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The Ameliorating Effect of Branched-chain Amino Acids Ingestion on Different Types of Muscle Soreness after Swimming and Full-marathon Running

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Abstract

ISHIKURA, K., MIYAZAKI, T., RA, SG. and OHMORI, H. The Ameliorating Effect of Branched-chain Amino Acids Ingestion on Different Types of Muscle Soreness after Swimming and Full-marathon Running. Adv. Exerc. Sports Physiol., Vol.20, No.1 pp.9-17, 2014. The effectiveness of branched-chain amino acids (BCAA) ingestion on delayed onset muscle soreness (DOMS) has been established in experimental exercise involving eccentric contraction (ECC). This placebo-controlled, randomized, double-blind study evaluated the effect of BCAA ingestion on two types of muscle soreness after swimming (which generally involves little ECC) and immediate onset muscle soreness (IOMS) after a full-marathon and on systemic fatigue. Subjects were 32 swimmers competing in a university swim meet and 22 non-professional runners participating in a full-marathon race. They received either 3.2g of BCAA or placebo three times a day, from the day before to two days after their events. Systemic fatigue and soreness in muscle regions (seven regions in swimmers, six in runners) were evaluated using a numeric rating scale before, immediately after, and one and two days after the events. In the swimmers, muscle soreness in the upper body (neck, upper arm, back, and low back), buttock, and thigh and systemic fatigue were significantly decreased after two days in the BCAA group. In the runners, IOMS occurred in all examined regions immediately after the marathon, and BCAA ingestion significantly decreased both muscle soreness in the anterior thigh, anterior lower leg, and buttock and systemic fatigue within two days. This study showed the effectiveness of BCAA ingestion on improving systemic fatigue, muscle soreness after swimming, and IOMS after a full-marathon. On the basis of these results, it is proposed that BCAA supplements can be administered to ameliorate muscle soreness and fatigue induced by various types of exercise.

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Introduction

Branched-chain amino acids (BCAA; valine, leucine, and isoleucine) are the main amino acids contained in skeletal muscle protein, and play many nutritional and functional roles. They serve as an energy source during exercise (20) and a signalling factor in protein synthesis (1,6,11,26), and are involved in deammoniation (29) and anti-inflammatory/immune responses (4,14,17). In addition, many studies have reported inhibitive effects of BCAA ingestion on exercise-induced delayed onset muscle soreness (DOMS) that peaks 24-72 hours after the exercise (10,23). For example, BCAA ingestion before squat exercise in female college students significantly decreased DOMS experienced two or three days after the exercise (23), and continuous BCAA ingestion from immediately before to two days after the exercise significantly inhibited DOMS induced by eccentric knee extension (10).

Most studies reporting the effectiveness of BCAA ingestion on DOMS have focused on DOMS caused by experimental exercise involving eccentric muscle contraction (ECC) (10,23). DOMS is characterized by its occurrence after unusual exercise or ECC (3,7), appearance approximately 24 hours after exercise, peak soreness between 24 and 72 hours after, and dissipation 5-7 days after (3). The exact mechanism of DOMS is not known, but is speculated to involve damage to skeletal muscle and connective tissue ultrastructure caused by excessive, extended muscle loading from ECC, and subsequent activation of immune responses (3,13,24). However, DOMS is occasionally observed in some exercise motions that involve little ECC. For example, most swimmers have experienced DOMS when increasing their training load, despite the fact that the main muscle contraction pattern in swimming exercise is a concentric muscle contraction against the resistance load of the water (19). One suggested explanation for this is exercise-induced fatigue, with DOMS caused by overextension of the skeletal muscles due to fatigue-induced decrease in muscle strength and abnormal patterns of muscle contraction and/or relaxation (18).

In addition to DOMS, other types of exercise-induced muscle soreness exist, such as immediate onset muscle soreness (IOMS), which occurs earlier than DOMS, immediately after exercise (9,27,28). IOMS is frequently observed in exercise involving running, particularly in long distance running such as the marathon event, with onset sometimes even occurring during exercise (9,27,28). Vickers confirmed that peak muscle soreness occurred immediately after endurance running (mean 35 km), but occurred two days after 10 min of bench-stepping exercise (28). Thus, the time course of exercise-induced muscle soreness differs according to exercise pattern.

Although the effectiveness of BCAA ingestion on DOMS experimentally induced by exercise is well established (10,23), its effectiveness on muscle soreness induced by swimming, which involves little ECC, and on IOMS induced by long distance running is unknown. Against this background, this study investigated, in a randomized, placebo-controlled, and double-blind manner supplemented by fieldwork, the inhibitive effect of BCAA ingestion on different types of exercise-induced muscle soreness in competitive swimmers following a regular training program and in non-professional full-marathon runners.

Methods

Subjects

In Study 1, 32 healthy members of a university swimming team who participated in an interuniversity competition held in August 2010 were recruited to a swimming experiment and randomly assigned to a BCAA supplementation (BCAA) group or placebo supplementation (Placebo) group before the competition. Participant data are shown in Table 1. There was no significantly difference in mean age between the groups, and both groups were predominantly male. As participants' swimming styles could not be unified, difference in swimming style was not considered in this study. All swimmers in this experiment participated in the competition with keeping regular training, however, the amount of training prior to the competition, was not checked in the present study.

