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Branched-Chain Amino Acid Supplementation in Sports. A Literature Review on Its Role in Mitigating Muscle Soreness and Enhancing Training Efficacy

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ABSTRACT
Athletes commonly use branched-chain amino acids to hasten recovery and decrease muscle soreness thus leading to increase in training frequency. Studies indicate that BCAA may modestly reduce delayed-onset muscle soreness. This effect seems to be greater when consumed both before and after the exercise. The evidence indicates a moderately increased efficacy of such intervention in untrained individuals and in specific muscle lengthening (eccentric) exercises. However, findings in the area of physical performance remain questionable. Some trials show limited improvements in strength and endurance in untrained individuals. Trials that evaluate fit individuals report no significant benefits. The lack of universal training protocol makes comparisons between different studies difficult and long-term efficacy remains unclear. Overall, BCAA may serve as a useful recovery aid in specific contexts, though their effectiveness as a standalone support appears vague and data concerning long-term effects is lacking.

Keywords: BCAA supplementation, branched-chain amino acids supplementation, delayed-onset muscle soreness, exercise induced muscle damage, physical exercise, isoleucine, valine, leucine

1. INTRODUCTION
One of the crucial areas in increasing the level of physical fitness is repeated exercise. The repetition of muscle strain results in remodelling and adaptation of the muscle, increasing its resistance to external stress and its strength of contractions (Franchi et al., 2017). In the literature three types of muscle contraction are distinguished, although named variously. The term "isometric contraction" is widely accepted. The proper name of the remaining two types is still debated. The terms "eccentric" and "concentric" are used commonly. Unfortunately, these terms

do not express the nature of the contraction properly (Faulkner, 2003). In this article, we will refer to these types of contractions as lengthening and shortening, following Faulkner's recommendations.

Whether a person is unaccustomed to a specific exercise or if the exercise is repeated in a short period of time, all three forms of muscle contraction can cause damage and pain. Repeated exercises cause exercise-induced muscle damage (EIMD), but muscle lengthening training seems to especially predispose to its development. The suggested cause is the lower recruitment of motor units in such type of exercise, resulting in greater mechanical stress and sarcomere overstretch (Whitehead et al., 2001; Douglas et al., 2017). Additionally metabolic parts, such as increased intracellular concentration of $Ca2+$, inflammation, increased reactive oxidative stress (ROS), alteration in membrane permeability also play a part, especially in endurance exercise, where lengthening contractions are less prevalent (Tee et al., 2007; Stožer et al., 2020). BCAA supplementation could act as a potential modulator of these pathways, as it plays a part in all of the aforementioned processes.

EIMD manifests clinically as delayed onset muscle soreness (DOMS). Typically, it peaks between 24 and 72 hours post-exercise and subsides within 5 days (McKune et al., 2012). DOMS is a group of symptoms that include stiffness, swelling, and overall muscle tenderness. The decreased range of motion and a temporary reduction in muscle strength also occur, collectively impairing athletic performance. Such symptoms result in decrease of exercise intensity and affect the exercise routine (Cheung et al., 2003; Stožer et al., 2020). Muscle recovery requires proper nutrition and time, hence the interest in amino acid supplementation to promote muscle repair and reduce soreness. Athletes often consume BCAA in the belief that they facilitate recovery, mitigate fatigue, and ultimately enhance performance. This review highlights possible mechanisms of BCAA action and aims to find evidence supporting such beliefs.

Possible mechanisms of action

The BCAA are metabolised within skeletal muscle. This acts as a meaningful pathway for energy production during long and intense exercise (Mann et al., 2021). The role of the BCAA is not limited to the period of exercise, as different pathways also contribute to muscle recovery after exercise. For example, leucine is a potent activator of the mammalian target of rapamycin complex 1 (mTORC1) signaling pathway, a nodal regulator of cell growth and protein synthesis. Activation of mTORC1 by leucine leads to a phosphorylation cascade of downstream targets such as p70S6 kinase and 4E-BP1, which in the end promote mRNA translation involved in muscle protein synthesis. This process is known for its role in the repair and remodeling of skeletal muscle following EIMD, as well as muscle hypertrophy (Blomstrand et al., 2006; Drummond et al., 2009; Wackerhage et al., 2019).

