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Enhancing recovery from plyometric circuit training: The synergistic impact of dynamic stretching, BCAA supplementation, and sports massage on DOMS

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ABSTRACT

Understanding the significance of efficient post-exercise recovery methods in alleviating muscle damage and addressing delayed onset muscle soreness (DOMS) among athletes following plyometric circuit training. The study aimed to determine the effect of dynamic stretching in water (active pool-based) and sports massage (SM) on muscle damage indices post-plyometric circuit training. A total of 30 participants were divided into three control groups and one experimental group, who were given two recovery protocols (APB + BCAA and sports massage) after the trial. Data were statistically analysed using a one-way ANOVA test with post-test measurements and a Bonferroni test ($P < 0.05$). It is concluded that statistically the APB + BCAA post-hoc test with SM did not show any significance. However, on average, APB + BCAA was preferable at reducing DOMS symptoms; measurements 3 and 4 in the intervention groups also showed a significant effect on the control group. The study findings underscore the valuable contribution of active recovery in water and the use of supplements in improving initial recovery outcomes after strenuous exercise or sports, aligning with the exercise recovery principle that highlights the inseparable relationship between nutrition and soft tissue modalities.

Keywords Stretching; dynamic; BCAA; massage; DOMS

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INTRODUCTION

The pursuit of physical fitness is a common goal among individuals engaged in structured exercise programs, often guided by specific performance metrics. Adherence to exercise programs aligned with the body's physiological principles not only enhances health but also optimizes physical performance (Genin et al., 2018; Lovato et al., 2015). Intensifying training effectiveness hinges on injury prevention and expediting the recovery process, which plays a pivotal role in harnessing the body's adaptive response to exercise stress (Impellizzeri et al., 2020). Consequently, after intense physical exertion, individuals may encounter exercise-induced muscle damage, a phenomenon commonly recognized as delayed-onset muscle soreness (DOMS) (Barnes, 2023; Setiawan et al., 2022). DOMS, characterized by muscle discomfort or pain, is frequently associated with various forms of muscle contractions, including isometric, concentric, eccentric, or combinations thereof (Mautner & Sussman, 2016; Ruas et al., 2022). While DOMS typically subsides with time, active recovery strategies can facilitate a faster recuperation (Ryu et al., 2016). Nevertheless, it is worth noting that the nature of muscle contractions, such as eccentric contractions, which can lead to a 30%–36% decline in strength, a 5%-7% reduction in range of motion (ROM), and increased muscle stiffness (Fares, 2022), also modulates the perception of pain (Santos et al., 2017; Sørensen et al., 2019).

Indicators of exercise adaptation also include changes in leukocyte and monocyte counts, blood lactate concentrations, and range of motion (Hui et al., 2014; Jajtner et al., 2014; Larkin-Kaiser et al., 2015; Manojlović & Erčulj, 2019; Nikolaidis, 2017; Rossato et al., 2015). Moreover, monitoring these physiological markers not only aides in determining the extent of recovery but also informs the implementation of targeted strategies to reduce the lingering effects of exercise-induced stress and accelerate the return to peak physical condition (Bachasson et al., 2017; Ware et al., 2018). This exhaustive strategy is necessary for optimising athletic performance and overall health. Even if a person reaches a previous level of performance, it does not necessarily indicate complete recovery from the previous training session, especially if perceived fatigue, muscle disintegration, DOMS, and inflammation persist (Dupuy et al., 2018). Therefore, it is essential to restore both physical performance and biochemical markers such as creatine kinase during the post-exercise recovery process.

Several efforts can be undertaken to recover, including nutritional interventions, updating training techniques, management of the recovery phase, and optimising strategies (French & Ronda, 2022). There are several procedures to optimise the physical condition of the body, including sports massage (SM) (Fitrianto & Prayoga, 2022) and recovery to reduce damage to muscle tissue. Sports massage is also widely practiced (Naderi, 2021), to reduce pain (Nelson, 2013), improve muscle performance post-exercise, and act as an effective treatment for muscle pain (Boguszewski et al., 2014). Combination treatment of PNF stretching post-exercise and post-exercise massage can help diminish the symptoms of muscle damage (Biosci et al., 2014). Sports massage mixed with cold water immersion also suggests a significant reduction in pain sensation (Angelopoulos et al., 2022; Romadhona et al., 2019) in other words, it is effective in reducing pain but cannot influence other important adaptations of the DOMS (Angelopoulos et al., 2022).