In Study 2, 22 healthy non-professional runners who participated in the 31st Tsukuba Full-Marathon held in November 2011 were recruited as volunteers. As in Study 1, the subjects were randomly assigned to the BCAA and Placebo groups before the marathon. Participant data are shown in Table 2. Similar to Study 1 participants, there was no significant difference in mean age between the two groups; however, the mean age was higher in Study 2 participants than in Study 1 participants. Both groups were predominantly male, as in Study 1. Time taken to complete the experimental task (goal time) in the BCAA group was shorter than in the Placebo group, but not significantly so ($P = 0.07$).

After explaining the purpose and protocol of these studies and the subject's right to withdraw at any time, informed consent was obtained from all subjects in accordance with the Declaration of Helsinki.

BCAA supplementation regimen

Both studies were carried out in a placebo-controlled, randomized, and double-blind manner. In the BCAA group in both studies, one sachet (4 g) of BCAA-enriched supplement (Aminofeel®; It was developed by a collaboration between Seikatsu Bunkasya Co. Inc., Chiba, Japan and Kurume University School of Medicine, Kurume, Japan.) consisting of 800 mg valine, 1,600 mg leucine, 800 mg isoleucine, minerals, and vitamins (12) was ingested three times a day for four days; specifically, one day before the event, on the day of the event, and one and two days after the event. The Placebo group in both studies received a placebo (4 g) containing a starch-based preparation of identical caloric content as the BCAA-enriched supplement. The Placebo group followed the same regimen as the BCAA group.

Assessment of muscle soreness and systemic fatigue

Local muscle soreness and systemic fatigue were assessed using an 11-point numeric rating scale (NRS) ranging from no pain [0] to the worst pain ever experienced [10] (25). The NRS sheet was self-completed by participants on the evening before the event (Pre), immediately after the event (Post), and one and two days after the event (day 1

Table 1. Participant data for swimmers: Study 1

Group	*N*	Age (mean ± SEM)	Sex (M : F)	Swimming stroke (Fr:Fly:Br:Ba:IM)
Placebo	16	20.5 ± 0.4	11 : 5	8 : 4 : 3 : 1 : 0
BCAA	16	20.5 ± 0.3	12 : 4	6 : 1 : 6 : 2 : 1

BCAA, branched-chain amino acids; *M*, male; *F*, female; *Fr*, freestyle; *Fly*, butterfly; *Br*, breaststroke; *Ba*, backstroke; *IM*, individual medley.

Table 2. Participant data for full-marathon runners: Study 2

Group	*N*	Age (mean ± SEM)	Sex (M : F)	Goal time (min: mean ± SEM)
Placebo	11	30.8 ± 3.9	10 : 1	262 ± 17
BCAA	11	30.3 ± 3.0	7 : 4	225 ± 17

BCAA, branched-chain amino acids; *M*, male; *F*, female; *Goal time*, time taken to complete the experimental task.

and day 2, respectively).

Muscle soreness was examined in seven body regions in the swimmers of Study 1 (neck, upper arm, back, low back, buttock, thigh, and lower leg) and in six body regions in the runners of Study 2 (anterior thigh, posterior thigh, anterior lower leg, posterior lower leg, low back, and buttock). The NRS used in both studies was expressed in relation to baseline (r-NRS). In Study 1, some participants had already experienced muscle soreness before the competition due to keeping regular training. Therefore, both the placebo and BCAA groups were further divided into subgroup; absent (MS[-]) and present (MS[+]) muscle soreness at Pre were defined as the NRS score of ≤ 2 and ≥ 3, respectively, by referring the report of Thompson *et al.* (25). The area under the curve (AUC) in the NRS during the experimental period (Pre to day 2) was calculated for muscle soreness and systemic fatigue. AUC calculated for the upper body (sum of individual AUCs for the neck, upper arm, back, and low back) and lower body (buttock, thigh, and lower leg) in Study 1 and for the thigh (anterior thigh, posterior thigh, and buttock) and lower leg (anterior lower leg and posterior lower leg) in Study 2 were then calculated.

Statistical analysis

Results are expressed as means ± SEM. Two-way ANOVA was performed to examine the main effects of BCAA supplementation and experimental period. Bonferroni correction was performed after one-way ANOVA to examine the difference between the examined time points in each group. Comparison between two groups was carried out by unpaired Student's *t*-test. $P<0.05$ was considered statistically significant.

Results

Study 1: Swimmers

Figure 1 shows the r-NRS scores after the swimming competition in relation to baseline for muscle soreness in the seven muscle regions (neck, upper arm, back, low back, buttock, thigh, and lower leg; Fig.1a-g, respectively) as well as for systemic fatigue (Fig.1h). After the event, the r-NRS score for all examined muscle regions was not significantly increased in either the BCAA or Placebo group. In the Placebo group, the r-NRS score in all examined regions except the neck and lower leg was slightly increased at Post, after which it increased or was maintained at day 1 before finally decreasing at day 2 (Fig.1b-f). The neck and lower leg scores in the Placebo group were also increased at day 1 before decreasing at day 2 (Fig.1a & 1g). In the BCAA group, the r-NRS score for all examined muscle regions was unchanged at Post, with the score gradually decreasing thereafter. One-way ANOVA analysis revealed significant differences for the upper body (neck, upper arm, back, and low back) and buttock between Post and day 2 in the BCAA group only (Fig.1a-e). For systemic fatigue, the

