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ORIGINAL RESEARCH

Effects of different doses of branched-chain amino acid supplementation on recovery following acute eccentric exercise

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Abstract

This study investigated the effect of different amounts of Branched-Chain Amino Acids (BCAA) supplementation on recovery from eccentric exercise. Nine healthy male subjects undertook 4 trials in a randomized crossover design. Participants ingested either a three different amount (2g, 10g, and 20g) of BCAA supplement or placebo before the eccentric exercise. Muscle pain, hunger, vertical jump, balance, and sprint performance were measured before exercise, immediately after exercise, 1, 24, and 48 h. after exercise. All the variables were checked regarding their normal distribution using the Shapiro-Wilk test and data were presented as means ±SD. A repeated-measure, two factor ANOVA was used to examine differences between the four trials over time for balance, speed, vertical jump, hunger, and muscle pain change. No differences were found at baseline values for balance, velocity, vertical jump, hunger, and muscle pain for four trials ($p > 0.05$). While the main effect of time was statistically significant for balance, speed, vertical jump, hunger, and muscle pain ($p<0.05$), the main effect of trial and the interaction effect (time*trial) were not statistically significant. It indicated that the measurements changed during the time, but not influenced by different doses of BCAA. In conclusion, there are no significant effects of different amounts of BCAA supplementation on recovery performance after acute eccentric exercise.

Keywords: BCAA, eccentric exercise, muscle damage, recovery, sports nutrition, supplement.

Introduction

Muscle pain occurred after exercise is a phenomenon that is encountered after severe, unconventional, and especially eccentric exercises, and it is examined in two stages as acute and delayed onset muscle soreness (DOMS) (Dokumacı & Çakır Atabek, 2016). Muscle fiber size increases and muscle hypertrophy occurs during the recovery process of DOMS (Brandner & Warmington, 2017). Muscle hypertrophy occurs when protein synthesis exceeds the rate of protein degradation (Schoenfeld, 2010). Damas et al. (2016) reported that hypertrophy occurs due to increased protein synthesis as a result of resistance trainings and especially the disappearance of DOMS, and this development positively affected the performance of athletes. Different methods are used to remove DOMS such as; warm-up and stretching before the exercise, massage applications, and the consumption of various supplements after exercise (Draper et al., 2020). Among these supplements, the effect of branched-chain amino acid (BCAA) intake has been the subject of recent research (Howatson et al., 2012; Stark et al., 2012; Dorrel & Gee, 2016).

In recent years BCAA use has been increasing rapidly among athletes to eliminate muscle damage and increase physical performance. According to researches,

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food supplements sales are expected to reach approximately 58 billion dollars by 2022 (Foure & Bendahan, 2017). There are twenty essential and non-essential amino acids in the human body (Nosaka et al., 2006). Among these amino acids, leucine, isoleucine, and valine are digested rapidly (30 min) after oral administration (Shimomura et al., 2010). BCAAs cannot be synthesized by the human body and should, therefore, be taken with diets (Nosaka et al., 2006). BCAAs (especially leucine) taken with exercise has been shown to induce mTOR and p70-S6 kinase, which play a key role in cell development (Hulmi et al., 2010). BCAAs increase protein synthesis by providing an anabolic effect (Nosaka et al., 2006; Shimomura et al., 2010; Hulmi et al., 2010; Tipton & Wolfe, 1998; Wolfe, 2000), accelerate recovery of DOMS (Rennie, 2001; Shimomura et al., 2004) and improve physical performance (Damas et al., 2016; Ratamess et al., 2003). The effects of BCAA on mental performance were examined and contradictory results were found. Pancar et al. (2018) reported that BCAA consumed before acute exercise did not affect mental performance, while Manzo (2017) reported that BCAA improves mental performance. Rennie (2001) found that 3-5 grams of BCAA injected into the muscle doubled protein synthesis. In addition, Dorrell et al. (2016) reported that 2 g BCAA consumption reduces protein degradation. In some studies, BCAA consumed after exercise has been reported to increase protein synthesis (Hulmi et al., 2010; Levengahen et al., 2001). Many studies have shown that pre-exercise consumption of BCAA increases protein synthesis and provides more anabolic effects by reducing protein degradation (Shimomura et al., 2010; Tipton et al., 2001; Biolo et al., 1997; Greer et al., 2007).