Furthermore, BCAA may affect another important part in muscle performance; central fatigue. It has been proven that it acts on serotonin synthesis in the brain through competitive inhibition of tryptophan transport across the blood-brain barrier (Blomstrand et al., 2006). This effect could hypothetically reduce perceived soreness and improve short-term outcomes.

In addition to anabolic stimulation, BCAA may attenuate muscle proteolysis. During and after strenuous exercise, muscle protein breakdown increases due to the inflammation mentioned above. Some evidence shows that BCAA provide antioxidant support through endothelial nitric oxide synthase, suppressing the mechanisms of muscle breakdown (Dantona et al., 2010). One of the older studies also suggested that higher intramuscular and arterial BCAA concentration results in protein breakdown inhibition through the increased ammonia production (MacLean et al., 1994).

This multifaceted role of BCAA in supporting both peripheral and central mechanisms explains their relevance as a nutritional strategy for athletes aiming to decrease the level of perceived DOMS, enabling faster recovery and improving exercise consistency in training. These proposed mechanisms explain why BCAA supplementation became so prominent among professional athletes. However, most of these mechanisms of action are hypothetical. Thus, the review of the evidence concerning effects on DOMS and muscle strength based on human subjects was conducted.

2. REVIEW METHODS

For this review, we searched PubMed and Google Scholar for articles published between January 1994 and April 2025. We focused on studies that researched the use of BCAA in repetitive exercises. We first checked the titles and abstracts. Then we read the full texts of the most relevant papers. We only used articles written in English and published in scientific journals. We carefully chose the best articles to include in this review, placing special emphasis on meta-analyses. Four hundred ten records were identified through database searching; no duplicates were removed. Three hundred fifty-eight records were excluded based on titles and abstracts. Sixty-two full-text articles were assessed for eligibility. Sixty-two articles were finally included in the qualitative synthesis. Additionally, eight records concerning the pathophysiology of EIMD and DOMS were retrieved through citation searching. The search database is visualized in Figure 1.

