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SHORT-TERM DIET MODIFICATION CAN MODERATE THE LEVELS OF FATIGUE INDICES IN TENNIS PLAYERS

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Aim. The Objective of this study was to investigate the effect of short-term diet modification on plasma levels of fatigue indices (including serotonin, dopamine, serotonin/dopamine ratio, ammonia, and lactate) following a two-hour tennis match. **Materials and methods.** 32 semi-professional male tennis players participated in a randomized cross-over design in the form of short-term diet modification (DM) and non-modification (N-DM) interventions. They played a formal two-hour match and plasma levels of fatigue indices and RPE scores of participants were determined before and after each tennis match. **Results.** The results of this study showed that after the match, the serotonin, dopamine, lactate, and ammonia increased significantly compared to pre-match in both interventions ($p < 0.001$) and that the increase in serotonin/dopamine ratio was only significant in N-DM ($p < 0.001$). However, the increase in ammonia ($p < 0.001$) and serotonin ($p < 0.05$) as well as the serotonin/dopamine ratio ($p < 0.05$) in DM was significantly lower than in N-DM. Although the change in lactate and dopamine levels was respectively 21% and 8% higher than in N-DM after the match, these changes were not significant. A large and moderate correlation was found between RPE and serotonin/dopamine ratio ($p < 0.001$) and other variables ($p < 0.001$) respectively, which was negative for dopamine ($p < 0.05$). **Conclusion.** In this study, it was shown that short-term diet modification, could modulate the majority of fatigue indices. Therefore, diet modification can be recommended to alleviate fatigue and maintain performance among tennis players. It was also shown that the serotonin/dopamine ratio can be the most reliable among fatigue indices.

Keywords: *tennis, fatigue, diet modification, lactate, ammonia, serotonin, dopamine, RPE.*

Introduction

Delaying fatigue and maintaining athletic performance are among the most important concerns of athletes, especially tennis players [17, 34] because fatigue may be associated with a decrease in performance accuracy and skill as well as an increase in the percentage of errors [24, 38]. Tennis involves high-intensity intermittent anaerobic activity and low-to-moderate activity bouts. So, the causes of fatigue are divided into three main categories: metabolic, neuromotor, and thermal. Metabolic factors include depleted energy stores, dehydration, exhaustion of energy, and micronutrient deficiencies [17, 23]. Despite the importance of nutrition in athletic performance and prevention of fatigue, it has been shown that many athletes do not follow a healthy eating pattern [28, 42], and although the rate of supplementation is high among athletes, a significant proportion of them lack adequate knowledge concerning supplements [28]. Carbohydrate supplementation is common among athletes, and its positive effect on blood glucose in endurance activities has been found. However, the results of many studies that have examined the effect of carbohydrate supplementation on athletes' performance are contradictory [20]. Studies reported the positive [1] or no effect [26] of carbohydrate on performance. The effects of carbohydrate consumption on other factors such as lactate and ammonia – as two indicators of fatigue – which increase following exercise are not clear [5, 13, 25, 39]. Studies investigating the impact of nutritional intervention on tennis players' fatigue and performance indices were in non-competitive match conditions such as match simulating and ball throwing machines [16, 46]. Therefore, the effect of nutritional interventions on preservation of skills in the natural situation needs to be clarified.

Considering central fatigue, studies examining the effect of nutritional intervention on central fatigue have focused on serotonin [19].

However, the role of dopamine should not be overlooked because it has an inhibitory role in serotonin function [8]. In addition, the serotonin/dopamine ratio has been found to be a more reliable indicator [7], while no study was found related to nutritional intervention, exercise and this ratio.

Concerning the effect of nutritional intervention on athletes' performance, it was observed that most studies have only evaluated the role of dietary supplements in exercise and that the role of dietary modification or their combination has been rarely studied. Therefore, the purpose of this study was to evaluate the effect of a short-term diet modification (DM) on fatigue indices (including serotonin, dopamine, serotonin/dopamine ratio, ammonia, and lactate) following two-hour tennis match as well as the relationship between these indicators with the rating of perceived exertion (RPE).