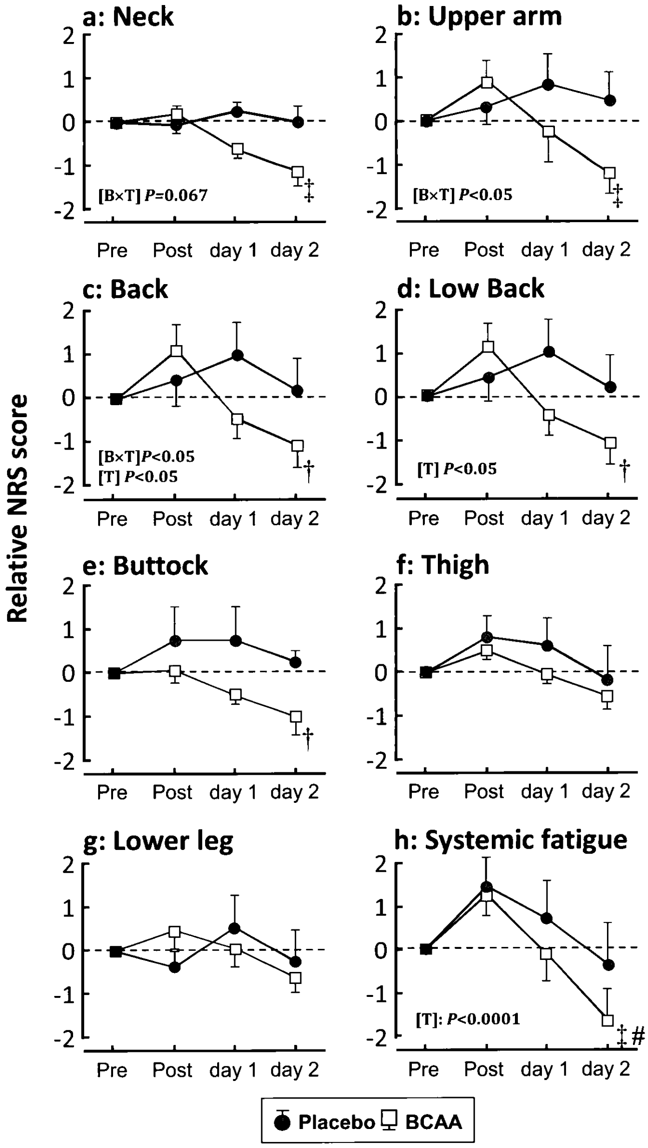

Fig. 1. Relative NRS score in Study 1 of swimmers for muscle soreness in the muscle regions of the neck (**a**), upper arm (**b**), back (**c**), low back (**d**), buttock (**e**), thigh (**f**), and lower leg (**g**), and systemic fatigue (**h**) from Pre to day 2 after the exercise event. NRS score is expressed in a relation to baseline (Pre). Abbreviation: **Pre**, day before swimming exercise; **Post**, immediately following swimming exercise; **day 1**, 1 day after swimming exercise; **day 2**, 2 days after swimming exercise. Values are expressed as means ± SEM. **[B]**, **[T]**, and **[B´T]** indicate the *P*-values for BCAA ingestion, experimental period, and the interactive factors of both, respectively, by two-way ANOVA. † $P<0.05$, ‡ $P<0.01$ vs. the corresponding value at Post, and # $P<0.05$ vs. the corresponding day 1 value analyzed by repeated measures one-way ANOVA followed by Bonferroni's *post hoc* analysis. One-way ANOVA *P* values were less than 0.01 for the neck, upper arm, back, low back, buttock, and systemic fatigue in the BCAA group.

r-NRS score in both groups was higher, although not significantly, at Post, and gradually decreased by day 2. At day 2, systemic fatigue was significantly lower than at Post and day 1 in the BCAA group only.

The average values of absolute NRS (a-NRS) score obtained from combination of two groups were 2.9 ± 0.5,3.6 ± 0.5,4.5 ± 0.4,5.1 ± 0.5,2.3 ± 0.4,3.4 ± 0.4,2.4 ± 0.4,and 5.3 ± 0.4 for the neck, upper arm, back, lower back, buttock, thigh, lower leg, and systemic fatigue, respectively. These findings implied that some swimmers had already experienced the muscle soreness at Pre, and therefore, the participants were further divided into the MS[−] and MS[+] subgroups. Figure 2 shows the a-NRS score of MS[−] and MS[+] subgroups in both supplemented groups. In the MS[+] subgroup, the a-NRS score was not further increased after the competition in all examined regions of both groups. One-way ANOVA analysis revealed that the a-NRS score for the neck and lower back in both groups, and for the upper arm, back, and buttock in the BCAA group was significantly decreased at day 2 compared those at Post (Fig.2a-e). In the MS[−] subgroup, the a-NRS score in the Placebo group was increased after the competition, and the absolute scores for the upper arm, back, and low back at day 1 and for the buttock and thigh at day 2 were more than 2 points (Fig.2f). On the other hand, the a-NRS score in the MS[-] subgroup after the competition was unchanged by the BCAA supplementation in all examined regions except for the back. The significant difference in MS[−] subgroup of both supplemented groups was not found since the number of subjects in the subgroups was too small to analyze statistically.

Figure 3 shows AUC of the NRS score for each of the muscle regions examined, for systemic fatigue, and for the upper body (subtotals for neck, upper arm, back, and low back) and lower body (subtotals for buttock, thigh, and lower leg). The AUC value for all muscle regions was lower in the BCAA group than in the Placebo group (Fig.3A). In the BCAA group, as the NRS scores gradually declined from baseline, the AUC value was negative for all muscle regions. Conversely, the AUC value in the Placebo group was positive for the upper arm, back, and buttock. In particular, the AUC value for the upper arm was significantly lower in the BCAA group than in the Placebo group. AUC for the upper body was negative in the BCAA group but positive in the Placebo group, a difference that was significant (Fig.3B). However, the AUC for the lower body was negative in both groups, with no significant difference between them.

