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ORIGINAL ARTICLE

Effects of branched-chain amino acids supplementation on physiological and psychological performance during an offshore sailing race

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Abstract The aim of the present study was to investigate the effect of protein diets, rich in branched chain amino acids (BCAA) on perceived exertion, mental and physical performance during an offshore sailing race that lasted 32 h. Twelve sailors were randomly allocated into one of two groups [Control (CON) and BCAA: $n = 6$/group]. The BCAA group consumed a standard diet of 11.2 MJ day^{-1} (58% carbohydrate, 30% fat, 12% Protein) along with a high-protein supplement of 1.7 MJ day^{-1} (40% carbohydrate, 35% protein, 25% fat) and 1.7 MJ day^{-1} composed of 50% valine, 35% leucine, and 15% isoleucine. CON was given a standard diet of 14.5 MJ day^{-1} (58% carbohydrate, 30% fat and 12% protein). During the race, heart rate was monitored. Subjects self-evaluated their feeling of fatigue every 3 h, and 12 samples of saliva from each subject were collected to perform cortisol assays. Before and after the race a vertical jump and a handgrip test were performed, and mental performance was evaluated with a standardized battery of tests. A significant increase in the feeling of fatigue was noted on the second day (D2) of race in both groups; the increase was higher in CON ($P < 0.05$). For both groups, salivary cortisol concentration followed a nycthemeral rhythm, with an alteration during the race as evidenced by high midnight cortisol levels between D1 and D2, and significantly decreased cortisol levels observed on D2 ($P < 0.05$). There was no change in physical performance at the end of the race in both groups. As a significant decrease ($P < 0.05$) in short-term memory performance was observed only in the CON group. These data indicate that an offshore sailing race enhances the feeling of fatigue, and decreases short-term memory performance. These detrimental consequences are reduced by a high-protein diet with BCAA.

Keywords Nutrition · BCAA · Performance · Vigilance · Offshore sailing

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Introduction

Offshore sailing induces psychological and physiological stress resulting from many factors including physical workloads, reduced sleep durations, thermic stresses, psychosensorial tasks, and nutritional intakes. Thus, competitive performance during offshore sailing depends on the mental and physiological performance of crewmembers (Bigard et al. 1998).

To improve crew performance, several studies (Fogelholm and Lahtinen 1991; Branth et al. 1996; Bigard et al. 1998) have proposed adapted nutritional intakes for offshore racing. These authors have reported that offshore racing crews have a very high level of energy intake, ranging between 14 and 18 MJ day^{-1}; this intake is equivalent to that of high-intensity training athletes. Branth et al. (1996) measured the energy expenditure of racing crews and showed that total energy expenditure was about 20 MJ day^{-1}, inducing a weight loss during the race. This energy deficit could be critical for physical and mental performance.

In addition to the balance between energy expenditure and intake, meal composition is another factor that influences performance. In fact, a rich carbohydrate diet induces sleep, decreases vigilance, and enhances the feeling of fatigue (Danguir and Nicolaidis 1979; Cunliffe et al. 1997). Research has also shown that branched-chain amino acids (BCAA), particularly leucine, undergo increased oxidation during prolonged endurance exercise (Henderson et al. 1985) and promote skeletal muscle protein synthesis (Layman 2002). It has also been suggested that BCAA improve mood vigilance and limit central fatigue because they compete with free-tryptophan (f-TRP) for uptake into the brain via the same transport mechanism (Blomstrand et al. 1997, Pardridge and Oldendorf 1975). Increased brain f-TRP concentrations lead to increased serotonin (5HT) synthesis which is associated with lethargy, fatigue and decreased exercise performance (Davis et al. 2000). BCAA supplementation studies have reported decreased perceived exertion and increased endurance performance (Blomstrand et al. 1991, 1997), and reduced brain serotonin synthesis (Gomez-Merino et al. 2001) and consequently improved mental or physical performance or no ergogenic effects (Davis et al. 1999). The same observations are reported in animals (Verger et al. 1994; Layman 2002). The controversial data in BCAA supplementation studies may relate to the level of carbohydrate (CHO) ingestion which reduces the competition between plasma-free fatty acids and f-TRP for the protein carrier, albumin, thereby, inhibiting the increase in plasma f-TRP with exercise It seems that ingestion of CHO reduces the release of fatty acids from adipose tissue and thus attenuates the increase in plasma FFA during exercise, which in turn releases less tryptophan from albumin (Davis et al. 1992; Verger et al. 1998). On the contrary, Welsh et al. (2002) have reported that CHO ingestion results in an increase in physical and mental function during intermittent exercise. The results obtained by Davis et al. (1999) do not support the hypothesis of an added benefit of BCAA supplements on fatigue. Thus, the potential for BCAA to improve performance above that achieved with carbohydrate alone has been questioned.