Materials and Methods

1. Subjects

Thirty-two semi-professional male tennis players (age: 27.3 ± 4.8 years; height: 179.9 ± ± 5.02 cm; weight: 75.5 ± 4.7 kg, BMI: 23.3 ± ± 1.01) volunteered to participate in this study. Inclusion criteria were complete physical and mental health, lack of history of chronic diseases, musculoskeletal injuries, or depression. The subjects had nationally ranked and record of at least three years of participation in national competitions and attended at least 90 minutes of training sessions no less than 5 days a week. Exclusion criteria were not observing at least one of the pillars of diet (amount of energy intake, ratio of macronutrients to total daily energy intake, eating habit before, during or after exercise), taking any effective medication or supplement and disastrous personal events. The participants were informed about the aspects of protocols, study methods and possible risks then completed the informed consent form. This research has been approved by the ethics committee of Shiraz University of Medical Sciences (IR.SUMS.REHAB.REC.1400.002).

2. Study Design

In the first briefing session, after introducing the study and the research, anthropometric measurements, aspects of protocols and study methods and possible risks, how to complete the 3-day diet registration form, general health questionnaire, physical activity level, medical history, and Beck depression inventory (BDI-II) as well as Borg scale 6–20 rating of perceived exertion (RPE) were explained to subjects.

32 participants who were eligible for research were invited to the second briefing session (3 days before the first match). Subjects were then randomly divided into two groups of diet modification (DM) and non-diet modification (N-DM) and after estimating their energy consumption, the diet was designed according to dietary preferences of each athlete. In the sessions that were held 3 days before each match, while delivering the diet of each person, final explanation was given regarding the match protocol, supplementation method and water consumption during the match.

This study is a randomized cross-over design with two interventions: short-term diet modification with carbohydrate intake during the match (DM) and without diet modification with placebo (N-DM). Each athlete faced his opponent in a total of two single tennis matches on the outdoor clay court according to the rules of the International Tennis Federation under official umpiring. The matches were designed in a way to finish with any result at the end of two hours. The interval between two matches was one week. The tournament table was without draw and based on the ranking of the Iranian Tennis Federation. This means that the players competed with each other according to the closest position in the ranking, regardless of which interventions of study they were in. To control the possible effective factors, the opponent of each athlete was fixed until the end of the research.

On the day of the match, at 7 o'clock in the morning, the subjects arrived at the sport complex on a fasting status. After blood sampling, a breakfast based on pre-determined units including 1–1.5 g of carbohydrate, 0.25 g of protein, and 0.15–0.2 g of fat per kg of body weight was given to the athletes of DM intervention. The subjects were not allowed to eat anything until warm-up. The warm-up was performed from 9 to 9:15 A.M. Afterward, they competed with their ranking opponent for two hours and blood samples were immediately taken from them. Thirty minutes after the competition, participants were asked to express their RPE according to a Borg 6–20 scale. DM and N-DM interventions were changed in the second week. All participants were asked to avoid strenuous exercise as well as caffeine and alcohol consumption for 48 hours prior to the match.

3. Dietary Intake Assessment

Non-consecutive 3-day dietary record method was used to collect dietary intake data. The total food and drink intake of participants were recorded for two days a week during training days as well as one weekend day. After that, all the reported foods of each participant were coded and converted to grams, and to analyze and estimate the total amount of energy received and the intake of each of macronutrients in the daily diet of each athlete, Modified Nutritionist IV software [Nutritionist IV (First Data Bank, USA), version 3.5.2] was used. For each athlete, energy intake was estimated in kcal/day, carbohydrate and protein consumption in g/kg, and lipids as the percentage of total energy intake. Finally, the received macronutrients were compared with nutritional recommendations of tennis athletes (Table 1).

4. Energy expenditure

Total energy expenditure (TEE) per day of each athlete was estimated using the following formula: TEE = BMR + TEF + TEA, and Harris-Benedict formula was used to measure basal metabolic rate (BMR). Also, 10% of the total daily energy consumption was considered as thermic effect of food (TEF) [14, 44]. To estimate the thermic effect of activity (TEA), athletes were instructed both verbally and in writing to accurately mention the amount of exercise per week (number of sessions per week and the duration of each session) in addition to the exact level of all daily physical activities. Finally, the thermal effect of activity (TEA) was obtained from the sum of the thermal effect of specialized exercise and the thermal effect of daily physical activity. Herewith, metabolic equivalents (METs) were used to measure the heat effect of daily physical activity [45], and the specialized thermal effect of tennis was considered to be 8 kcal/h/kg [14]. The received energy data were compared with the estimated energy consumption, and then the percentage of difference was recorded. If this rate was ± 10%, the intake energy would be considered "adequate" [18].