According to the results of these studies, BCAA intake can have positive effects on performance. Studies reveal information that consuming BCAA before exercise may provide more positive effects. However, there is no clear information about how much BCAA should be consumed. Dorrell et al. (2016) compared low (6 g) and high (18 g) BCAA uptake, but this study has considerable methodological shortcomings. In this study, the dose (3g +3 g / 9 g + 9 g) was given at two different times, immediately before and immediately after the training. In addition, there are deficiencies such as low number of subjects (n = 5), BCAA amount not calculated according to body weight and inadequate diet control.

To date, there are a limited number of acute studies investigating the effect of BCAA use on recovery and physical performance. When these studies are examined, it is seen that the results of the studies are very contradictory.

Some of these studies report that BCAA reduces DOMS and accelerates recovery (Howatson et al., 2012; Dorrell & Gee, 2016; Greer et al., 2007). This effect was not observed in some studies (Nosaka et al., 2006; Shimomura et al., 2010; Foure et al., 2016; Jackman et al., 2010). The possible reason for the contradictory results of the research is the methodological differences (frequency of exercise, duration of exercise, BCAA intake time, BCAA amount, subject selection, diet control). Therefore, further research is needed to determine the effect of BCAA on DOMS and physical performance. To the best of our knowledge, no study has been conducted to determine the effective BCAA dose (low, moderate, high) before exercise, and to assess the effect of these doses on recovery and physical performance. Therefore, the aim of this study was to investigate the effect of different doses of branched-chain amino acid supplementation on recovery following acute eccentric exercise.

Methods

Study Group

The study started with 12 participants and was completed with 9 active male participants because of 3 people quitting the research for various reasons. The mean age of the participants (n = 9) was 21.78 ± 1.20 years, body weight was 68.47 ± 7.49 kg, BMI was 21.90 ± 1.17 kg / m2 and height was 176.56 ± 4.40 meters (Table 1). In the last six months, those who used supplements or drugs, smokers, alcohol users, patients with any illness, had severe resistance training, or those who performed unusual types of exercise related to the lower extremities were not included in the study.

Table 1
Descriptive characteristics of subjects at baseline.

Variables	Mean ± SD
Age (years)	21.78 ± 1.20
Body weight (kg)	68.47 ± 7.49
Height (m)	176.56 ± 4.40
BMI (kg/m^2)	21.90 ± 1.71

Experimental Design

The average body weight of sedentary young men is 70 kg (Baysal, 2011). In line with this information, the BCAA amounts were determined by considering the body weight of each participant. Therefore, 2 g BCAA (2gBCAA/70kg)*Body weight, for 10 g BCAA = (10gBCAA/70kg)*Body weight, 20 g BCAA = (20gBCAA/70kg)* Body weight calculations were made. Nine healthy voluntary male subjects undertook 4 (placebo, 2g, 10g, and 20g BCAA) trials in a randomized crossover design. Between the trials, seven-day recovery time was given to overcome the effect of exercise. The study was performed with a single blinding method. Participants did not know to which trial (placebo, 2g, 10g, and 20g BCAA) they have participated. In the placebo group, aspartame was used as a sweetener and it was tried to ensure that the taste was not different from BCAA. In order to eliminate the effect of circadian rhythm, all trials were conducted at the same time of day. Measurements were performed before BCAA intake, immediately after exercise, 1, 24, and 48 hours later. After a warm-up, the subjects' static balance, speed, vertical jump, subjective feeling of hunger, and subjective feeling of pain were measured. Participants were not informed about the placebo or amount of BCAA they received. They warmed up again for exercise 20 minutes after BCAA intake. Exercise protocol was applied 30 minutes after BCAA intake and measurements were repeated immediately after exercise. Measurements were performed in the following order; static balance, vertical jump, speed test, subjective feeling of hunger, and muscle pain. The study was approved by the Clinical Research Ethics Committee of Bursa Uludag University Faculty of Medicine (2018-4/14) and was conducted by the World Medical Association Helsinki Declaration. This study was supported by Bilecik Şeyh Edebali University Scientific Research Projects (2018-02. BSEÜ.20-01).

Damaging Exercise Protocol

Participants completed a total of 100 drop-jumps (height 0.6 m) by jumping vertically with maximum force (five sets of 20 drop-jumps, 2 min rest between sets, 10 s rest between each jump). This protocol has been previously shown to cause significant elevations in muscle damage indices (Jackman et al., 2010; Guven et al., 2009; Vatansever et al., 2011).