On the other hand, biochemical markers like creatine kinase can be lowered using methods like branched-chain amino acids (BCAA), which have been shown to stop CK and LDH from increasing (Khemtong et al., 2021). This makes BCAA a valuable supplement for athletes engaged in strenuous exercise, helping maintain muscle strength and preventing damage (Lim, 2020). The overall effect of BCAAs on DOMS after one training session is more likely to increase muscle recovery by reducing DOMS in trained subjects (Weber et al., 2021), and can reduce pain (Sanjaya et al., 2021). Additionally, active recovery strategies have demonstrated their effectiveness in mitigating the risk of DOMS (Fares, 2022). Techniques such as using a foam roller, which has been found to effectively reduce CK levels (Ali et al., 2023), and engaging in dynamic stretching to improve range of motion (ROM) (Chen et al., 2015; Herda et al., 2013).

In recent years, research on recovery from DOMS (Delayed Onset Muscle Soreness) has shown promising results in relieving symptoms of muscle damage, including restrictions in range of motion (ROM), decreased muscle strength, muscle soreness, and pain intensity (Majhi & Mondal, 2021; Mantovani et al., 2017; Righi et al., 2020; Yu et al., 2022). A combined approach of various interventions has been explored and offers potential benefits in reducing symptoms of exercise-induced muscle damage (Jalalvand et al., 2012). Furthermore, stretching the muscles after the cool-down phase is also an important component in improving flexibility and reducing muscle soreness. It is important to remember that stretching is effective in addressing the effects of DOMS, which is a secondary response to inflammation or swelling, rather than microtrauma of myofilament proteins (Paine, 2023). As such, these strategies provide a diverse approach in improving recovery and reducing the impact of DOMS in athletes.

To date, there have been several studies on how to recover from DOMS, including research by (Şahin et al. 2022). Active recovery has been shown to be effective in reducing the severity and duration of muscle damage (Fares, 2022; Mrakus et al., 2022). Training in water has also been shown to improve the recovery of muscle physiological function against DOMS symptoms (Roberts et al., 2014), and training in water facilitated leg muscle recovery and showed faster improvements in symptoms of muscle soreness, stiffness, and muscle strength (Harty et al., 2019). Based on this, athletes and active individuals who require rapid recovery between training sessions or gruelling physical activities should implement well-supported nutrition and supplementation strategies to enhance and aid the recovery process. The results of this study are expected to make an important contribution to understanding how to reduce the impact of DOMS and other related symptoms, as well as serve as a reference for the development of more effective sports recovery protocols involving nutrition, supplementation, and active recovery aspects.

This study aimed to test the effectiveness of a comprehensive exercise recovery approach. This approach includes the use of dynamic stretching in the pool combined with branched chain amino acid (BCAA) supplementation to reduce the impact of DOMS (Delayed Onset Muscle Soreness) and other associated symptoms. In addition, the effects of sports massage on soft tissue recovery after exercise will also be analysed. This study is important as no previous research has combined these two approaches into one comprehensive recovery approach. Therefore, this study has urgency in providing new insights into how to reduce the impact of DOMS and other related symptoms. The results of this study may also help in the development of more effective exercise recovery protocols, which will benefit athletes and physically active individuals. As such, this study has the potential to improve our understanding of exercise recovery and provide tangible benefits to exercise practitioners.

METHOD

This research is experimental. The pre-and post-control group design approach was used to measure the effect of dynamic stretching and sports massage on DOMS. The research was conducted in Banjarmasin City, South Kalimantan. The sampling technique was purposive sampling, with thirty subjects (20.06 ± 2.2) recruited from the Borneo Sport Science Physical Condition Training Club. The characteristic of subject is described in Table 1. Subjects were classified as active and trained participants. The exclusion criteria include: not participating in structural strength training and/or other physical activity involving strength training at least 24 hours prior to data collection, having no history of lower extremity injury, neurological disorders, and/or low back pain. Besides, participants were asked not to carry out any additional treatment and use of supplements from 24 hours before and during data collection. All participants were asked to submit written and informed consent before their participation. After the screening process, participants were randomly allocated into three groups; the APB + BCAA group, the SM group, and the control group which did not undergo any recovery treatment. The dependent variable in this study is DOMS, which was measured by collecting data on the range of motion (ROM) and measured by a universal goniometer. In this study, the focus was on the lower body for data collection. Measurement of post-exercise pain levels (muscle pain) using a visual analogue scale (VAS). Elevated serum creatine kinase (CK) activity was used as a marker of muscle damage.