As offshore sailing is a combined stress, the Hypothalamic-Pituitary-Adrenal (HPA) axis is stimulated, with an increase of cortisol secretion (Frankenhauser 1989). Recent human studies support the hypothesis of a cortisol–memory connection, reporting either positive or negative effects of glucocorticoids on memory (Beckwith et al. 1986; Kirschbaum et al. 1996). CHO ingestion could inhibit cortisol secretion as suggested by Bird et al. (2006).

Thus, the purpose of the present study was to investigate the effect of protein diets rich in BCAA on perceived exertion, and mental and physical performance during an offshore sailing race. Heart rate was also measured. As measuring steroid hormone levels in saliva (a non-invasive, stress-free method) is now possible and as the excellent linear correlation between salivary and free serum cortisol concentrations has been reported (0.97) (Vining et al. 1987; Lac et al. 1993), saliva cortisol concentrations were also measured to evaluate the stress induced by the competition. It was hypothesized that a protein diet rich in BCAA would improve performance and reduce perceived exertion.

Materials and methods

Subjects

Twelve male offshore sailing competitors (Table 1) actively involved in endurance training, 10 h a week for at least 10 years, volunteered to participate in this study. They were not taking any drugs or medications and had no history or endocrine disorders before or during this study. All participants underwent medical prescreening prior to participation in the study and ethical approval to conduct the study was granted by the local University Human Ethics Commitee.

The percentage of body fat of each participant was estimated from four measurements of skinfold thickness according to Durnin and Rahaman (1967).

Experimental design

This study was carried out during a 33-h sailing race which included several crews. The subjects were separated into two crews of six each. Each boat has six crew members.

They were boarded on two different ships, a Dufour 45 and a Selection 37, which had the same rating. Their performances were thus identical. The results of a certain number of regattas are analyzed using a statistical model in order to draw up a table of performances of reference for the boats of series sailing in this gauge. Thus, if all the boats of a regatta are led to their performance of references, they all will be equal.

Table 1 Morphological parameters for the two crews

	Crew 1 ($n = 6$)	Crew 2 ($n = 6$)
Age (year)	35.2 ± 3.4	37.1 ± 4.1
Weight (kg)	71.3 ± 5.6	73.4 ± 6.2
Height (cm)	177.3 ± 6.2	179.7 ± 7.1
Body fat mass (%)	19.3 ± 4.3	17.3 ± 5.2
Body mass index (Kg m^{-2})	21.4 ± 3.1	22.3 ± 4.3

Values are given ±SEM

The start of the race was on day one (D1) at 9 a.m. and the race finished at 6 p.m. on the day two (D2). The race took place in the Mediterranean Sea between two buoys placed in front of Saint Cyprien and Argeles, separated by a distance of five nautical miles. This short distance was chosen to ensure frequent maneuvers during the race.

The total distance covered was 155 nautical miles. The two boats finished the race separated by only 1 nautical mile (15 min).