5. Dietary intervention

The short-term dietary modification is described in (Table 1). Athletes were recommended to follow the specified diet from the day before the match until the end of it. The exact amount of macronutrients in the recommended range was selected according to the activity level of each athlete and that the diet of each athlete was designed according to individual interests and habits.

From onset of warm-up, DM subjects received a carbohydrate drink, and the N-DM ones consumed a placebo drink with the same taste and color. The drinks of each tennis player were divided equally into 4 bottles and were given to them at 30-minute intervals, and each athlete had to consume one-third of each bottle at 10-minute intervals. Athletes had free access to mineral water. According to the recommendations of (Table 1), tennis players would consume 0.7 g/kg/h of carbohydrates during the match; therefore, for equalization, a 6.4% carbohydrate drink was prepared and given to athletes (0.7 g/kg/h) by dissolving a certain amount of tasteless carbohydrate powder (GLYGO-MAIZE, Optimum Nutrition Company) in mineral water (Nestle Pure Life Company, made in Iran) with the following specifications: Ca 38, Mg 7.8, Na 1, HCO3 132, Fluoride 0.07, Chloride 1.5, No3 3.5, No2 0.01, pH = 7.8, TDS 178 mg/l; for example, the drink of an 80 kg athlete was 1750 ml and contained 112 g of carbohydrates within two hours.

6. Blood Sample Analysis

Five ml blood was taken from anterior brachial vein was taken in two stages of fasting

Table 1

Macronutrient consumption criteria in tennis players over 18 years based on 1.5–3 h/day training [32, 33, 36, 44]

Nutrients	Daily requirements	Before training	During training	After training
Carbohydrates	• (6–10 g/kg/day)	• 1–4 h Pre- exercise (1–4 g/kg) • 36–48 h Pre-match > 90 min: (10–12 g/kg/day)	• (0.7 g/kg/h) or (30–60 g/h) • beverage concentration 6–8%	• (1–1.2 g/kg) first 1 h or (0.8 g/kg) + protein (0.25–0.3 g/kg) • first 24h after match (8–10 g/kg/day)
Protein	• (1.4–2 g/kg/day) 0.25–0.3 g/kg every 3–5 h	• 1–4 h Pre- exercise (0.25–0.3 g/kg)	• (0.25 g/kg) in case of high intensity training > 2.5h	• (0.25–0.3 g/kg) + CHO (0.8 g/kg) first 1 h
Fat	• Do not restrict to <20% total energy expenditure • Consider limiting fat intake only during carbohydrate loading, or pre-race if GI comfort concerns			

and immediately after the match. Blood samples taken at each step were immediately sent to the laboratory in purple EDTA anticoagulated tubes to separate plasma by centrifugation and keep in pre-coded microtubules at –70 °C up to the end of sampling. Lactate level at each stage was measured using a blood sample from the earlobe by a portable Lactate Scout Analyzer (made in Germany) with a sensitivity of 0.1 mmol/l. Serotonin and dopamine levels were measured after the second match and completion of the samples according to instructions of ZELLBIO ELISA kits (made in Germany) with a sensitivity of 1.2 ng/ml for serotonin and 1.5 ng/l for dopamine. The Ion Selective Electrode method was used to evaluate the plasma ammonia levels.

7. Statistical Analysis

The Shapiro – Wilk test was used to determine the normality of the data. To compare changes independent variables over time between intervention conditions, two-way repeated measures ANOVA with time and intervention as the main within-group factors was conducted. Correlation analysis was performed to examine the association between RPE and variables. Our criterion for considering the size of the correlation was: r = 0.1–0.29 = small, 0.3–0.49 = moderate, 0.5–0.69 = large, 0.7–0.89 = very large, 0.9–0.99 = nearly perfect, 1 = perfect [15]. Statistical analysis was conducted using IBM SPSS statistics version 23 software for windows, and significant level was accepted at $p \leq 0.05$.

Results

Energy balance and macronutrients intakes

As shown in (Table 2), the adequacy of the daily consumption of macronutrients was remarkable in athletes. The percentage difference between the average energy intake and energy expenditure was lower and higher than the recommended range in 31.25% and 50% of subjects, respectively. In the study of the type, amount, and time of food received by athletes before, during, and after exercise, it was observed that 56.25%, 78.12% and 40.62% of athletes had mistaken food habits before, during and, after exercise, respectively. Therefore, required to modify the diet in at least one of the criteria of energy balance, the amount of macronutrients consumed during the day or in meals during, before, and after exercise.