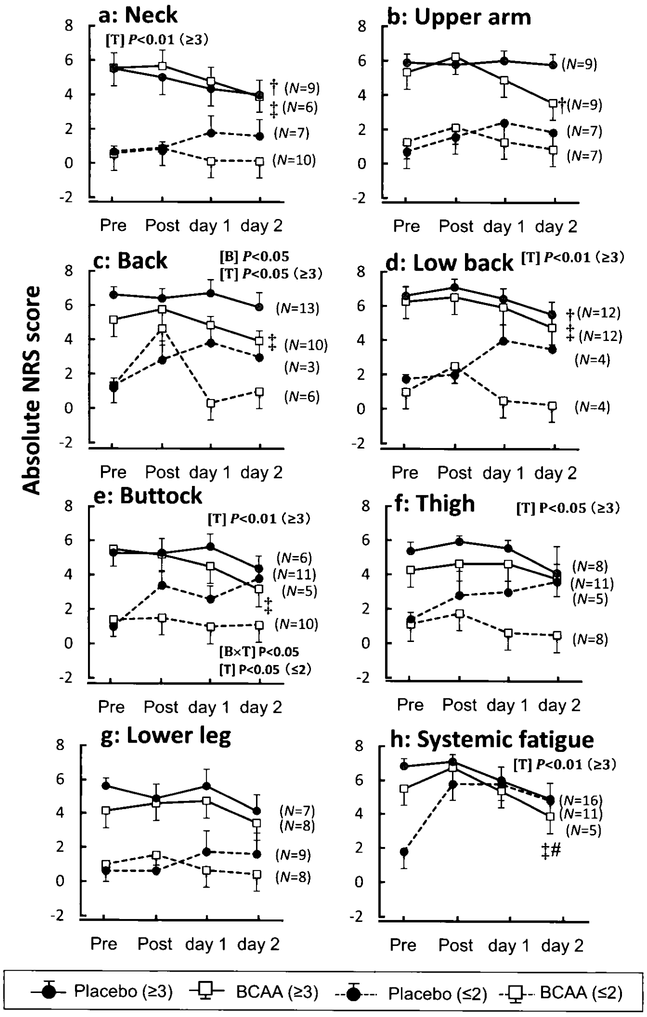

Fig. 2. Absolute NRS score for muscle soreness and sytemic fatigue of Study 1 in the subgroups classified by the NRS score at Pre. Both Placebo and BCAA groups were further divided into two subgroups; absent and present muscle soreness at Pre were defined as NRS score of ≤ 2 and ≥ 3, respectively, by reference to the classification reported by Thompson *et al.* (25). Values are expressed as means ± SEM, and the numbers in the parenthesis of the side of each line on the graph show the number of subjects in the respective subgroups. In the subgroups of muscle soreness present, one-way ANOVA *P* values were less than 0.05 for the neck, upper arm, back, low back, buttock, and systemic fatigue, and for the neck, low back, thigh, and systemic fatigue in the BCAA and placebo groups, respectively. Abbreviations, statistical analysis method, and symbols are same in Figure 1.

Study 2: Full-marathon runners

The NRS scores for muscle soreness and systemic fatigue in Study 2 are also expressed in relation to baseline (Fig.4). In both the BCAA and Placebo groups, the scores for muscle soreness in all six regions (Fig.4a-f) as well as for systemic fatigue (Fig.4g) were found to be significantly higher at Post on one-way ANOVA. Since the increase in score peaked at Post, IOMS was observed in all examined muscle regions after the marathon. At Post, the mean NRS scores for the anterior thigh (Fig.4a), posterior thigh (Fig.4b), posterior lower leg (Fig.4d), and systemic fatigue

(Fig.4g) were close to eight points in both groups, and the scores for the anterior thigh, posterior thigh, and buttock were lower, although not significantly, in the BCAA group compared to the Placebo group.

In comparison analysis, one-way ANOVA revealed significantly increased scores at day 1 compared to Pre for the anterior thigh, posterior thigh, and posterior lower leg and for systemic fatigue in both groups, and for the anterior lower leg (Fig.4c) and buttock (Fig.4f) in the Placebo group. At day 2, significantly higher scores compared to those at Pre were observed for the anterior thigh and systemic fatigue in the Placebo group, and for the posterior lower leg in both groups. The decrement in NRS score for muscle soreness at day 2 was significantly less than that at Post for the anterior thigh, anterior lower leg, low back, and buttock in both groups. However, significantly decrease of the NRS score at day 1 for anterior lower legs and buttock, at day 2 for posterior lower legs, and at day 1 and day 2 for systemic fatigue compared to those at Post was observed in the BCAA only.

Figure 5 shows AUC for muscle soreness and systemic fatigue over the experimental period. In all examined muscle regions except the posterior lower leg, the AUC was lower in the BCAA group than in the Placebo group, but with no significant difference between the two groups (Fig.5A). The AUC for the thigh (subtotals for anterior thigh, posterior thigh, and buttock) tended to be lower ($P = 0.09$) in the BCAA group than in the Placebo group, while there was no difference for the lower leg (subtotals for anterior and posterior lower leg) between the two groups (Fig.5B).