Environmental conditions

The wind velocity ranged between 5 and 35 knots during the race. The race had two main sailing conditions: Up-wind and down-wind. The spinnaker was required to be hauled for almost every down-wind board. The temperature ranged from a high of 15°C during the day and a low of 4°C during the night.

In spite of sufficient crewmembers on board, all crewmembers were required to stay awake.

Nutritive intervention

The subjects were randomly allocated into one of two groups, the first one received a protein-rich diet (BCAA, $n = 6$) while the second group [control (CON) group] was given a standard diet (CON, $n = 6$).

The BCAA group consumed a standard package diet providing 11.2 MJ day^{-1} (58% carbohydrate-423 g, 30% fat-87.3 g, 12% Protein-57.4 g) with two dietary supplements of 1.7 MJ day^{-1} each: the first was a mixture available in powder form containing 50% valine, 35% leucine, and 15% isoleucine (72.5 g protein). This mixture was dissolved in water, and was ingested every 6 h during the sailing period. The second supplement consisted of 35% protein-25.3 g (in the form of ham and chicken), 40% carbohydrate-41 g and 25% fat-11.2 g in the form of a powder, ingested every 6 h. Large dose of BCAA was supplied in order to obtain a saturation of BCAA/TRP brain barrier common carrier. To reduce the specific taste of BCAA as much as possible, BCAA were added in yoghourt aromatized with vanilla.

CON group consumed a standard package diet providing 14.5 MJ day^{-1} (58% carbohydrate-509 g, 30% fat-113 g, 12% Protein-74.6 g).

The BCAA supplementation and standard diet were packaged in identical form. It was thus given to each subject according to a randomized double-blind procedure.

The diet of the participants was also controlled during the 2 days preceding the race to avoid influencing the physiological parameters measured during the race.

Physiological measurement during the sailing period

Heart rate was measured continuously during the sailing period. R–R periods were collected using a Bauman cardiofrequencymeter (Fleuriez, Switzerland) with a sampling rate of 1,000 Hz from ECG signal.

A computer was placed in each boat in order to capture data and to make calculations for three 10-h periods corresponding to the beginning (Period 1: 9 a.m.–7 p.m. D1), the middle (Period 2: 8 p.m.–6 a.m. D1–D2) and the end of the race (Period 3: 8 a.m.–6 p.m. D2). The resting heart rate used as a CON was measured during a 10-min period in supine position prior to the start of the race. There were two periods: 7–8 p.m. (D1) and 6–8 a.m. (D2) during which heart rate was not collected to allow for the treatment of data on board.

Hormonal assay

Twelve saliva samples were collected during the 2 days of the competition according to the following schedule: day one (D1) upon waking (9 a.m.), 12, 3, 6 and 9 p.m; day two (D2) at 12, 3 a.m., 6 a.m., 9 a.m., 12 a.m, 3 p.m. and 6 p.m.

Subjects salivated into tubes (Starstedt) and within 5 min typically produced volumes of 5–10 ml, sufficient for subsequent preparation for radioimmunoassay.

The saliva samples were stored at 4°C on board. Then, after the race, samples were stored at −30°C until assay. The assay of saliva cortisol was carried out using a radioimmunological method following a technique routinely used and validated in our laboratory sensitivity: 15 pg; accuracy: 10.5%; intra-assay reproductibility: 6.1%).

Performance measures before and after the sailing period

In order to evaluate the performance of each subject, we chose specific tests that appeared to adequately represent the salient aspects of physical fitness in sailing (Bigard et al. 1998). Subjects performed the tests between 5 and 6 p.m. on the day before the race, and just after the end of the competition on day two between 6 and 7 p.m.

Hand-grip strength: muscular strength was measured three times for each subject. (Harpenden dynamometer, British Indicators, Ltd.). The subjects performed the test with the hand that they would use most often for maneuvers (dominant hand). The strength score was recorded in kilogram (kg).