Fatigue indices

Lactate: the effect of intervention × time interaction [$F(1.23,18.57) = 0.27$, $p > 0.05$] and the main effect of intervention [$F(1,15) = 1.96$, $p > 0.05$] were not significant (Fig. 1-A); but the main effect of time was significant [$F(1.80,27.12) = 453.6$, $p < 0.001$, $\eta^2 = 0.96$]. Subsequently, the results of post hoctests showed that there was a significant difference only between before and after the tennis match, which means that the tennis match significantly increased the blood lactate levels of tennis athletes in both interventions.

Ammonia: Examination of plasma ammonia levels also indicated that the effect of intervention × time interaction was not significant [$F(1.07,16.04) = 0.42$, $p > 0.05$], but as can be seen in (Fig. 1-B), the main effect of time [$F(1.68,25.21) = 200.06$, $p < 0.001$, $\eta^2 = 0.93$] and the main effect of intervention [$F(1,15) = 36.97$, $p < 0.001$, $\eta^2 = 0.71$] were significant. Afterward, the results of post hoc tests showed that there was a significant difference only between before and after the tennis match as well as a significant difference in post-match intervention, meaning that the tennis match significantly increased plasma ammonia levels in the tennis players in both interventions. However, post-match ammonia levels in DM significantly less increased than N-DM.

Table 2

Distribution of percentage of energy balance and adequacy of daily macronutrients intake in tennis players

	Energy balance %	Carbohydrate g/kg/day	Protein g/kg/day	Lipid % total energy
Recommended range	**–10% to +10%**	**6–10**	**1.4–2**	**20–30%**
less than range n (%)	10 (31.25%)	18 (56.25%)	4 (12.5%)	2 (6.25%)
In the range n (%)	6 (18.75%)	4 (12.5%)	15 (46.87%)	12 (37.5%)
More than range n (%)	16 (50%)	10 (31.25)	13 (40.62%)	18 (56.25%)

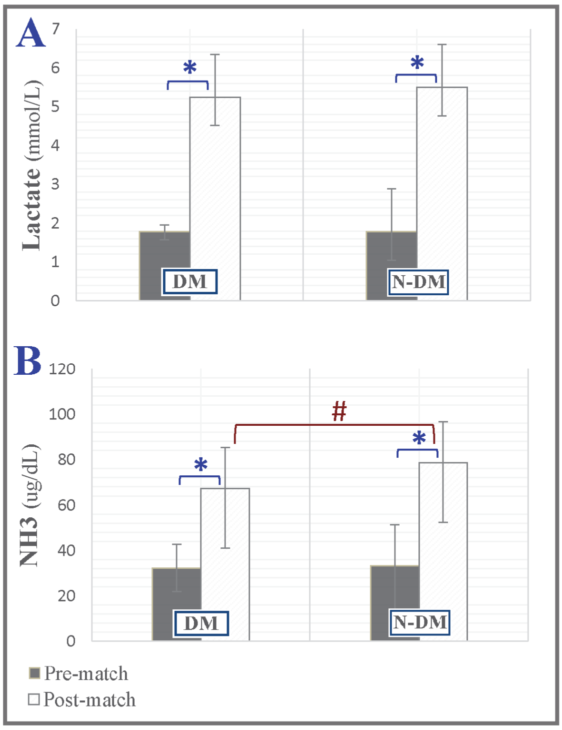

Fig. 1. Comparison of blood Lactate (A) and Ammonia (B) in DM and N-DM measurements:
– significant differences in interventions;
* – significant differences in times

Serotonin: It was observed that the effect of intervention × time interaction was not significant [F (1.04, 15.56) = 0.43, $p > 0.05$] and that the main effect of time [(F(1.59, 23.99) = 105.29, $p < 0.001$, $\eta^2 = 0.87$] as well as the main effect of intervention [(F(1,15) = 6.36, $p < 0.05$, $\eta^2 = 0.29$] was significant. According to (Fig. 2-A), post hoc tests showed that the tennis match caused a significant increase in plasma serotonin levels in both interventions, but this increase in DM was significantly less than in N-DM.

