. doi: 10.1093/ajcn/72.2.573S

35. Fujita S, Dreyer HC, Drummond MJ, Glynn EL, Volpi E, Rasmussen BB. Essential amino acid and carbohydrate ingestion before resistance exercise does not enhance post-exercise muscle protein synthesis. J Appl Physiol 2009;106(5):1730-39. doi: 10.1151/japplphysiol.90395.2008

36. Crowe M, Weatherson JN, Bowden EBF. Effects of dietary supplementation on exercise performance. Eur J Appl Physiol 2006;97:664-72. doi: 10.1007/s00421-005-0036-1

37. She P, Olson KC, Kadota Y, Inukai A, Shimomura Y, Hoppel CL, *et al.* Leucine and protein metabolism in obese Zucker rats. Plos One 2013;8(3):e59443. doi: 10.1371/journal.pone.0059443

38. Gastin PB. Energy system interaction and relative contribution during maximal exercise. Sports Med 2001;31(10):725-41. doi: 10.2165/00007256-200131100-00003

39. Robergs RA, Ghiasvand F, Parker D. Biochemistry of exercise-induced metabolic acidosis. Am J Physiol Regul Integr Physiol 2004;287:R502-R16. doi: 10.1152/ajpregu.00114.2004