Vertical jump: vertical jumping height was determined on a resistive platform (Ergojump®, Psion®, Rome Italy) which was connected to a digital timer. Each subject was asked to jump up vertically three times from a fixed semi-squat position with the hands at the hips. The peak height of the jump was recorded and the highest jump was selected for analysis. Data were treated according to the method of Bosco et al. (1983).

Psychological parameters

Fatigue Evaluation

An analog visual scale was used to evaluate fatigue experienced by the crew members. This scale is a traditional scale used in our laboratory and has been validated (Lagarde and Batejat 1995). The scale provides subjective information on how subjects feel. The subjects were asked to self-evaluate their feeling of fatigue on the analog visual scale every 3 h during the sailing period.

Memory search test

In order to measure psycho-physiological performance a memory-search test was used (Lagarde and Batejat 1995). The test was carried out twice; once just before sailing and the second time at 6.30 p.m. just after the end of the race.

The task comprises of the memorization of a block of a four letters. The participants memorize the set of letters, and then initiate the test by pressing on one of the response keys as instructed. Then, they indicate whether the probe letter presented at the center of the screen is a member of the memory set by pressing on the appropriate key. Response times and errors are calculated.

One day before the race, all the subjects underwent a standardized learning program of the memory search test.

Statistical analysis

All data were analyzed using the SPSS/PC statistical package (version 10.0).

Data are presented as mean ± SEM.

To determine whether significant differences existed between BCAA group and CON group performance parameters between the trials, data were analyzed using a two-way analysis of variance (ANOVA) with repeated measurements (group, time). A post hoc Newman–Keuls test was performed to determine the location of the difference, in the event of an ANOVA revealing a significant main effect.

Statistical significance was set at $P < 0.05$.

Results

Physiological parameters

Table 2 shows the heart rates obtained at rest and during sailing. Heart rates during the sailing period were significantly higher than those at rest ($P < 0.05$) for both the groups. There was no difference between the two groups for all three sailing periods.

Table 2 Mean heart rate values obtained at rest and during the race for the both groups

Periods (bpm)	CON	BCAA
Rest control	63.0 ± 4.2	64.9 ± 6.9
Period 1	79.0 ± 1.5*	83.6 ± 5.9*
Period 2	75.5 ± 2.5*	72.0 ± 2.1*
Period 3	78.4 ± 1.2*	71.5 ± 1.7*

CON control, *BCAA* BCAA and protein supplementation

Values are given ±SEM

* Significantly different between rest period ($P < 0.05$)

Period 1: 9a.m.–7 p.m. D1; Period 2: 8 p.m.–6 a.m. D1–D2 and Period 3: 8 a.m.–6 p.m. D2

Table 3 shows the salivary cortisol concentrations measured during the experiment for both groups during the race.

For both group's, salivary cortisol concentration followed a nycthemeral rhythm with higher values in the morning and lower values in the evening. However, the normal pattern of cortisol secretion was altered during the race with a modification of the nycthemeral rhythm as evidenced by high midnight cortisol levels between D1 and D2, and significantly decreased cortisol level observed at 9 a.m., 12 p.m., 3 p.m. and 6 p.m. as compared to day one (D1) in both groups ($P < 0.05$). (−38.1, −31.3, −31.6 and

Table 3 Mean Salivary cortisol concentration obtained during the race for the both groups

Period (h)	CON	BCAA
Day 1		
9	17.65 ± 4.54	18.54 ± 4.21
12	12.65 ± 2.59	11.98 ± 3.02
15	10.62 ± 2.65	10.11 ± 2.65
18	7.02 ± 2.59	6.91 ± 1.91
21	5.58 ± 1.84	6.04 ± 3.1
Day 2		
0	5.6 ± 1.58	7 ± 1.47
03	9.4 ± 2.32	9.5 ± 2.32
06	12.9 ± 4.01	11.47 ± 3.85
9	10.32 ± 3.32$^{\$}$	11.48 ± 2.19$^{\$}$
12	8.01 ± 2.75$^{\$}$	8.25 ± 1.96$^{\$}$
15	7.23 ± 2.36$^{\$}$	6.92 ± 1.18$^{\$}$
18	5.2 ± 2.45$^{\$}$	5.42 ± 1.94$^{\$}$