Warm-Up Protocols

In warm up, the first 10 minutes of low-intensity aerobic exercise (jogging) and then static stretching exercises for lower extremity muscles were performed.

Dietary Protocol

Participants followed routine nutrition and physical activity programmes during the study. Participants were asked to follow their diet 24 hours before the exercise trial and 48 hours after the exercise. They were supported by the dietician to eat the same foods or similar foods in the same amounts during the next trial weeks. Participants were asked not to exercise 24 hours before the test and to avoid alcohol and caffeine-containing substances. The dietary intake was analyzed by using a diet analysis software (BEBIS) (Guven et al., 2009).

Subjective Measurements of Hunger

Ratings of subjective feelings of hunger were reported on 100 mm visual analogue scales (VAS) at baseline, immediately after exercise and 1, 24, 48 hours after baseline, as described previously (Vatansever et al., 2011). For hunger assessment, on one end (0 mm) of the scale was the descriptor "not at all hungry" and on the other extreme (100 mm) was the descriptor "totally hungry".

Subjective Measurements of Muscle Pain

Ratings of subjective feelings of pain were reported on 100 mm visual analogue scales (VAS) at baseline, immediately after exercise and 1, 24, 48 hours after baseline. The level of muscle soreness was quantified using a 100 mm VAS in which 0 indicated "no pain" and 100 represented "extreme pain".

Anthropometric Measurements

Height was measured to the nearest 0.1 cm using a Holtain fixed wall stadiometer. Body mass was measured to the nearest 0.01 kg using a beam balance. BMI was calculated as weight in kilograms divided by the square of height in meters.

Balance Test

The balance performances were determined by the Technobody ProKin PK 200 instrument with a 30 second static balance test (Pancar et al., 2018).

Vertical Jump Test

On command, participants performed a maximal vertical jump by descending to 90^0 knee angle and touching the device with their dominant arm. 3 trials were taken with 60 s intervals and the highest value was recorded.

Sprint Test

Sprint evaluation was accomplished through a speed test that was carried out in a straight 20m-line (Impellizzeri et al., 2008).

Data Analyses

Statistical analysis was carried out using SPSS version 23. 0 (SPSS, Inc., Chicago, IL, USA). All the variables were checked regarding their normal distribution using the Shapiro-Wilk test and data are presented as means ± SD. A repeated-measures, two factor ANOVA was used to examine differences between the four trials over time for balance, speed, vertical jump, hunger, and muscle pain change. Between-trial differences at each time point were examined using one-way ANOVA and Bonferroni post hoc tests when significant interactions were found. Mauchly's sphericity test was conducted to examine sphericity for the repeated measures analyses. If the assumption of sphericity was violated, the Greenhouse-Geisser adjustment was used to protect against type I error.

Results

Total Energy and Protein Intake

According to the trials, the total calorie, and protein intake, respectively, control trial: 1904.75 ± 357.88 kcal and 76.40 ± 13.40 g protein, 2gr BCAA trial: 2031.74±435.12 kcal and 79.36±14.20 g protein, 10 gr BCAA trial 2022.07 ± 443.53 kcal and 78.39 ± 14.91 g protein, 20 gr BCAA trial 2069,19±553,18 kcal and 78.58 ± 13.54 g protein. No significant differences were observed between trials in energy or protein intake in the 24 h before each trial (Repeated-measures, two factor ANOVA, p>0.05).

Balance Performance

Baseline balance performance did not differ significantly (Repeated-measures, two factor ANOVA, p>0.05) between trials. A repeated-measures, two factor ANOVA revealed a main effect of time (p<0.05) for balance performance, but there was no main effect of trial and no interaction effect (Figure 1), indicating that balance performance changed significantly during the trials but was not influenced by different doses of BCAA (Placebo, 2gr, 10gr, and 20gr).

Vertical Jump

Baseline vertical jump performance did not differ significantly (Repeated-measures, two factor ANOVA, p>0.05) between trials. A repeated-measures, two factor ANOVA revealed a main effect of time (p<0.05) for vertical jump performance, but there was no main effect of trial and no interaction effect (Figure 2), indicating that vertical jump performance changed significantly during the trials but was not influenced by different doses of BCAA (Placebo, 2gr, 10gr, and 20gr).