Dopamine: The effect of intervention × time interaction [F(1.02,15.32) = 0.14, $p > 0.05$] and the main effect of intervention [(F(1,15) = 1.76, $p > 0.05$] were not significant. However, the main effect of time [(F(1.27,19.1) = 27.65, $p < 0.001$, $\eta^2 = 0.65$] was significant. Finally, post hoc test showed that the tennis match significantly increased plasma dopamine levels in both interventions, and as can be seen in (Fig. 2-B), the increase in DM (106.5 ± 39.4 ng/l) was slightly more than N-DM (98.5 ± 25.4 ng/l), but the difference between the two interventions was not significant.

Serotonin/dopamine ratio: The effect of intervention × time interaction was not significant [(F(1.1,16.5) = 0.75, $p > 0.05$] but the main effect of time [(F(1.58, 23.63) = 7.86, $p < 0.001$, η^2 = = 0.34] also the main effect of intervention [(F(1,15) = 5.28, $p < 0.05$, $\eta^2 = 0.13$] was significant. Post hoc tests showed that this ratio increased in both DM and N-DM after the match but that this increase was significant only in N-DM ($p < 0.001$). According to (Fig. 2-C), the comparison of DM and N-DM subjects showed no significant difference between the pre-tests ($p > 0.05$), while there was a significant difference between DM and N-DM post-tests ($p < 0.05$).

RPE: Summary of the results of correlation between subjects' RPE scores with research variables is given in (Table 3), which shows that there is a large correlation between RPE and serotonin/dopamine ratio that is the highest coefficient between the variables. Also, the correlation between RPE and other variables was moderate, which was negative for dopamine ($p < 0.05$).

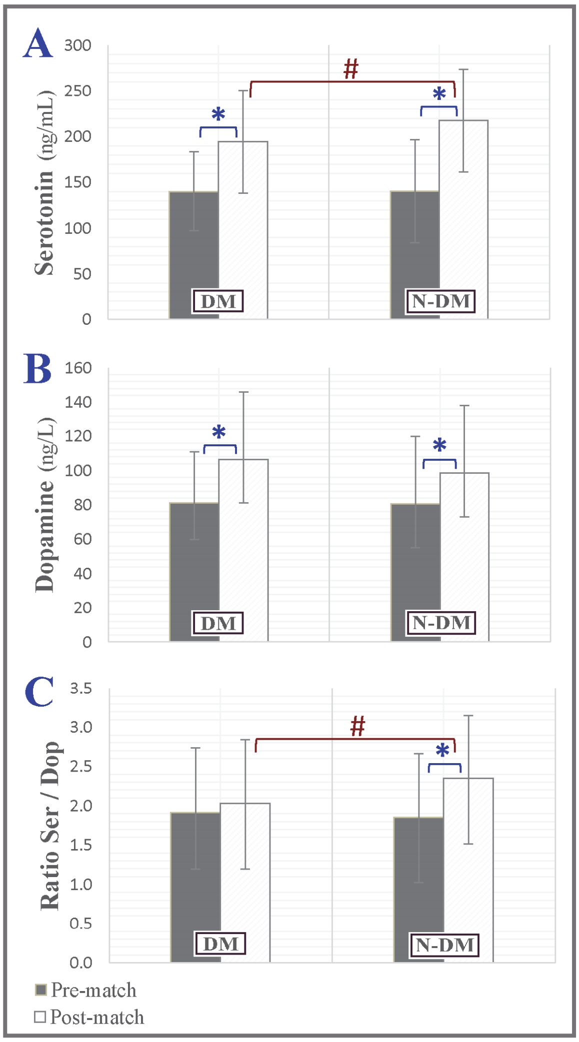

Fig. 2. Comparison of plasma serotonin(A) Dopamine(B) and serotonin/Dopamine Ratio(C) in DM and N-DM measurements

Table 3

Correlations between RPE and physiological values after the match

	Serotonin	Dopamine	Ser/Dop ratio	Lactate	Ammonia
RPE (all post-match tests)	$r = 0.4$ $p < 0.001$	$r = -0.31$ $p < 0.05$	$r = 0.58$ $p < 0.001$	$r = 0.42$ $p < 0.001$	$r = 0.48$ $p < 0.001$

Discussion

Lactate: The results of the present study showed that blood lactate levels increased in both DM and N-DM interventions immediately after a two-hour tennis match. Although this increase was 21% higher in N-DM intervention, the difference was not significant. This means that short-term diet modification with carbohydrate intake during exercise did not have a significant effect on the level of lactate accumulation in the blood.