Discussion

In support of previous studies, BCAA ingestion was effective for improving exercise-induced DOMS. Moreover, this study also found novel ameliorating effects of BCAA on muscle soreness resulting from swimming exercise, on IOMS after full-marathon running, and on systemic fatigue after both forms of exercise.

Few studies have investigated DOMS resulting from swimming exercise since the movements involved in swimming do not generally involve ECC. To our knowledge, only one study by O'Connor *et al.* has observed swimming-induced DOMS during short-term overtraining in competitive college swimmers (19). In their study, significant elevations in muscle soreness scores were observed in

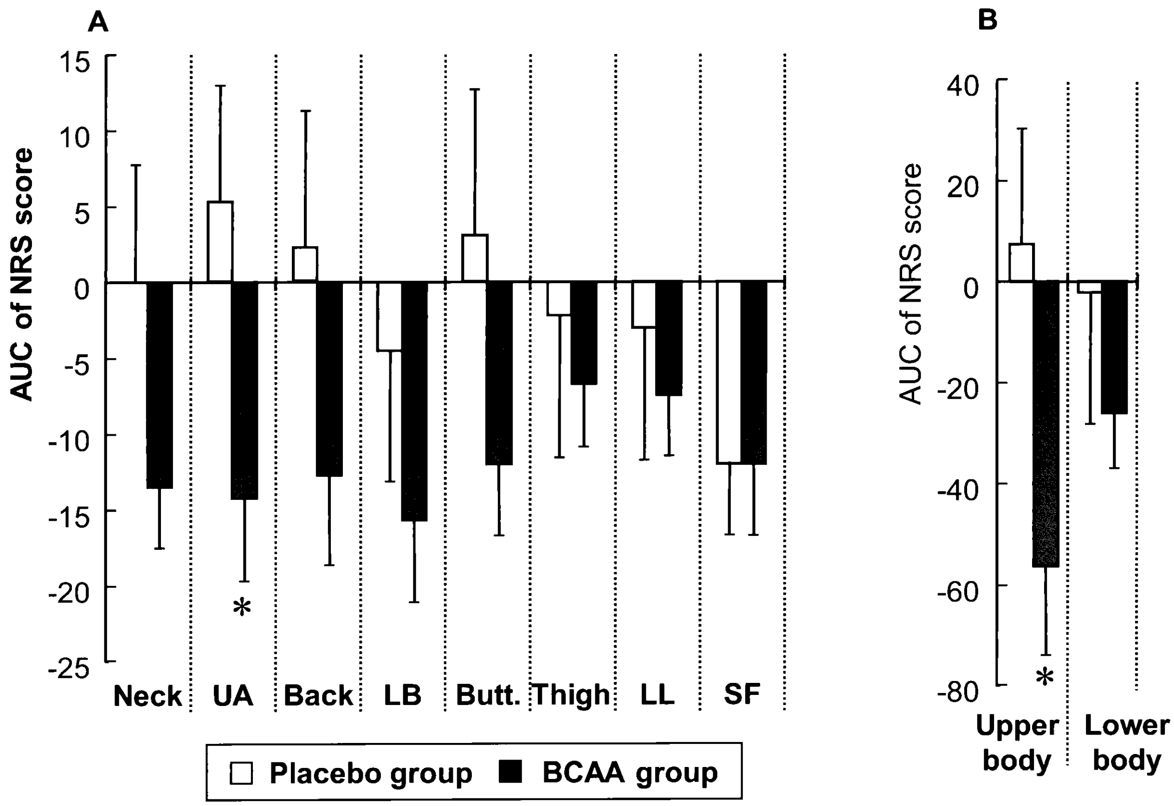

Fig. 3. AUC of NRS score for muscle soreness and systemic fatigue during Study 1. **A:** AUC value for the muscle regions examined and systemic fatigue, **B:** AUC for the upper body (subtotals for neck, upper arm, back, and low back) and lower body (buttock, thigh, and lower leg). AUC was calculated as the sum of the NRS score expressed in relation to baseline until day 2 after the event. Abbreviation: **UA,** upper arm; **LB,** low back; **Butt,** buttock; **LL,** lower leg; **SF,** systemic fatigue. Data are means ± SEM. *$P < 0.05$ vs. the Placebo group by unpaired Student's *t*-test.