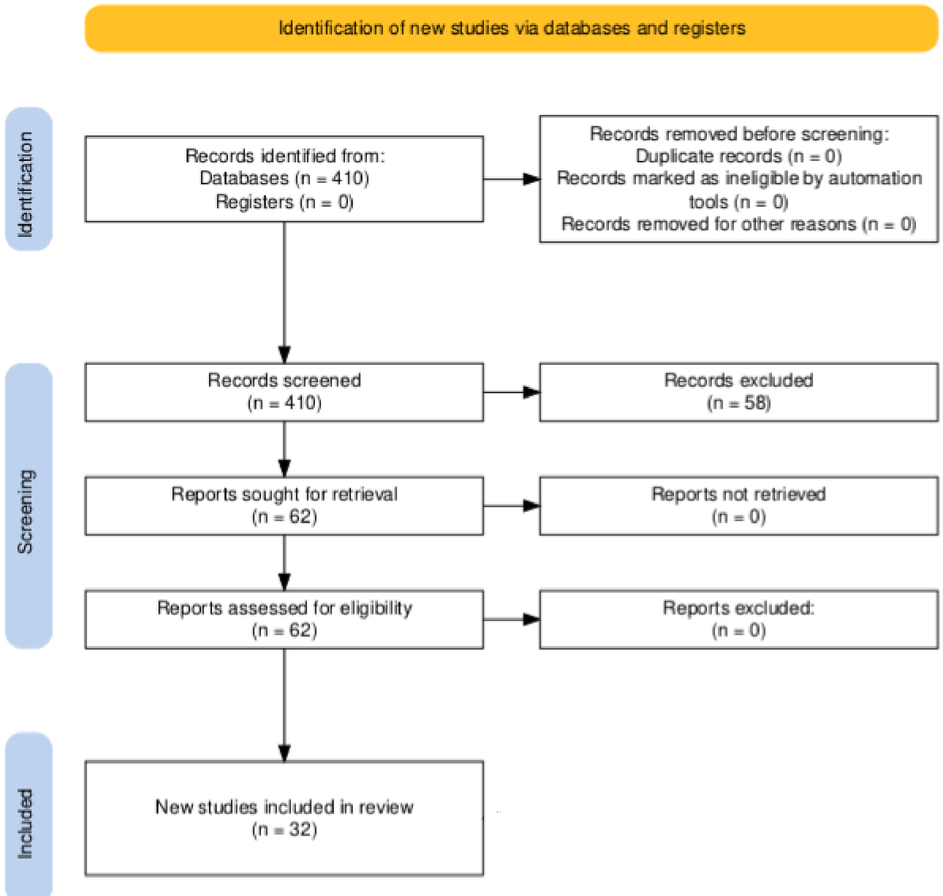

Figure 1. PRISMA flowchart

3. RESULTS AND DISCUSSION

Effects on Delayed Onset Muscle Soreness

Numerous studies have examined the efficacy of BCAA supplementation in reducing DOMS, following different exercise protocols known to elicit muscle damage. One of the most comprehensive investigations, which synthesized data from randomized controlled trials, concluded that BCAA supplementation results in a statistically significant but modest reduction in DOMS, especially when consumed both before and after exercise (Weber et al., 2021). This evidence suggests that timing of supplementation may be an essential factor of efficacy. The authors concluded that the administration of BCAA after the EIMD could be ineffective. This result is of great significance, as many athletes tend to supplement BCAA only after exercise. Moreover, it has been shown that BCAA supplementation is helpful in well-trained subjects. This meta-analysis complements an earlier one, which reported that BCAA supplementation reduced the perceived muscle soreness across a younger population aged 21 to 25 and across various exercise modalities. This research noted that individuals who were less trained appeared to benefit more from BCAA intake, possibly due to their increased susceptibility to muscle damage from novel exercise stimuli (Fedewa et al., 2019). The study population was small and the studies included were of moderate heterogeneity, so the study did not assess the power of effect. It shows that populations consisting of middle to elderly aged individuals should be evaluated more thoroughly, as the evidence in this area is lacking.

Different systematic review and meta-analysis examined both subjective and objective markers of muscle damage. While the study confirmed a reduction in soreness, it had a similar conclusion, that variability in dosing, timing, and study design makes generalizations difficult. Indeed, dosing strategies vary widely across studies. Daily supplementation ranged from 5 grams to about 20 grams (Doma et al., 2021). Some research stresses the importance of optimized dosing regimens. It suggested that split doses administered both pre- and post-exercise may be more beneficial than single bolus intake. Different regimens and doses could explain the difference among the studies (Arroyo-Cerezo et al., 2021).

One study with proper formalised protocol took in scope endurance exercise. The findings did not support that 0.17 g/kg of BCAA supplementation at pre- and post- exercise attenuated muscle soreness in collegiate basketball players. Additionally, the study did not show significant decreases in subjective soreness scores and creatine kinase (CK) levels, contrary to other research (Khemtong et al., 2021). It highlights the possibility that the effectiveness of BCAA supplementation may be exercise-specific. Endurance or muscle lengthening dominant modalities may elicit a different response than high-intensity or sprint-type efforts.

A recent meta-analysis has revealed that BCAA supplementation significantly reduced creatine kinase (CK) levels immediately after the exercise and 96 h post-EIMD. Moreover, a substantial impact on the delayed onset of muscle soreness was proven at 24 h, but not immediately post-EIMD. As much as the reduction of creatinine kinase concentration is prominent, the effect on other EIMD biomarkers, such as LDH, is absent (Salem et al., 2024).

In summary, the current body of evidence indicates that BCAA supplementation may confer modest reductions in DOMS. This effect appears to be particularly strong in untrained individuals. Meta-analyses (Fedewa et al., 2019; Mehran et al., 2020; Khemtong et al., 2021; Weber et al., 2021; Salem et al., 2024) suggest that the best outcomes occur when BCAA are consumed both before and after the exercise. Additionally, the effect seems to be dosage dependent, with a high leucine content being particularly beneficial. The impact seems to be observable up to 72 hours. Nevertheless, findings remain mixed. Some meta-analyses (Doma et al., 2021) failed to demonstrate significant benefits. These findings indicate the importance of exercise modality, physical fitness, supplementation schedule, and individual variability. Future research should focus on optimizing supplementation protocol, and identification of responders versus non-responders through different supplementation approaches. Greater emphasis should be placed upon middle to elderly aged populations, as evidence in this area is modest.