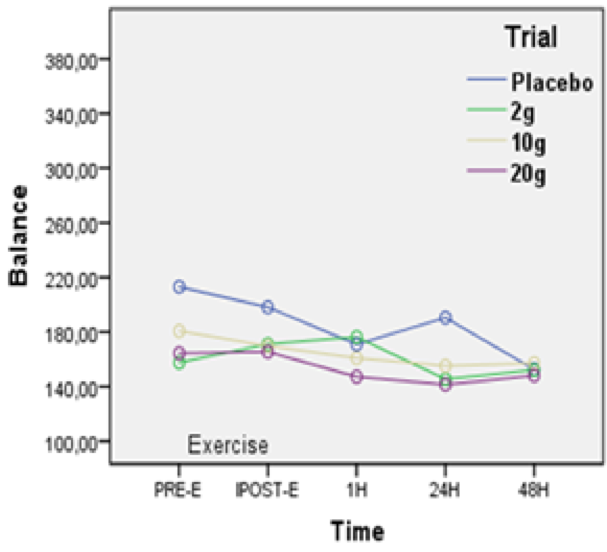

Figure 1. Balance performance values over 48 h during the four trials.

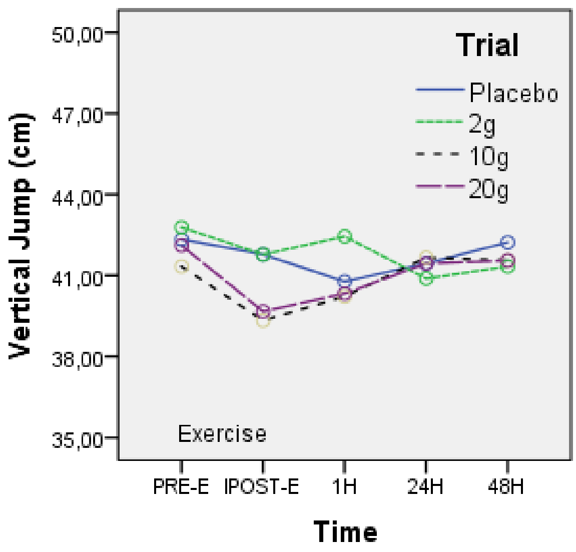

Figure 2. Vertical jump performance values over 48 h during the four trials.

Muscle Pain

Baseline muscle pain values did not differ significantly (Repeated-measures, two factor ANOVA, p>0.05) between trials. A repeated-measures, two factor ANOVA revealed a main effect of time (p<0.05) for muscle soreness, but there was no main effect of trial and no interaction effect (Figure 3), indicating that muscle soreness changed significantly during the trials but was not influenced by different doses of BCAA (Placebo, 2gr, 10gr, and 20gr).

Hunger

Baseline hunger did not differ significantly (Repeated-measures, two factor ANOVA, p>0.05) between trials. A repeated-measures, two factor ANOVA revealed a main effect of time ($p<0.05$) for hunger, but there was no main effect of trial and no interaction effect (Figure 4), indicating that hunger changed significantly during the trials but was not influenced by different doses of BCAA (Placebo, 2gr, 10gr, and 20gr).

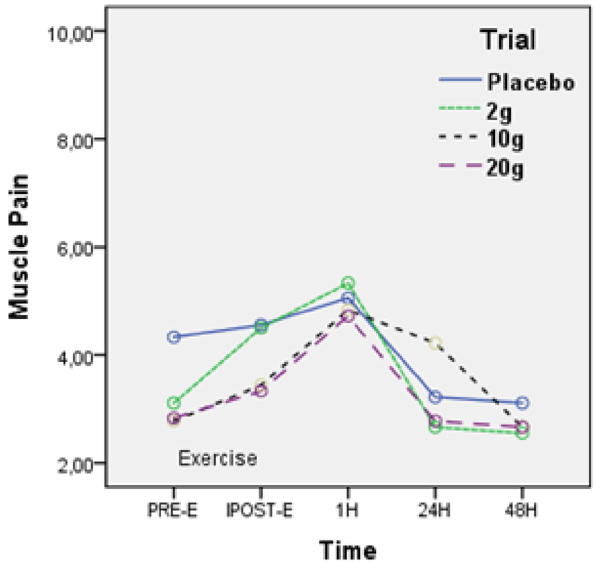

Figure 3. Muscle pain values over 48 h during the four trials.