Table 1. Physical Characteristics of Subjects (mean ± SD)

Variable	Mean ± SD
Age (years)	20.0 ± 2.2
Height (cm)	168.7 ± 6.0
Weight (kg)	59.4 ± 9.0
BMI (kg)	21.2 ± 3.4

The research procedure involved 3 groups performing 3 sets of 1:1 plyometric training circuits (30 seconds of working out: 30 seconds of rest) and 3 minutes of rest between sets. The research process was measured 4 times; before exercise, after 8 hours of intervention, after treatment, and after 24 hours on the basis that DOMS will appear and culminate from that time (Coker et al., 2019; Fleckenstein et al., 2021;

Sonkodi et al., 2021; Torre et al., 2021). The experimental group of sports massage was treated immediately after 8 hours of intervention. SM sports that involved manual therapy on the lower body muscles were carried out by a therapist. The treatment lasted about 30 minutes. Massage techniques comprise sliding, effleurage, scrubbing, kneading, and vibration (Fares, 2022). Meanwhile, the subjects from the pool-based dynamic stretching experiment group combined BCAA supplements immediately after the 8-hours intervention. As many as 7 grams of BCAA (XTEND BCAA, BPOM: 261979004035) serving (1 scope 250 ml water) of powder dissolved in 250 ml of water were administered before pool-based dynamic stretching, walking, jogging, side walking, walking backward, and jumping in water was performed for 30 minutes. The control group received no supplements and underwent passive recovery. Participants were instructed not to disclose or discuss interventions with the evaluator. Details of the research procedure are shown in Figure 1.