CON control, *BCAA* BCAA and protein supplementation

Values are given ±SEM

$^{\$}$ Significantly lower compared to the first day for the two groups (P < 0.05)

−21.6%, respectively, for the BCAA group; −41.5, −36.7, −31.9 and −19.5%, respectively, for the CON group).

There was no difference between CON and BCAA on mean saliva cortisol concentrations at all times during the race.

Performance measures

Hand grip test and vertical jump test

Handgrip strength and vertical jump were not influenced by the race in both groups (see Fig. 1).

Fatigue test

The BCAA group evaluated themselves as being less tired than the CON group ($P < 0.05$) during the night and on day two (D2) of sailing (see Table 4). However, no difference was noted between the groups during the first day.

Memory search task

Figure 2 presents the performances of the groups on the memory test.

The CON group had a significant increase in percentage of errors when their performance after the race was compared to that before the race (+ 78. 4%, $P < 0.05$). No difference was noted in the BCAA group.

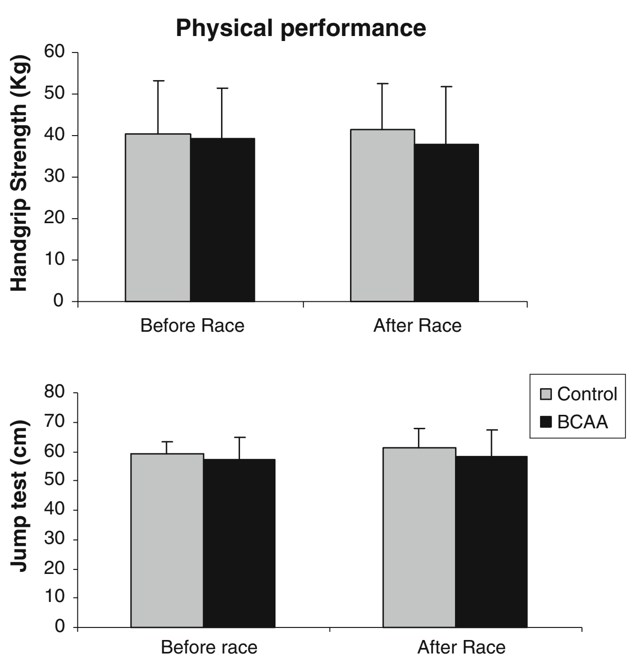

Fig. 1 Hand-grip strength and Vertical jump performance (Mean ± SEM) before and after the race between Control and BCAA groups before and after the race

Table 4 Comparative effects of two different diets on feeling of tiredness during the race

Period (h)	CON	BCAA
Day 1 (arbitrary index)		
9	35.2 ± 4.2	36.3 ± 2.9
12	27.4 ± 3.1	27.4 ± 3.6
15	32.5 ± 2.1	30.6 ± 4.9
18	28.2 ± 2.5	30.5 ± 4.7
21	33.9 ± 3.9	32.2 ± 3.4
Day 2 (arbitrary index)		
0	55.7 ± 4.3	46.6 ± 7.1*
03	75.6 ± 6.8	59.7 ± 9.2*
06	67.4 ± 10.2	51.3 ± 8.7*
9	54.7 ± 6.9$	42.7 ± 7.3*
12	48.5 ± 5.1$	39.3 ± 6.6*,$
15	50.3 ± 6.3$	39.6 ± 5.4*,$
18	59.4 ± 4.9$	44.5 ± 4.3*,$