Effects on performance and exercise adaptation

Research on the anabolic potential of branched-chain amino acids in the context of resistance exercise and muscle strength performance has not been abundant. Most of the performed studies produced mixed findings. Few studies have directly investigated whether BCAA supplementation contributes to improvements in muscular strength, hypertrophy, or performance measures.

Several studies have examined BCAA supplementation in the context of resistance training and muscular strength. One study found out that BCAA supplementation reduced ratings of perceived exertion in untrained males during an acute resistance exercise session. Performance in terms of repetitions were unaffected, as well as total lifted weight (Greer et al., 2011). Similarly, an eight-week randomized controlled trial involving resistance untrained males found that BCAA supplementation, when combined with heavy resistance training, significantly improved peak power output (Spillane et al., 2012). However, the effect of the supplementation did not differ significantly from placebo. The study concluded that the effect could be attributed to the exercise schedule itself, as both groups' body endurance measurements did not differ significantly.

Another investigation examined the acute effects of BCAA at the dose of 0.087 g/kg body mass supplementation in resistance-trained athletes recovering from a single bout of hypertrophy-focused training. The study showed significant differences regarding the isometric strength at 24 hours post-exercise (placebo ~87% vs. BCAA ~92%) and jump height (placebo ~93% vs. BCAA ~96%) (Spillane et al., 2012). The differences, however, were minor and could be attributed to decreased DOMS at 24 hours past the exercise time. Another study compared the ingestion of a carbohydrate and BCAA beverage to carbohydrate-only supplementation during upper-body resistance training. No significant improvements in strength or power output were found in terms of acute resistance (Smith et al., 2018).

Other research has focused on endurance performance metrics. In a trial involving high-intensity endurance cycling validated exercise protocol on untrained adults, a commercially available BCAA-alanine-carbohydrate sports supplement was shown to reduce perceived exertion and significantly impact time-to-exhaustion performance metrics after nine weeks of supplementation. Maximal oxygen consumption and power at lactate threshold did not show a significant difference. The explanation might lie in the central effect of BCAA on fatigue. This would not directly enhance physical output (Gervasi et al., 2020). Similarly, a different randomized study conducted during prolonged skiing at altitude observed that BCAA supplementation prevented a decrease of maximal workload in a short time after multiple training sessions; however, it was not significant for retaining the isometric force of the femoral quadriceps muscle (Bigard et al., 1996). Another study simulating a soccer match on a treadmill showed that BCAA supplementation improved psychomotor response times under conditions of variable exercise intensity. It points out a beneficial effect on short-term neuromuscular coordination or mental fatigue (Wiśnik et al., 2011). It is worth noting that BCAA reduced multiple-choice reaction time even before the exercise.

A similar effect of BCAA was also observed in a randomized trial over two days of simulated handball games. All athletes demonstrated improved agility and decreased fatigue markers in consecutive days of handball games (Chang et al., 2015). It seems that BCAA influences subjective fatigue perception, but the translation to measurable performance is vague. This stand in line with a trial of taekwondo athletes, which investigated supplementation of BCAA and creatine within a multi-ingredient buffering system. In the supplemented group there was a reduced ammonia accumulation after high-intensity exercise. However, aerobic capacity was not significantly affected in all supplemented group (Durkalec-Michalski et al., 2021).

Not all studies agree on these short-term benefits. For instance, when tested in a standardized sprint-based protocol, which included rapid directional changes, BCAA supplementation failed to accelerate recovery or improve performance metrics. It may be the case that ergogenic potential of BCAA does not extend uniformly across all exercise types (Khemtong et al., 2022). Akin contrasting findings were observed in a double-blind randomized study on professional volleyball players. The subjects received short-term BCAA supplementation. This intervention did not lead to significant improvements in vertical jump performance, indicating that highly trained athletes, BCAA may not meaningfully enhance physical performance even in a shorter period (Calleja Gonzalez et al., 2020).

Population differences also appear to influence the BCAA supplementation outcomes. One crossover trial involved frail and pre-frail elderly individuals, population often omitted in research regarding BCAA. The study found that BCAA supplementation significantly improved resistance training endurance (Ikeda et al., 2016). These conclusions further support the thesis that untrained individuals benefit more from BCAA. The effects of BCAA supplementation and outcomes in different original studies were summarized in Table 1.