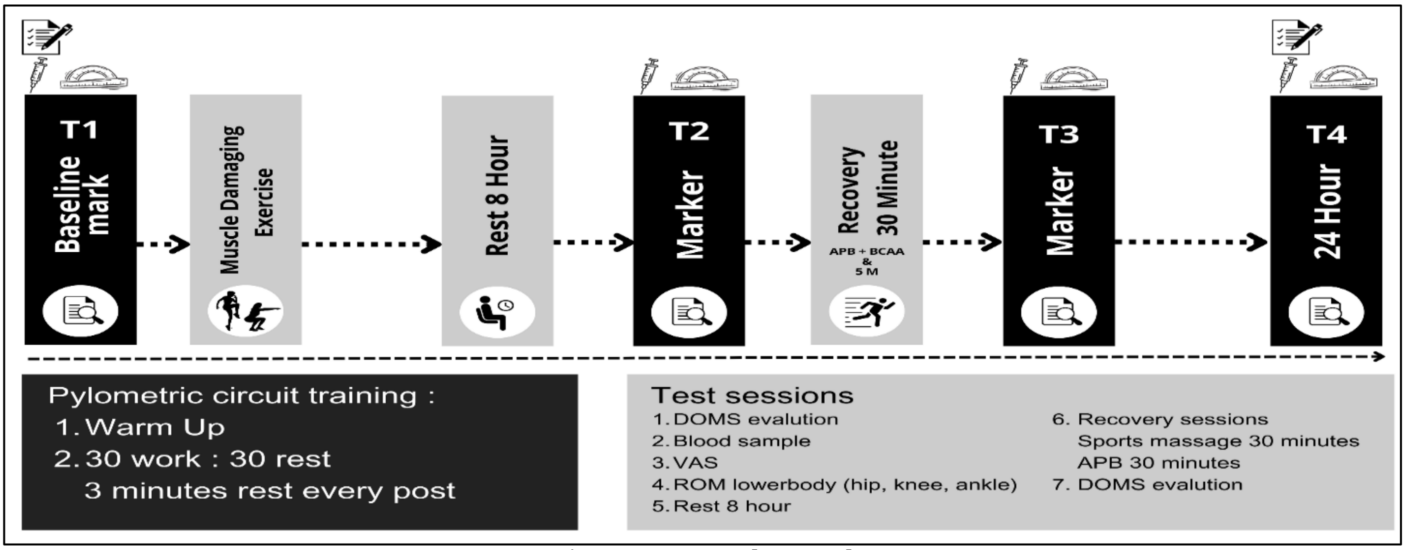

Figure 1. Research Procedure

Data analysis was carried out by testing the normality and homogeneity of the data. Differences between measurements of water-based dynamic stretching treatments and sports massage were examined using a one-way ANOVA test performed to discover differences between the three groups and an appropriate post-hoc analysis according to Scheffe's method (Johnson, 2022). Statistical significance was predetermined for all statistical procedures at p 0.05.

RESULTS AND DISCUSSION

Functional data and symptoms before and after the implementation of the intervention and control were analyzed using one-way variance and post-hoc tests with Bonferroni correction applied to one-way ANOVA for all tests. The significance level was set at $P < 0.05$, which had previously passed the Kolmogorov-Smirnov normality prerequisite test and homogeneity showed that testing pain as measured by (VAS), hip, knee & and ankle joint range of motion (ROM), and markers of muscle tissue damage as measured by serum (CK) were statistically significant, especially in the third measurement after treatment and fourth measurement after 24 hours of treatment. The mean and standard deviation are shown in Table 2 and Figures 1-5.

Figure 1 presents the score of changes in muscle pain as evaluated using the Visual Analog Scale (VAS). VAS scores suggest improvement over time. Muscle pain developed 8 hours post-exercise in every three groups. In comparison, the experimental group showed significantly lower symptoms of DOMS than the control group 8 hours post-training ($p = 0.000$) and earlier recovery than the control group 24 hours post-training ($p = 0.000$). Decreased pain severity after 24 hours and the discrepancy scores of the APB + BCAA group were preferable to sports massage and control.

Figure 2 indicates the changes in blood CK of three groups. CK concentration increased significantly and continuously after exercise in every group from pre-exercise, immediately post-exercise, 8 h ($p = 0.039$), and 24 h (p = 0.013). Further tests showed that CK levels had increased significantly after exercise (post-D0, D1, D2, and D3), compared to pre-exercise concentrations (pre-D0). Furthermore, levels improved significantly at D1 and D2 compared to post-D0 ($p < 0.05$). The APB + BCAA group had a sustained and significant increase in CK concentration and better recovery compared to sport massage and control groups from 111.6 ± 74.0 U/L before exercise (pre-D0) to 112.9 ± 105 U/L, 128.0 ± 73.1 U/L, and at 24 hours 86.3 ± 44.4 U/L.

Figures 3, 4, and 5 illustrate changes in lower body ROM (hip, knee, & and ankle) between the three groups. In the APB + BCAA and sport massage groups, hip ROM had a significant effect between groups after treatment (p = 0.009), knee (p = 0.000), and ankle (p = 0.004), compared to before exercise. However, it lowered 24 hours after exercise (p = 0.000), knee (p = 0.000), and ankle (p = 0.000). The APB + BCAA experimental group attained higher ROM than sports massage at 24 hours hip 26.8 ± 3.6, knee 131.6 ± 6.6, and ankle 33.4 ± 2.2, whereas sport massage had a higher ROM than the control hip 28.2 ± 2.6, knee 129.3 ± 7.2, and ankle 30.6 ± 3.7. Comparison between groups after treatment revealed significant differences in the APB+BCAA and SM groups compared to the control 24 hours post-training.

Table 2. Mean and Standard Deviation of Creatine Kinase, Soreness Sensations (VAS) and Range of Motion (Hip, Knee, Ankle) with APB+ BCAA and Sport Massage (SM) to DOMS (APB, N=10), (SM, N=10) and Control Group (CON, N=10) Groups after Stimulated Plyometric Exercise.