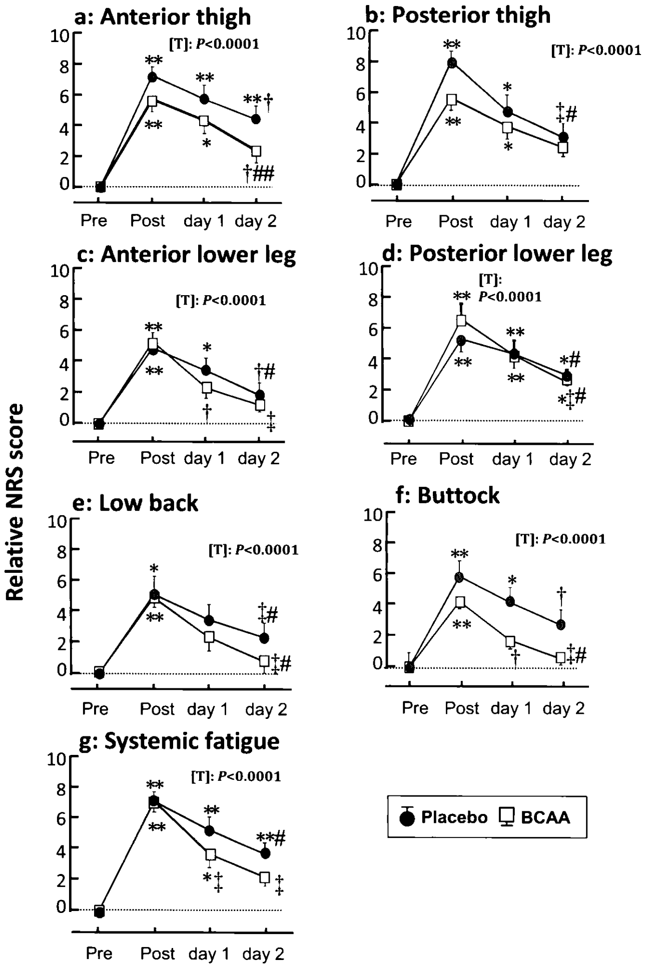

Fig. 4. NRS score in Study 2 of full-marathon runners for muscle soreness in the anterior thigh (**a**), posterior thigh (**b**), anterior lower leg (**c**), posterior lower leg (**d**), low back (**e**), buttock (**f**), and for systemic fatigue (**g**) from Pre to day 2. Abbreviation: **Pre,** one day before the full marathon, **Post,** immediately following the marathon; **day 1,** one day after the marathon; **day 2,** two days after the marathon. Values are means ± SEM. **[T]** indicates the *P*-value in the experimental period by two-way ANOVA test. *$P<0.05$, **$P<0.01$ vs. baseline (Pre), † $P<0.05$, ‡ $P<0.01$ vs. the corresponding value at Post, and $^{\#}P<0.05$, $^{\#\#}P<0.01$ vs. the corresponding day 1 value analyzed by repeated measures one-way ANOVA followed by Bonferroni's *post hoc* analysis. One-way ANOVA *P* values in all examined regions and systemic fatigue were less than 0.01.

association with increased training, and the additional training load resulted in DOMS by day 3 (19). In the present study, swimmers were already experiencing muscle soreness before the competition because they had continued regular training in the preparation period before the high-level competitive event. Therefore, muscle soreness in swimmers was evalueted by dividing into the subgroups that muscle soreness was absent and present at Pre. In the subgroups of muscle soreness present at Pre, the muscle soreness was not increased after the competition in both supplemented groups. On the other hand, the soreness in the subgroups absent muscle soreness at Pre was peaked at day 1 or day 2 in the Placebo group, but significantly difference could not be found due to small number of subjects in the subgroups. This finding shows that some participants experienced swimming-induced DOMS. In the BCAA group, the significantly decrease of a-NRS score in the subgroup that muscle soreness was present at Pre was observed for the upper arm, back, and buttock at day 2 compared to that at Post. Futhermore, the score in the subgroup that soreness was absent at Pre was not increased in most regions by the BCAA supplementation. In addition, the r-NRS for the neck, upper arm, back, low back, and buttock regions in the BCAA group was significantly lower at day 2 than immediately after the event. It suggested that BCAA might be able to suppress any types of muscle soreness induced by swimming exercise. Since it has been hypothesized that muscle soreness in swimming is likely to be caused by decreased muscle strength and abnormal patterns of muscle contraction and/or relaxation due to fatigue (18), muscle soreness would be induced mainly in the skeletal muscle groups of the upper body, which are the protagonistic muscles used in swimming exercise. O'Connor *et al.* also observed that DOMS depended on the muscle activity involved in swimming exercise, finding that DOMS score was higher in the shoulder and upper arm and lower in the shin (19). Thus, the reason for the ineffectiveness of BCAA in ameliorating in the lower body in the present study might be due to lower fatigue from swimming in the lower body than in the upper body.

On the other hand, the degree of IOMS caused by full-marathon running was significant, and was the highest immediately after the event in all skeletal muscle regions examined in the present study, although it gradually decreased by day 2. Among the muscle regions examined, the degree of IOMS immediately after the event was the highest in the thigh and buttock regions, and was largely, but not significantly, allayed by the BCAA regimen.

In contrast to muscle soreness experienced by the swimmers after the swimming event, the elevated IOMS after the full-marathon did not recover to baseline. The reason for this difference between the two forms of exercise might be due to a greater extent of muscle damage induced by the longer duration of activity in marathon running. The significant differences in muscle soreness in the anterior thigh, anterior lower leg, and buttock as well as in systemic fatigue during the recovery period compared to those at baseline improved more quickly in the BCAA group than in the Placebo group. This finding indicates that the BCAA regimen might have had a beneficial effect on the early recovery of muscle soreness.