In carbohydrate metabolism, if its oxidation is disrupted and pyruvate production in sarcoplasm exceeds its oxidation capacity in mitochondria for reasons such as oxygen deficiency and low mitochondrial oxidative capacity, pyruvate is converted back to lactate. The lactate produced in the muscle enters the bloodstream during exercise and, depending on the individual's capacity, enters the liver and is converted back to pyruvate [23].

Due to the high-intensity intermittent anaerobic and low to moderate severity bouts in tennis, ATP production is provided by both anaerobic and aerobic systems. Analysis of professional tennis matches shows that the effective rally or competition time (percentage of total rally time in a match) is about 20–30% on clay courts. This interval nature of tennis reduces the dependence on anaerobic glycolysis for ATP production and provides significant opportunities for lactate clearance. However, it seems that the cumulative effects of intense intermittent activity during the match put pressure on the athlete and gradually exhaust the athlete until the end of the match. There are also cases in which tennis athletes experience temporary fatigue, which reduces their ability for some time after high-intensity activity and limits their performance [11, 17].

In some studies, high lactate concentrations were reported in long games or long intense rallies, which revealed that lactate accumulation is higher in service games than in return games. Blood lactate levels may reach 8.6 mmol/l even in professional players [29, 30]; Reed et al. [37] reported that blood lactate levels reached 10.6 mmol/l while tennis training drills. In the present study, lactate levels also increased, which was probably due to the cumulative effect of lactate production during two hours of the match as well as poor clearing probably because of reasons such as being semi-professional and dietary deficiencies of the subjects. It should be noted that lactate levels of our study were 5.25 and 5.5 mmol/l for DM and N-DM respectively and did not reach the extreme levels, which is likely a function of the interval nature of tennis. In the present study, it was also observed that there is a slight difference (21%) between the percentage of increase in lactate levels after the match between DM and N-DM individuals. Although this difference was not significant, this small difference was probably because of stable PCr and ATP levels, reduced ADP, AMP, IMP, and most importantly, decreased Pi as well as more PDH activity and thus decreased lactate production. Obviously, it should be noted that the accumulation of muscle lactate does not lead to fatigue during exercise, but they seem to be a good indicator of fatigue or play a role in causing fatigue in humans. This may be due to a decrease in muscle pH, which releases higher levels of K^+ from active muscles and leads to the feeling of tiredness [3]. Some investigations have found that blood lactate levels remain low during tennis match. Most of these reports represent average levels from the concentration of the first to the final game, so the low levels reported can be justified [9, 10].

Ammonia: Assessment of plasma ammonia levels also showed that after the tennis match, ammonia levels increased in both interventions, but this increase in DM intervention was significantly less than in N-DM intervention.

According to previous research results, it was expected that ammonia as the factor of central and peripheral fatigue would increase after a two-hour tennis match, which could be due to an imbalance in ammonia production and its clearance in active muscles during the match. This increase of ammonia in strenuous activity may increase peripheral fatigue to the point of toxicity to the brain and muscles [31].

The main cause of ammonia accumulation in submaximal exercise is AMP deamination and catabolism of nitrogenous compounds such as amino acids, especially branched-chain amino acids (BCAA). However, the accumulation of ammonia in intense and long-term training has another factor, namely reduced muscle glycogen sources and the resulting inhibition of re-phosphorylation for ADP and ATP synthesis, IMP increase, and eventual ammonia production [39]. This rise in ammonia levels is called metabolic stress because its effect on the feeling of fatigue and contraction of active muscles cannot be ignored. Rising ammonia levels may also enhance ammonia transport from the blood-brain barrier (BBB), disrupt brain mitochondria and inhibit motor activity due to glutamate stimulation in parts of the brain that control motor activity [31, 47].

The findings of the present study were consistent with those of Carvalho-Peixoto's research [5]. In that study, the effect of glutamine consumption with or without carbohydrate on ammonia levels of professional runners was examined, and it was concluded that supplementation was ineffective within the first hour but increased plasma ammonia levels to a lower extent in the second hour. The results of the present study were also in agreement with the study of Snow [41] who showed that in a 2-hour workout, 250 ml of 8% carbohydrate solution every 15 minutes could modulate the increase in ammonia from 60 to 120 minutes.