CON control, *BCAA* BCAA and protein supplementation

Values are given ±SEM

* Significantly different between Control group and BCAA group (P < 0.05)

$ Significantly higher compared to the first day (P < 0.05)

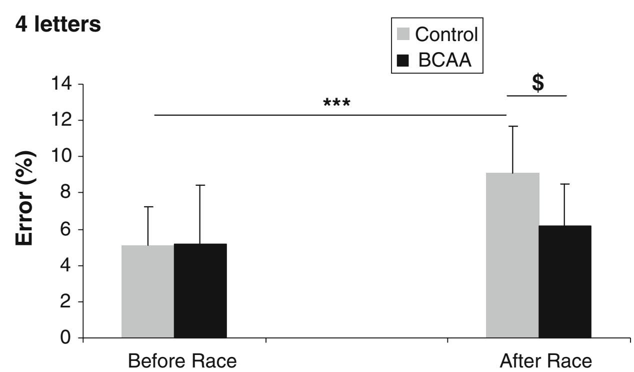

Fig. 2 Percentage of error for the four letters memorization test (Mean ± SEM) sailing between Control and BCAA groups before and after the race. $: Significantly different between Control and BCAA ($P < 0.05$). ***: Significantly different between before and after the race ($P < 0.05$)

Discussion

The aim of the present study was to investigate the effect of an offshore sailing race on physical and mental performances of the crew and to determine if a diet rich in protein (in particular, BCAA) would reduce the negative effect of fatigue. Two main findings emerged from this study:

– Decrease in short-term memory performance was noted only in the CON group.
– Food constituents of diet are able to influence the feeling of fatigue.

In spite of the different stressors involved during sailing, Handgrip strength and vertical jump performances were preserved. This result is in line with previous studies, which have also shown that maximal anaerobic power was preserved at the end of several days of intensive physical exercise such as alpine skiing or a military combat course (Guezennec et al. 1994). It also appears that sleep deprivation has no effect on short-term maximal exercise capacity (Lagarde and Batejat 1995; Mougin et al. 1996; Myles 1985).

Heart rates reflect the cardiovascular load imposed by sailing. We recorded heart rates of only 79.0 ± 1.5–83.6 ± 5.9 beats/min during sailing. Previous studies (Bachemont et al. 1984; Portier and Guezennec 2003) also recorded low heart rates during sailing with 470-class or laser®. The low values noted in our study could be explained by long periods without maneuvers and by the fact that our participants changed their functions at different time. During the race, we also noted reduced cortisol concentrations. This last result is unexpected because the participants were submitted to various stressors including physical activity, moderate cold stress during a night without period of sleep. In fact, physical or psychological stresses have been reported to increase the activity of the hypothalamus-pituitary adrenal axis, with a subsequent rise in cortisol level (Kirschbaum and Hellhammer 1994). Yet, the normal pattern of cortisol secretion was altered during the race with a modification of the nycthemeral rhythm as evidenced by high midnight cortisol between D1 and D2 and decreased cortisol level on the day 2. Indeed, previous studies have shown that in healthy subjects midnight plasma cortisol concentrations generally fall until 50 nmol l^{-1} (Gonzales-Ortiz et al. 2000) and peak before awakening. As saliva cortisol represents 3–5% of the plasma cortisol, the values obtained at midnight (5.6–7.0 nmol l^{-1}) should correspond to plasma values of 190–230 nmol l^{-1}. Finally, at the end of the race, the last sample measured at 6 p.m. showed the lowest cortisol values during the 33-h race. The reduction in salivary cortisol noted in our study could be attributed to sleep deprivation and fatigue. In fact, our results show that a long period without sleeping, physical work and cold exposure enhanced feelings of fatigue during the night and at the end of the second day of sailing whatever the group. However, the feeling of fatigue was lower in the BCAA than in the CON group ($P < 0.05$).