Although differences in the mechanism between IOMS

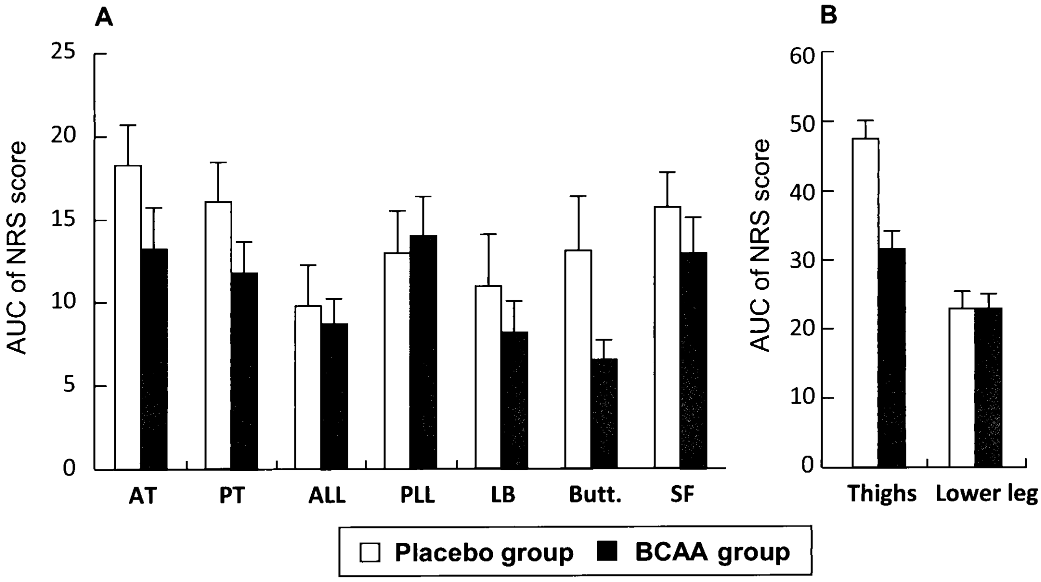

Fig. 5. AUC of NRS score for muscle soreness in the examined regions and for systemic fatigue during Study 2. **A:** AUC value for the muscle regions examined and systemic fatigue, **B:** AUC for the thigh (subtotals for anterior thigh, posterior thigh, and buttock) and lower leg (anterior and posterior lower leg). AUC was calculated as the sum of the NRS score expressed in relation to baseline until day 2 after the event. Abbreviation: **AT**, anterior thigh; **PT**, posterior thigh; **ALL**, anterior lower leg; **PLL**, posterior lower leg; **LB**, low back; **Butt**, buttock; **SF**, systemic fatigue. Data are means ± SEM.

and DOMS have not been fully elucidated, it has been conjectured that DOMS is caused by the destruction and subsequent inflammation of muscle fiber and connective tissue ultrastructure due to strong mechanical extension, such as ECC (3,13). The inhibitive effect of BCAA on DOMS might be due to its various functions, including stimulation of protein synthesis (1,6,11,26) and change in inflammatory/immune responses (4,14,17). On the other hand, the metabolites induced by endurance muscle activities are suggested to be the cause of IOMS (2,3,16,21,22). Namely, IOMS is suggested to be the result of multiple responses to damaged muscle caused by oxidative stress (2,15,16,21,30), increased ATPase activity due to ATP depletion by endurance exercise (21), muscle cell damage by Ca^{2+} infusion (3), autophagy (2), and other factors (8). A previous study has shown that BCAA decreased plasma granulocyte elastase concentration elevated by repeated running exercise (14), and therefore, the suppression of inflammation might be one possible mechanism of the inhibitive effect of BCAA on IOMS. However, many metabolic factors are likely to be associated with the onset of IOMS. The exact mechanism of such BCAA inhibition is still unclear, and further studies are warranted.

In both the swimmers and full-marathon runners, systemic fatigue was the highest immediately after the events, and at its peak was approximately equal to that of muscle soreness immediately after the events. Previous studies have reported that BCAA inhibited exercise-induced central fatigue since BCAAs could compete with tryptophan, which is converted into the inhibitory neurotransmitter serotonin upon transportation into the brain (5). Accordingly, the peak systemic fatigue observed in our subjects immediately after the events might be associated with the central fatigue usually caused by exercise. On the other hand, the present study did not observe the inhibitive effect of BCAA ingestion on systemic fatigue immediately after the events. However, elevated systemic fatigue seen immediately after was significantly decreased at day 2 by BCAA ingestion in both the swimmers and marathon runners. Matsumoto *et al.* showed that significant increases in muscle soreness and fatigue, which were positively correlated, after three days of running training were significantly inhibited by the BCAA ingestion (14). This suggests that the effectiveness of BCAA on systemic fatigue might be a result of its action on peripheral fatigue rather than on central fatigue. Therefore, the effectiveness of BCAA on systemic fatigue in the present study might be due specifically to its effect on muscle soreness rather than on central fatigue.

Conclusions

In summary, this study found an inhibitive effect of BCAA ingestion on muscle soreness after swimming exercise involving little ECC, and on IOMS after running a full-marathon. In particular, higher levels of effectiveness of BCAA ingestion were observed in the protagonistic muscles in the upper body of swimmers and in the trunk and legs of runners. Aditionally, systemic fatigue after both swimming and full-marathon running was quickly improved by BCAA ingestion. These results suggest a novel use for BCAA to ameliorate various forms of exercise-induced muscle soreness and fatigue, in addition to its established inhibitive effects on exercise-induced DOMS.

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Conflict of Interest

The authors have no conflicts of interest to declare.