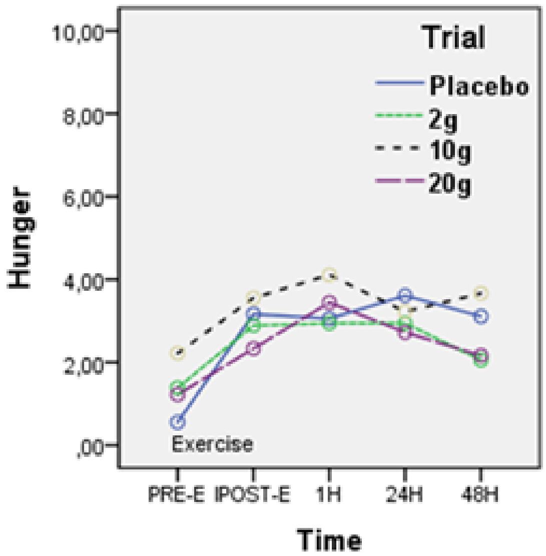

Figure 4. Hunger values over 48 h during the four trials.

Speed Performance

Baseline speed did not differ significantly (Repeated-measures, two factor ANOVA, $p>0.05$) between trials. A repeated-measures, two factor ANOVA revealed a main effect of time ($p<0.05$) for sprint performance, but there was no main effect of trial and no interaction effect (Figure 5), indicating that sprint performance changed significantly during the trials but was not influenced by different doses of BCAA (Placebo, 2gr, 10gr, and 20gr).

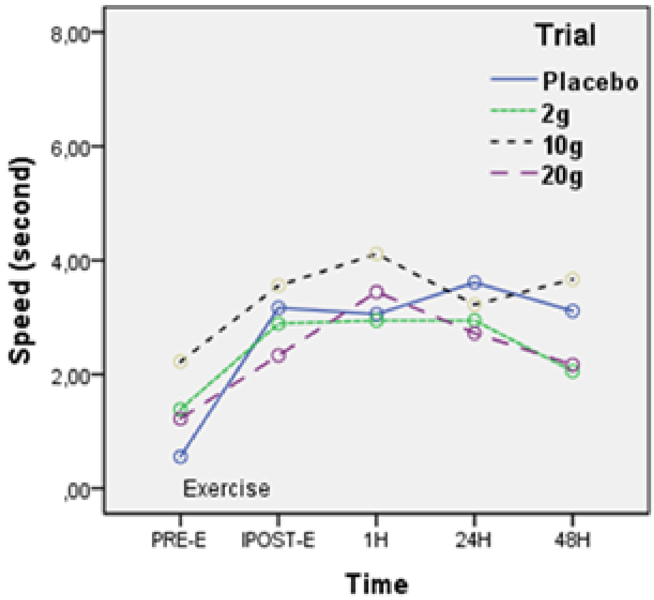

Figure 5. Speed performance values over 48 h during the four trials.

Discussion

This study aimed to determine the effect of different amounts of BCAA before exercise on muscle recovery and performance. As a result of the study, it was observed that BCAA, consuming before exercise, didn't improve vertical jump, speed, static balance performances, subjective feelings of muscle pain, and hunger.

In recent years, people exercising at all levels have been using BCAA frequently to improve performance and accelerate recovery. However, there is no clear information about when and in what amount BCAA should be taken. Pre-exercise intake of BCAA has been shown to have an anabolic effect (Hulmi et al., 2010) and thus improve performance (Damas et al., 2016). Contrary to these studies, our study findings showed that pre-exercise intake of BCAA did not affect recovery and performance.