Measurements		Baseline	After Rest 8 Hours	After Intervention 30 minutes	After 24 Hours
Creatine Kinase	APB + BCAA	111.6 ± 74.0	112.9 ± 105.2	128.0 ± 73.1	86.3 ± 44.4
	SM	129.1±104.1	122.5 ± 131.4	216.5 ± 164.1	120.6 ± 87.1
	CON	124.3 ± 67.9	132.7 ± 101.8	290.4 ± 146.9	174.8 ± 45.5
VAS	APB + BCAA	1.0 ± 0.9	5.4 ± 2.1	3.4 ± 2.0	1.8 ± 1.4
	SM	0.9 ± 0.8	5.2 ± 1.4	3.4 ± 2.1	1.5 ± 1.4
	CON	1.1 ± 0.9	3.8 ± 1.6	5.7 ± 1.2	7.2 ± 1.0
Rom hip adduction	APB + BCAA	27.9 ± 4.1	20.4 ± 4.2	23.9 ± 2.4	26.8 ± 3.6
	SM	27.3 ± 2.9	18.7 ± 3.6	22.4 ± 2.7	28.2 ± 2.6
	CON	28.7 ± 3.4	22.7 ± 2.3	19.2 ± 2.4	17.1 ± 2.3
Rom knee flexy	APB + BCAA	112.6 ± 7.5	78.6 ± 13.3	103.2 ± 6.8	109.8 ± 8.4
	SM	110.0 ± 9.8	78.0 ± 14.3	88.7 ± 14.3	101.8 ± 13.5
	CON	109.5 ± 9.2	89.8 ± 13.3	82.0 ± 12.0	64.5 ± 12.7
Rom ankle inversion	APB + BCAA	31.2 ± 3.6	23.5 ± 4.0	27.7 ± 3.9	29.6 ± 4.2
	SM	30.7 ± 3.7	21.5 ± 3.5	25.8 ± 3.6	29.7 ± 3.5
	CON	31.7 ± 4.7	25.0 ± 4.9	20.8 ± 5.1	17.5 ± 2.5

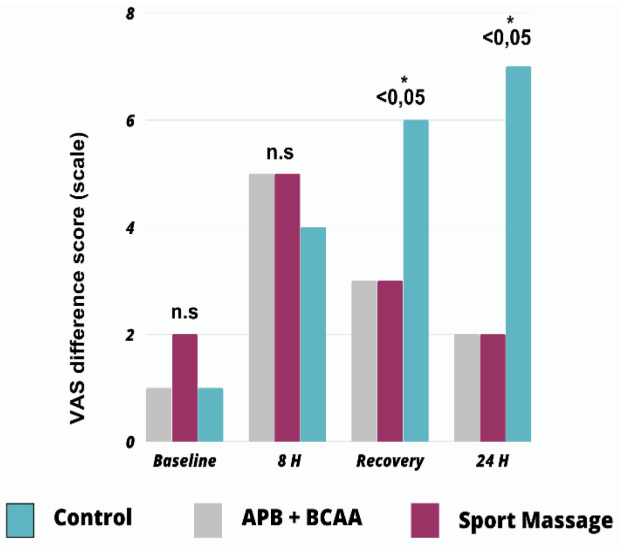

Figure 1. Muscle Pain Scale Before T1, 8 Hours after T2, after T3, and 24 Hours after T4.

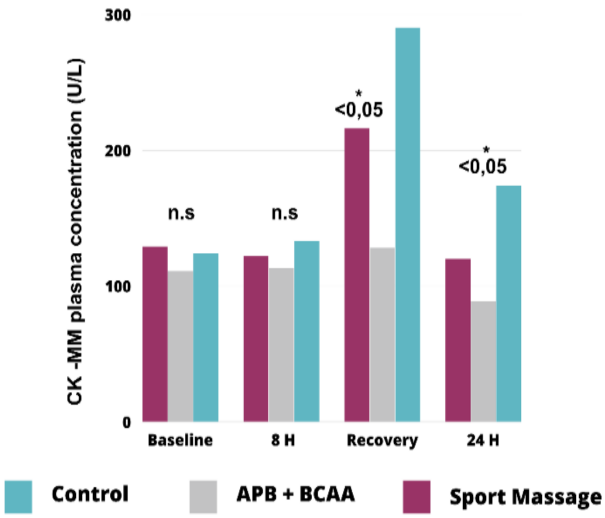

Figure 2. Creatine Kinase before T1, 8 Hours after T2, after T3, and 24 Hours after T4