References

1) Anthony J C, Anthony T G, Kimball S R, Vary T C, and Jefferson L S. (2000) Orally administered leucine stimulates protein synthesis in skeletal muscle of postabsorptive rats in association with increased eIF4F formation. J Nutr 130: 139-145.
2) Appell H J, Soares J M, and Duarte J A. (1992) Exercise, muscle damage and fatigue. Sports Med 13: 108-115.
3) Armstrong R B. (1984) Mechanisms of exercise-induced delayed onset muscular soreness: a brief review. Med Sci Sports Exerc 16: 529-538.
4) Bassit R A, Sawada L A, Bacurau R F, Navarro F, Martins E, Jr., Santos R V, Caperuto E C, Rogeri P, and Costa Rosa L F. (2002) Branched-chain amino acid supplementation and the immune response of long-distance athletes. Nutrition 18: 376-379.
5) Blomstrand E, Hassmen P, Ek S, Ekblom B, and Newsholme E A. (1997) Influence of ingesting a solution of branched-chain amino acids on perceived exertion during exercise. Acta Physiol Scand 159: 41-49.
6) Bolster D R, Jefferson L S, and Kimball S R. (2004) Regulation of protein synthesis associated with skeletal muscle hypertrophy by insulin-, amino acid- and exercise-induced signalling. Proc Nutr Soc 63: 351-356.
7) Cleak M J, and Eston R G. (1992) Muscle soreness, swelling, stiffness and strength loss after intense eccentric exercise. Br J Sports Med 26: 267-272.
8) Hikida R S, Staron R S, Hagerman F C, Sherman W M, and Costill D L. (1983) Muscle fiber necrosis associated with human marathon runners. J Neurol Sci 59: 185-203.
9) Howatson G, McHugh M P, Hill J A, Brouner J, Jewell A P, van Someren K A, Shave R E, and Howatson S A. (2010) Influence of tart cherry juice on indices of recovery following marathon running. Scand J Med Sci Sports 20: 843-852.
10) Jackman S R, Witard O C, Jeukendrup A E, and Tipton K D. (2010) Branched-chain amino acid ingestion can ameliorate soreness from eccentric exercise. Med Sci Sports Exerc 42: 962-970.
11) Kadowaki M, and Kanazawa T. (2003) Amino acids as regulators of proteolysis. J Nutr 133: 2052S-2056S.
12) Kawaguchi T, Nagao Y, Matsuoka H, Ide T, and Sata M. (2008) Branched-chain amino acid-enriched supplementation improves insulin resistance in patients with chronic liver disease. Int J Mol Med 22: 105-112.
13) MacIntyre D L, Reid W D, and McKenzie D C. (1995) Delayed muscle soreness. The inflammatory response to muscle injury and its clinical implications. Sports Med 20: 24-40.
14) Matsumoto K, Koba T, Hamada K, Sakurai M, Higuchi T, and Miyata H. (2009) Branched-chain amino acid supplementation attenuates muscle soreness, muscle damage and inflammation during an intensive training program. J Sports Med Phys Fitness 49: 424-431.
15) Maughan R J, Donnelly A E, Gleeson M, Whiting P H, Walker K A, and Clough P J. (1989) Delayed-onset muscle damage and lipid peroxidation in man after a downhill run. Muscle Nerve 12: 332-336.
16) Miles M P, and Clarkson P M. (1994) Exercise-induced muscle pain, soreness, and cramps. J Sports Med Phys Fitness 34: 203-216.
17) Negro M, Giardina S, Marzani B, and Marzatico F. (2008) Branched-chain amino acid supplementation does not enhance athletic performance but affects muscle recovery and the immune system. J Sports Med Phys Fitness 48: 347-351.
18) Nosaka K. (2000) Exercise and muscle pain. Nihon Rinsho 58 Suppl: 464-468. (in Japanese)
19) O'Connor P J, Morgan W P, and Raglin J S. (1991) Psychobiologic effects of 3 d of increased training in female and male swimmers. Med Sci Sports Exerc 23: 1055-1061.
20) Platell C, Kong SE, McCauley R, and Hall JC. (2000) Branched-chain amino acids. J Gastroenterol Hepatol 15: 706-717.
21) Pyne D B. (1994) Exercise-induced muscle damage and inflammation: a review. Aust J Sci Med Sport 26: 49-58.
22) Pyne D B, Baker M S, Telford R D, and Weidermann M J. (1997) A treadmill protocol to investigate independently the metabolic and mechanical stress of exercise. Aust J Sci Med Sport 29: 77-82.
23) Shimomura Y, Inaguma A, Watanabe S, Yamamoto Y, Muramatsu Y, Bajotto G, Sato J, Shimomura N, Kobayashi H, and Mawatari K. (2010) Branched-chain amino acid supplementation before squat exercise and delayed-onset muscle soreness. Int J Sport Nutr Exerc Metab 20: 236-244.
24) Szymanski D, J. (2001) Recommendations for the avoidance of delayed onset muscle soreness. Strength Cond J 23: 7-13.
25) Thompson D, Nicholas C W, and WilliIOMS C. (1999) Muscular soreness following prolonged intermittent high-intensity shuttle running. J Sports Sci 17: 387-395.
26) Tipton K D, Rasmussen B B, Miller S L, Wolf S E, Owens-Stovall S K, Petrini B E, and Wolfe R R. (2001) Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. Am J Physiol Endocrinol Metab 281: E197-206.
27) Tveiten D, and Bruset S. (2003) Effect of Arnica D30 in marathon runners. Pooled results from two double-blind placebo controlled studies. Homeopathy 92: 187-189.
28) Vickers A J. (2011) Time course of muscle soreness following different types of exercise. BMC Musculoskeletal Disorders 2:

29) Watanabe A, Shiota T, Takei N, Fujiwara M, and Nagashima H. (1986) Ammonia detoxification by accelerated oxidation of branched chain amino acids in brains of acute hepatic failure rats. Biochem Med Metab Biol 35: 367-375.

30) Weiss S J. (1986) Oxygen, ischemia and inflammation. Acta Physiol Scand Suppl 548: 9-37.

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