When the studies are examined, it is seen that the results are quite conflicting. While some studies showed that BCAA supplementation positively affected performance (Howatson et al., 2012; Dorrell & Gee, 2016; Gee & Deniel, 2016) some studies reported that BCAA did not (Van Dusseldorp et al., 2018). Ra et al. (2018) compared the effect of repeated BCAA (3 day/9.6g/day) loading (before and after) on muscle damage after eccentric exercises in a study conducted with 15 young male participants. Their study showed that BCAA supplementation before exercise had a more beneficial effect in reducing muscle damage induced by eccentric exercise compared to repeated supplementation after exercise. In a similar study, Howatson et al. (2012) examined the effect of 10 grams of BCAA or placebo twice daily for 12 days in trained men who completed a training of 100 drop-jumps. Compared to placebo, plasma Creatine Kinase (CK), perceived pain, and force generation were all improved during the first 24 hours, in addition, the perceived pain was significantly lower up to 48 hours after exercise in the BCAA-supported group. However, it was reported that BCAA didn't effect on vertical jump as in our findings.

Vanduseldorp et al. (2018) investigated the effect of BCAA supplementation on recovery from eccentric exercise. Twenty men received a BCAA supplement or placebo before and after eccentric exercise. The creatine kinase, vertical jump, maximum voluntary isometric contraction, jump squat, and perceived pain were evaluated. The creatine kinase concentrations increased above baseline after 4, 24, 48, and 72 hours in both groups. Though the BCAA group was found to be lower at 48 hours compared to the placebo, there was no significant difference between the groups for the vertical jump or jump squat. As a result of this study, the researchers emphasized that BCAA supplementation can reduce muscle pain after muscle damaging exercise.

According to our findings, there was no difference between acute and pre-exercise BCAA consumption in terms of recovery performance. Similar to our results, Foure et al. (2016) reported that 7 g of BCAA per day did not affect the recovery of quadriceps maximum voluntary isometric contraction in recreational men following muscle damage. Similarly, Jackman et al. (2010) found no difference in the ability to force generation in sedentary men with 29.3 g of BCAA supplementation. In addition to these studies, Kirby et al. (2012) also reported that 250 mg/kg BCAA did not effect on force generation and vertical jump performance. Although the effect of different doses on performance has been studied in many studies, there are contradictions. When these studies are examined, we see that there are quite different methodological differences between BCAA intake time and amounts. For example, there are several doses (days) studies before exercise (Howatson et al., 2012; Van Dusseldorp et al., 2018). There are also single dose acute studies just before exercise available (Dorrell & Gee, 2016; Gee & Deniel, 2016). Therefore, the comparison of the results of these studies is not very accurate. As the number of comprehensive, controlled, and methodically closer studies on this subject increases, the effects of BCAA will be more clearly identified. Howatson et al. (2012) investigated different BCAA supplementation; the first 7 days in the morning and evening, 8. day before and after training, the remaining days in the morning. In this study, BCAA supplementation time is not clear. In addition, this study has methodological limitations (nutrition following, exercise protocol). In the other study with several doses, it has been shown that there is no effect on performance in parallel with our findings (Van Dusseldorp et al., 2018). Conflicting results have also been observed in studies on single use of BCAA (Dorrell & Gee, 2016; Gee & Deniel, 2016). BCAA intake before and after exercise has been found to have positive effects on performance. This effect may be due to methodological limitations (nutrition following, exercise protocol) or BCAA supplementation after training is thought to have a positive effect. Thus, it was observed that different doses (placebo, 2g, 10g, 20g BCAA) did not have a positive effect on performance just before training.

As a result, the limited number of studies conducted in this field contradict each other. The reason for the contradictory results is thought to be due to the methodological differences used in studies such as selected exercise protocol, exercise type, exercise duration and mode, lack of nutrition follow-up in some studies, characteristics of participants, BCAA content, intake time and amount. More controlled and experimental studies are needed in this area to determine the effect of BCAA on recovery and exercise performance.

Conclusion

In conclusion, we can conclude that BCAA at different doses used before exercise does not improve recovery performance after exercise. According to these findings, it can be said that BCAA consumed 2g, 10g, and 20g before exercise does not have a positive effect on recovery. However, many studies are needed to determine the effect of BCAA on performance. The possible effects of BCAA can be better demonstrated by researches using different methodological methods such as the effect of different doses before exercise, the effect of different doses after exercise, the effect of different doses before and after exercise, the effect of different groups of subjects, the effect of different types of exercise and so on.

Authors' Contribution

Study Design: ŞV, SP, RZ, ŞŞ, YZB, HT; Data Collection: ŞV, SP, RZ, ŞŞ, YZB, HT; Statistical Analysis: ŞV, SP, RZ, ŞŞ, YZB, HT; Manuscript Preparation: ŞV, SP, RZ, ŞŞ, YZB, HT; Funds Collection: ŞV, SP, RZ, ŞŞ, YZB, HT.