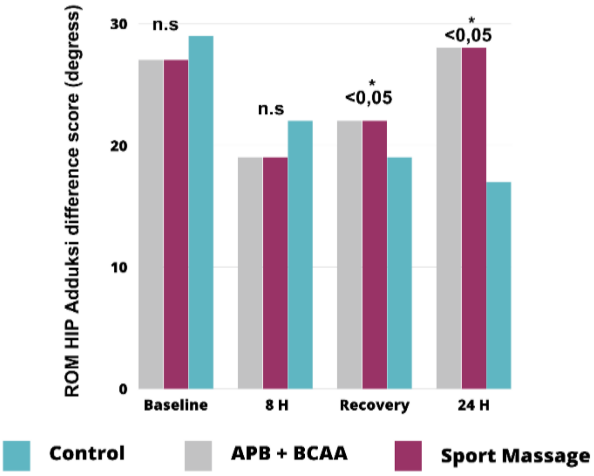

Figure 3. Range of Motion before T1, 8 Hours after T2, after T3, and 24 Hours after T4

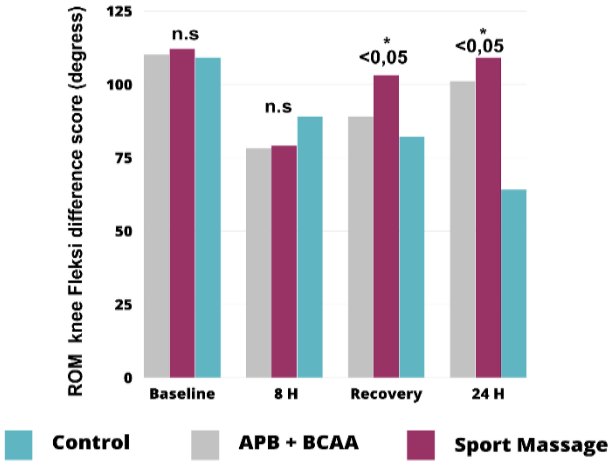

Figure 4. Range of Motion before T1, 8 Hours after T2, after T3, and 24 Hours after T4

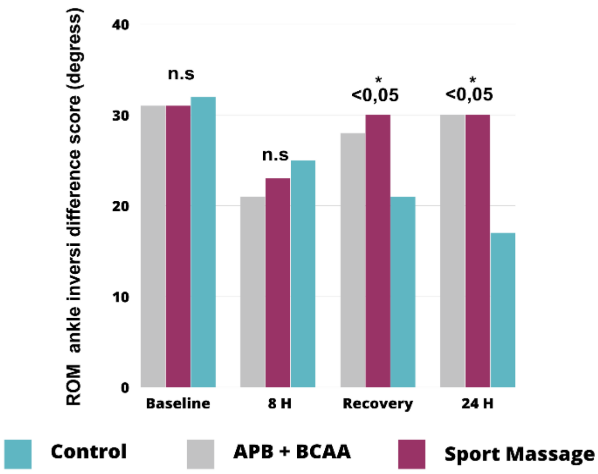

Figure 5. Ankle Range of Motion before T1, 8 Hours after T2, after T3, and 24 Hours after T

This study aimed to evaluate the effects of two types of interventions, namely APB + BCAA and SM, on reducing the functional effects of DOMS and compare them with a control group. The findings showed significant differences in recovery between these interventions and provided insight into the management of DOMS in the context of physical exercise. These findings indicated that the application of the two interventions (APB + BCAA and SM) successfully reduced the functional effects of DOMS significantly compared to the control group. However, in the post hoc test, there was no statistically significant difference between the two experimental groups. Nonetheless, based on the mean scores, APB + BCAA appeared more desirable or resulted in faster recovery compared to SM, both from the measurements after the intervention and 24 hours after exercise. Pain scale, creatine kinase, and ROM had a significant increase 8 hours after exercise and then dropped significantly 24 hours after exercise. In particular, statistics showed significance in the intervention group when the third measurement was taken immediately after the intervention and the fourth measurement after 24 hours. DOMS typically appears 8 to 24 hours after cell damage and usually peaks 24 to 48 hours after exercise (Costello, 2013; Wheeler & Jacobson, 2013).