Table 1. Effects of BCAA supplementation on different types of physical performance

Study	**Exercise protocol**	**Main Outcomes**
Greer et al., 2011	90-minute cycling at 55% peak VO_2	Decrease of perceived fatigue, no difference in performance compared to placebo
Spillane et al., 2012	Heavy resistance training over 8 weeks	No difference in muscle performance and fat-free mass compared to placebo
Smith et al., 2018	Bench press, bent-over row, incline press, and close-grip row	No significant performance benefits compared to placebo were observed
Gervasi et al., 2020	Ten 90 s sprints interspersed by ten 3 min recovery phases followed by final step time to exhaustion over 9 weeks	Decreased perceived fatigue at week 9, no improvement in lactate threshold and VO_{2max}
Bigard et al., 1996	Six sessions of ski mountaineering for 6-8 hours	No difference compared to carbohydrate ingestion on bicycle peak power output
Wiśnik et al., 2011	Multiple-choice reaction time on a treadmill	Reduction in reaction time compared to placebo
Chang et al., 2015	Simulated bouts of handball game followed by sprints	Improvement of sprint time compared to placebo
Durkalec-Michalski et al., 2021	8-week standard taekwondo training period	No differences in aerobic capacity compared to placebo

Calleja Gonzalez et al., 2020	Maximal countermovement jump over a week	No difference in jump height compared to placebo
Ikeda et al., 2016	Upper and lower limb isometric strength, Functional Reach Test and the Timed Up and Go test	Significant improvement in the BCAA group after crossover

Most of the meta-analysis focused on DOMS, EIMD and biochemical markers of muscle damage (Fedewa et al., 2019; Mehran et al., 2020; Khemtong et al., 2021; Weber et al., 2021; Salem et al., 2024). Among these, it was shown that BCAA supplementation lowers indirect biomarkers of muscle damage, such as creatinine kinase, but only one meta-analysis concerning muscle performance was found. It showed no advantage over placebo in terms of muscle strength and performance in the short-term (up to 48 hours) (Doma et al., 2021).

No meta-analyses assessing the long-term effect of BCAA supplementation and muscle performance were found. We hypothesize that the main cause is that few studies investigating the long-term effects of BCAA supplementation on muscle strength and performance were conducted. Further studies exploring this topic are needed.

Current evidence suggests that BCAA supplementation may offer selective benefits for muscle strength and performance. The effects seem to depend on the training status of the individual. The type and duration of the exercise, and the presence of other nutritional supplementation also seem to affect BCAA supplementation outcomes significantly. Some trials show modest improvements in strength and reduced fatigue or muscle damage, particularly in untrained or elderly populations. On the other hand, most of the studies report none to minimal performance enhancement. Therefore, the utility of BCAA as a standalone anabolic aid remains dubious. The most effective application may lie in targeted strategies combined with resistance training. Prolongation of endurance activity and supplementation in populations with greater susceptibility to muscle loss seems to affect the outcomes additionally.

4. CONCLUSION

Review of the current evidence shows a modest role of BCAA supplementation in either the mitigation of delayed onset muscle soreness or the enhancement of exercise outcomes. BCAA, especially leucine, appears to modulate muscle protein metabolism through mTORC1 activation, central fatigue inhibition, and the effect on ROS mechanisms. These pathways provide a plausible biological mechanism of action for BCAA benefits. Nonetheless, clinical data suggest only modest reductions in DOMS. The effect seems to be more abundant when the supplementation occurs both pre-exercise and post-exercise. Untrained individuals, as well as subjects in resistance-based modalities, probably benefit more from the supplementation. The differences in study design, dosing, and participant characteristics prevent the generalization of these findings. BCAA supplementation may hold practical value as a recovery aid in some contexts—particularly for novice athletes, aging populations, or under prolonged exercise conditions. However, its effect in performance enhancement appears limited in the scope of the reviewed evidence. Future research is needed to fully assess the impact of BCAA supplementation on long-term physical performance.

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Conflict of interest
The authors declare that there is no conflict of interest.

Data and materials availability
All data sets collected during this study are available upon reasonable request from the corresponding author.

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