Ethical Approval

The study was approved by the Clinical Research Ethics Committee of Bursa Uludag University Faculty of Medicine (2018-4/14) and was conducted by the World Medical Association Helsinki Declaration.

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Conflict of Interest

The authors hereby declare that there was no conflict of interest in conducting this research.

References

Baysal, A. (2011). Nutrition (p.70). Ankara; Hatipoğlu Press.

Biolo, G., Tipton, K. D., Klein, S., & Wolfe, R. R. (1997). An abundant supply of amino acids enhances the metabolic effect of exercise on muscle protein. *Am J Physiol Endocrinol Metab*, 273(1),122-129.

Brandner, C. R., & Warmington, S. A. (2017). Delayed onset muscle soreness and perceived exertion after blood flow restriction exercise. *J Strength Cond Res,* 31(11), 3101-3108.

Damas, F., Phillips, S. M., Libardi, C. A., Vechin, F. C., Lixandrao, M. E., Jannig, P. R., & Tricoli, V. (2016). Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. *The Journal of Physiology*,594(18), 5209-5222.

Dokumacı, B., & Çakır Atabek, H. (2016). Delayed onset muscle soreness and mechanisms: Relation with oxidative stress: Review. *Turkiye Klinikleri Journal of Sports Sciences,* 8(1), 22-34.

Dorrell, H., & Gee, T. (2016). The acute effects different quantities of branched-chain amino acids have on recovery of muscle function. *Sports Nutrition and Therapy*,1(3),115-115.

Draper, S. N., Kullman, E. L., Sparks, K. E., Little, K., & Thoman, J. (2020). Effects of intermittent pneumatic compression on delayed onset muscle soreness (DOMS) in long distance runners. *International Journal of Exercise Science*,13(2),75-86.

Foure, A., Nosaka, K., Gastaldi, M., Mattei, J. P., Boudinet, H., Guye, M., Vilmen, C., Le Fur, Y., Bendahan, D., & Gondin, J. (2016). Effects of branched-chain amino acids supplementation on both plasma amino acids concentration and muscle energetics changes resulting from muscle damage: A randomized placebo controlled trial. *Clin Nutr*, 35, 83–94.

Foure, A., & Bendahan, D. (2017). Is branched-chain amino acids supplementation an efficient nutritional strategy to alleviate skeletal muscle damage? A systematic review. *Nutrients*, 9(10), 1047.

Greer, B. K., Woodard, J. L., White, J. P., Arguello, E. M., & Haymes, E. M. (2007). Branched-chain amino acid supplementation and indicators of muscle damage after endurance exercise. *Int J Sport Nutr Exerc Metab*, 17(6), 595-607.

Gee, T. I., & Deniel, S. (2016). Branched-chain amino acid supplmentation attenuates a decrease in power-producing ability following acute srtength training. *J Sports Med Phys Fitness,* 56(12), 1511-1517.

Guven, O., Ozdemir, G., & Ersoy, G. (2009). Determination of veteran athletes' nutrition habits and nutrition knowledge in Ankara. *Spormetre The Journal Of Physical Education and Sport Sciences*, 7(3),125-133.

Howatson, G., Hoad, M., Goodall, S., Tallent, J., Bell, P. G., & French, D. N. (2012). Exercise-induced muscle damage is reduced in resistance-trained males by branched chain amino acids: a randomized, double-blind, placebo controlled study. *J Int Soc Sports Nutr,* 9(1), 20.

Hulmi, J. J., Lockwood, C. M., & Stout, J. R. (2010). Effect of protein/essential amino acids and resistance training on skeletal muscle hypertrophy: A case for whey protein. *Nutr Metab*, 7(1), 51.

Impellizzeri, F. M., Rampinini, E., Castagna, C., Martino, F., Fiorini, S., & Wisloff, U. (2008). Effects of plyometric training on sand versus grass on muscle soreness and jumping and sprinting ability in soccer players. *Br J Sports Med*, 42, 42-46.

Jackman, S. R., Witard, O. C., Jeukendrup, A. E., & Tipton, K. D. (2010). Branched-chain amino acid ingestion can ameliorate soreness from eccentric exercise. *Med Sci Sports Exerc*, 42(5), 962-970.