These findings support the results of previous research highlighting the symptoms of DOMS. Previous research has shown that active recovery through movement in water can reduce muscle damage and improve the recovery process (Theanthong et al., 2012). In addition, protein consumption immediately after exercise has been shown to be beneficial in promoting muscle recovery and muscle building, with approximately 4 to 15 grammes of BCAAs being able to help reduce muscle protein breakdown, post-workout injury, and

DOMS (Kume & Yasuda, 2020; Pearson et al., 2023). The study also revealed a positive impact of dynamic stretching on DOMS symptoms in muscles, suggesting an attempt to incorporate an element of water hydrostatic pressure. This approach is popular, practical, affordable, and consistent with the principle of hydrostatic pressure, which plays a role in reducing muscle tension, localised swelling, and pain sensations while increasing blood flow to the muscles (Muanjai & Namsawang, 2015). Pool-based exercises that include stretching movements in water are designed to relieve pain, provide a sense of relaxation, and strengthen muscles.

They also aim to reduce joint stiffness and muscle spasms, improve range of motion and motor coordination, and provide increased self-confidence (Galvão-Moreira et al., 2021). The hydrostatic pressure effect of water, including immersion up to the neck, has a positive potential for muscle strength recovery. This is related to its ability to reduce the risk of swelling (Leeder et al., 2012) and reduce the impact of loads on the lower limbs. Additionally, movement in water does not involve eccentric contractions, meaning that no muscle damage occurs during active recovery with reduced muscle soreness (Diong & Kamper, 2014). The results of a comparative study between the two types of recovery exercises, both in water and out of water, showed that significant differences in pain reduction were only seen in the group that performed the exercises in water (Beyranvand et al., 2023). In conclusion, the use of water as a medium for recovery exercises appears to have real benefits in addressing DOMS symptoms and facilitating better muscle recovery.

In addition to in-water exercises, active stretching also has significant benefits for recovery after strenuous exercise. This finding is consistent with previous research (Lima et al., 2019; Opplert & Babault, 2018), which demonstrated that dynamic stretching can have a significant positive effect on muscle performance, especially in terms of strength, power, sprinting, and leaping performance. This indicates that dynamic stretching can effectively reduce muscle damage that usually occurs due to eccentric exercise (Chen et al., 2015). Not only that, but active pool-based stretching methods have also shown tremendous potential for reducing stress on the lower body muscles and effectively helping to reduce muscle damage while accelerating the overall recovery process. This approach provides a comprehensive solution for addressing DOMS symptoms and supports more optimal muscle recovery. Therefore, the combination of in-water training and dynamic stretching can be a highly effective strategy to achieve holistic post-workout recovery.

Not only limited to recovery through soft tissue modalities, the findings from this study also highlight the important role of nutrition and supplements in the recovery process. The consumption of protein as soon as possible after exercise has been shown to improve muscle recovery and building (Arroyo-Cerezo et al., 2021), while the intake of 4-15 grammes of BCAAs can help reduce muscle protein breakdown, post-workout injury, and DOMS (Kume & Yasuda, 2020). BCAAs, particularly leucine, are effective supplements in reducing exercise-induced muscle damage by promoting regeneration of damaged cell membranes and increasing the endogenous synthesis of HMβ and its metabolite HMG-CoA (Nicastro et al., 2014). Overall, BCAAs may help improve muscle recovery by minimising DOMS in trained subjects (Weber et al., 2021) and may reduce the impact of muscle damage caused by physical exercise in certain situations (Fouré & Bendahan, 2017). Therefore, the consumption of protein and BCAA supplements after resistance training is considered important in supporting effective muscle recovery.

The results of this study imply that SM (sports massage) can help reduce muscle soreness. Although SM is one of the most popular interventions for supporting sports recovery (Patra et al., 2023; Xie et al., 2023), some arguments state that SM does not always have a positive impact (Dakić et al., 2023). However, in support of the data obtained, systematic reviews and meta-analyses show that massage after strenuous exercise can effectively reduce DOMS and improve muscle performance. For example, a 30-minute post-exercise massage can increase perceived recovery, reduce pain, and improve knee strength and vertical jump performance (Kargarfard et al., 2016). Another opinion regarding SM interventions is that the timing of massage will affect its immunomodulatory effects. Massage will be more effective if administered soon after injury (Waters-Banker et al., 2014). Massage has been proposed to relieve exercise-induced pain by reducing interstitial inflammatory mediators, oedema, and muscle tension (Kargarfard et al., 2016; Waters-

Banker et al., 2014). Neural changes thought to be caused by massage are also believed to reduce muscle tension, potential spasm, and pain.