A main finding of this study is that a decrease in short-term memory performance was noted only in the CON group. Deijen et al. (1999) also reported that combined stress, which included physical and psychological components, during a military combat course decreases memory performance. Ryman et al. (1985) and Myles (1985), studying the effects of simultaneous physical and mental load, showed a deterioration in several psychocognitive tasks such as logical reasoning. Exhaustive physical exercise alone has also been seen to decrease the performance in the Stroop test (Blomstrand et al. 1997). Sleep deprivation seems to be more important than physical exercise fatigue to have a detrimental effect on mental performance (Lagarde and Batejat 1995). Another hypothesis formulated to explain the influence of environmental stress on short-term memory impairment suggests that cortisol concentrations are associated with impaired memory performance (Kirschbaum et al. 1996). The effect of cortisol on neuronal activity in regions of the brain that play a role in learning and memory are mediated via specific mineralcorticoid receptors (MR), which have a high affinity for glucocorticoids (GC), and glucocorticoid receptors (GR), which have a lower affinity for GC than MR. De Kloet et al.(1999) have proposed that memory performance is optimal when GC levels are mildly elevated (high MR/GR ratio) and less than optimal when GC levels are too low or too high (low MR/GR ratio). Abercrombie et al. (2003) showed an inverted-U shaped function between cortisol and memory in humans. In this view, cognitive function is enhanced when most of the MRs and only part of the GRs are activated (top of the inverted-U shape function). However, when circulating levels of corticosteroids are significantly decreased or increased, as it is the case in our study on the second day of the race in both groups, (extremes of the inverted-U shape function), cognitive impairments will result (Fig. 2). However, the reduction in cortisol secretion is similar in the two groups and cannot explain the difference in cognitive impairment in CON group.

Data in the literature have showed that diet (e.g., BCAA) is able to influence the feeling of fatigue and short-term memory performance. However, Calders et al. (1999) reported that the effect of BCAA administration on endurance performance could be related to carbohydrate availability. In our study, BCAA were given with a low carbohydrate diet so that their action could not be attributed to carbohydrate metabolism. Our results confirm the beneficial role of BCAA on mental performance. In fact, it has been previously shown that BCAA supplementation influences ratings of perceived exertion, and improves the performance in a colour task (Blomstrand et al. 1997; Verger et al. 1998). The influence of a BCAA diet on the perception of fatigue and performance on a mental task is possibly due to 5-HT synthesis at the brain level (Lieberman et al. 1982). Because free tryptophan competes with BCAA for transport across the blood brain barrier into the CNS, reducing the plasma concentration of tryptophan to BCAA (f-TRP:BCAA) through the provision of exogenous BCAA has been suggested as a means to attenuate the development of central fatigue (Gomez-Merino et al. 2001; Meeusen et al. 2006). Increased brain 5-HT results from an insulin-induced decrease in plasma fTRP: BCAA ratio and brain TRP uptake (caused by an increased uptake of BCAA by skeletal muscle and thus a decrease in their plasma concentration) (Fernstrow and Wurtman 1971; Wurtman 1988). 5-HT system is also involved in learning and memory processes, and it has been suggested that 5-HT system activation may impair learning and memory, whereas a reduced brain serotoninergic level may enhance these functions (Meneses 1999).

In conclusion, the data presented in this study emphasize that the different environmental stressors involved in an offshore sailing race enhance the feeling of fatigue and decrease short-term memory performance without detrimental consequences on maximal muscle power.

Ingestion of a high protein diet rich in BCAA preserves memory performance, and appears to decrease the feeling of fatigue. However, a diet rich in BCAA should not be administered over a long period because it amplifies the ammonia increase. Since ammonia can readily cross the blood-brain barrier, it may enter the CNS where its excessive accumulation may have a profound effect on cerebral function (Meeusen et al. 2006), and on physical glycogen storage (Bigard et al. 1996). These observations have practical implications for sailors who participate in solitary races with reduced sleep times.

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