Kirby, T. J., Triplett, N. T., Haines, T. L., Skinner, J. W., Fairbrother, K. R., & McBride, J. M. (2012). Effect of leucine supplementation on indices of muscle damage following drop jumps and resistance exercise. *Amino Acids*, 42, 1987–1996.

Levenhagen, D. K., Gresham, J. D., Carlson, M. G., Maron, D. J., Borel, M. J., & Flakoll, P. J. (2001). Postexercise nutrient intake timing in humans is critical to recovery of leg glucose and protein homeostasis. *Am J Physiol Endocrinol Metab*, 280(6), 982-993.

Manzo, M. (2017). *The effect of BCAA supplementation on mental performance following exercise*. Sacred Heart University. Academic Festival, 66.

Nosaka, K., Sacco, P., & Mawatari, K. (2006). Effects of amino acid supplementation on muscle soreness and damage. *Int J Sport Nutr Exerc Metab*, 16(6), 620-635.

Pancar, S., Vatansever, Ş., & Birinci, Y. Z. (2018). The effect of BCAAs on mental performance after exercise. *Scholars Journal of Arts, Humanities and Social Sciences*, 6(12), 2269-2274.

Ra, S.G., Miyazaki, T., Kojima, R., Komine, S., Ishikura, K., Kawanaka, K, Hond, A., Matsuzaki, Y., & Ohmori, H. (2018). Effect of BCAA supplement timing on exercise-induced muscle soreness and damage: a pilot placebo-controlled double-blind study. *J Sports Med Phys Fitness*, 58(11), 1582-1591.

Ratamess, N. A., Kraemer, W. J., Volek, J. S., Rubin, M. R., Gomez, A. L., French, D. N., & Newton, R. U. (2003). The effects of amino acid supplementation on muscular performance during resistance training overreaching. *J Strength Cond Res*, 17(2), 250-258.

Rennie, M. J. (2001). Control of muscle protein synthesis as a result of contractile activity and amino acid availability: Implications for protein requirements. *Int J Sport Nutr Exerc Metab*, 11(1), 170-176.

Schoenfeld, B. J. (2010). The mechanisms of muscle hypertrophy and their application to resistance training. *J Strength Cond Res*, 24(10), 2857-2872.

Shimomura, Y., Murakami, T., Nakai, N., Nagasaki, M., & Harris, R. A. (2004). Exercise promotes BCAA catabolism: Effects of BCAA supplementation on skeletal muscle during exercise. *J Nutr*, 134(6), 1583-1587.

Shimomura,Y., Inaguma, A., Watanabe, S., Yamamoto, Y., Muramatsu, Y., Bajotto, G., & Mawatari, K. (2010). Branched-chain amino acid supplementation before squat exercise and delayed-onset muscle soreness. *Int J Sport Nutr Exerc Metab,* 20(3), 236-244.

Stark, M., Lukaszuk, J., Prawitz, A., & Salacinski, A. (2012). Protein timing and its effects on muscular hypertrophy and strength in individuals engaged in weight-training. *J Int Soc Sports Nutr*, 9(1), 54.

Tipton, K. D., & Wolfe, R. R. (1998). Exercise-induced changes in protein metabolism. *Acta Psychiatr Scand,* 162(3), 377-387.

Tipton, K. D., Rasmussen, B. B., Miller, S. L., Wolf, S. E., Owens-Stovall, S. K., Petrini, B. E., & Wolfe, R. R. (2001). Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. *Am J Physiol Endocrinol Metab*, 281(2), 197-206.

Vatansever, S., Sonmez-Tiryaki, G., Bugdayci, G., & Ozen, G. (2011). The effects of exercise on food intake and hunger: Relationship with acylated ghrelin and leptin. *J Sports Sci Med,* 10, 283–291.

Van Dusseldorp, T. A., Escobar, K. A., Johnson, K. E., Stratton, M. T., Moriarty, T., Cole, N., McCormick, J. J., Kerksick, C. M., Vaughan, R. A., Doklandy, K., Kravitz, L., & Mermier, C. M. (2018). Effect of branched-chain amino acid supplementation on recovery following acute eccentric exercise. *Nutrients*, 10, 1389.

Wolfe, R.R. (2000). Protein supplements and exercise. *Am J Clin Nutr*, 72(2), 551-557.