There are several theories related to DOMS, such as lactic acid, muscle spasm, connective tissue damage, muscle damage, and inflammation (Mautner & Sussman, 2016). The integration of these theories may explain DOMS. The main cause of DOMS is eccentric contraction, which results in the most severe micro-injury condition, while SM can increase blood flow to the muscle and reduce muscle oedema (Souza-Silva et al., 2018). Massage for 20–30 minutes immediately after or up to 2 hours after exercise has been shown to be effective in reducing DOMS for 24 hours after exercise (Torres et al., 2012). SM is the most effective recovery technique for reducing the concentration of CK and IL-6 circulating in the blood after exercise (Dupuy et al., 2018). It can also regulate immune compounds when applied after exercise, and these compounds can have a direct impact on fatigue and signs of exercise-induced muscle damage (Tejero-Fernández et al., 2015). Nonetheless, SM is mostly evaluated based on its contribution to reducing pain perception while mitigating negative effects on athletes' functional capacity, although results from these studies are relatively unsupportive of this belief.

All interventions in our study are proved effective in mitigating the negative consequences that often accompany plyometric training. Notably, the significant reduction in pain sensation persisted consistently across all measurements, encompassing individuals who received supplementary interventions and soft tissue modalities as well as those in the control group who did not. Specifically, sports massage (SM) emerged as a positive contributor to alleviating the adverse outcomes associated with delayed-onset muscle soreness (DOMS). Massage on the lower body for 30 minutes brings down pain caused by fatigue and swelling (Han et al., 2014). Furthermore, another study by Guo et al. (2017) showed that massage therapy significantly decreased muscle soreness levels at 24, 48, and 72 hours after intense exercise. In addition, it promotes massage as being associated with a small but statistically significant improvement in flexibility and pain sensation after DOMS is induced (Davis et al., 2020). Thus, it can be an alternative for recovery after strenuous exercise that effectively facilitates DOMS recovery.

These findings present a promising alternative for post-strenuous exercise recovery with the potential to facilitate DOMS recuperation effectively. However, it is essential to acknowledge the limitations of our study. The variables were assessed over a 24-hours period, which may not capture longer-term differences in some measures. Future research should explore the application of these interventions to professional athletes and employ extended methodological designs. Furthermore, it is crucial to investigate the combined effects of other active interventions like active progressive bracing (APB) and supplements such as branched-chain amino acids (BCAA). Despite these limitations, our study stands out for its methodological originality. It is the first study to evaluate the combined use of APB+BCAA and SM as a comprehensive DOMS recovery strategy, mirroring real sports conditions where recovery is integral to all forms of training. This variable has been largely overlooked in previous athlete-focused studies. The incorporation of organised recovery programmes and post-exercise interventions played a pivotal role in shaping the outcomes of our study. These findings hold significant clinical relevance, endorsing the use of soft tissue and supplement modalities, particularly SM, to enhance DOMS symptom management and advocating for structured cool-down programmes following strenuous exercise.

CONCLUSION

In conclusion, the study demonstrated significant differences in APB+BCAA and sports massage versus the control group for the DOMS marker, which had significant implications for recovery after strenuous exercise. The researchers observed that APB+BCAA had better recovery results on average, indicating its potential as a promising intervention for mitigating the effects of DOMS. Meanwhile, sports massage appeared to be effective in reducing pain associated with DOMS markers, aligning with findings from previous research. Furthermore, our study revealed a notable improvement in overall hip, knee, and ankle range of motion (ROM) following the interventions, underscoring the positive impact of these recovery modalities. It is worth noting that active recovery in water, combined with the use of supplements like BCAA, can play a pivotal role in influencing recovery outcomes after demanding physical activities. These findings contribute valuable insights to the field of sports science and recovery strategies, emphasise the multifaceted approaches that can be employed to enhance post-exercise recuperation and minimise the effects of DOMS.

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CONFLICT OF INTEREST

The authors have declared that we have no conflicts of interest regarding the authorship and/or publication of this article.

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