The mechanism of carbohydrate effect on ammonia accumulation seems to be the relative reduction in pure AMP catabolism in active muscle by maintaining phosphocreatine levels and ATP re-synthesis late in long-term exercise. Besides, carbohydrate intake is likely to reduce protein degradation and amino acid catabolism, thereby decreasing ammonia accumulation by maintaining muscle glycogen storage; in the present study, ammonia accumulation was significantly lower in DM intervention. Some studies have acknowledged that the lack of carbohydrates in athletes' diets leads to more ammonia accumulation [5, 40].

Serotonin: Regarding the serotonin variable, the results showed that after a two-hour tennis match, plasma serotonin levels increased in both DM and N-DM interventions, but this increase was 17% lower in DM. In other words, after the match, 57% and 40% increase was observed in plasma serotonin levels of N-DM and DM subjects, respectively. Therefore, short-term diet modification had a positive effect on inhibiting the increase of serotonin as an indicator of central fatigue.

In fact, serotonin (5-hydroxytryptamine; 5-HT) is a neurotransmitter in the brain that is produced from the essential amino acid tryptophan. 80–90% of tryptophan is transported in the blood by binding to its carrier (albumin), and the rest freely circulates in the blood. Free tryptophan in the blood is easily transported through BBB by specific transporter proteins, which is then hydroxylated by tryptophan hydroxylase to generate serotonin. Therefore, any condition elevating free tryptophan in plasma will increase the concentration of this amino acid in CNS and thus increase 5-HT biosynthesis [8].

During prolonged exercise, the concentration of free fatty acid (FFA) increases in the blood. FFA competes with tryptophan for albumin binding, which results in a marked increase in free tryptophan and eventually elevates tryptophan concentration in the brain, in turn leading to increasing serotonin production in the brain [7, 8, 34]. In addition, the specific tryptophan transporter in BBB is also a transporter of BCAAs, and if the concentration of BCAAs increases in the plasma, this will cause more competition between tryptophan and BCAAs for entering into the brain and hence less tryptophan moves into the brain. Plasma BCAA concentrations also decrease during prolonged exercise. This condition increases cerebral tryptophan uptake, which will be amplified if accompanied by an increase in plasma free tryptophan concentration due to exercise [7, 8, 34]. Therefore, following exercise, serotonin synthesis increases and rising brain HT-5 can cause feelings of lethargy and lack of motivation to continue exercising; in other words, it exacerbates the feeling of fatigue. As a result, increasing concentration of this neurotransmitter in CNS during exercise may interfere with mental and physical functions [4, 6]. Increase of serotonin following exercise in the present study was similar to some previous findings [21, 48].

Adequate diet and, above all, proper carbohydrate intake during exercise appear to reduce tryptophan by releasing blood glucose and providing adequate levels of muscle and liver glycogen by delaying FFA accumulation because FFA itself is a strong competitor to tryptophan for albumin binding. Adequate carbohydrate levels will also maintain BCAA levels and reduce the ratio of free tryptophan to BCAAs. As mentioned, BCAAs compete with tryptophan to pass through BBB and it is inevitable that higher concentrations of BCAAs will cause less tryptophan to enter the brain and less serotonin to be synthesized [4]. In the present study, as mentioned, serotonin increased after exercise, but by modifying the short-term diet and consuming 0.7 g/kg/h of carbohydrates during the match, this increase was adjusted by 17%, which was similar to some previous findings [19].

Dopamine: Dopamine (DA; 3,4-dihydroxyphenylethylamine) is another neurotransmitter involved in central fatigue mechanisms. The results showed that dopamine levels increased immediately after a two-hour tennis match, and its level increased by 31% and 23% in DM and N-DM subjects, respectively. This means that short-term diet modification with carbohydrate intake during exercise causes a relatively greater increase in dopamine levels, but this was not statistically significant. Dopamine is synthesized from the amino acid tyrosine, which crosses BBB and converts to L-3,4-dihydroxyphenylalanine (L-DOPA) by tyrosine hydroxylase and finally to DA by dopa carboxylase. The limiting step in the synthesis of this monoamine is the tyrosine hydroxylase step, which is stimulated by calcium [8]. It seems that increasing activity of the dopaminergic system is a function of rising central calcium levels at the beginning of exercise, which increases tyrosine hydroxylase activity by activating the calcium-calmodulin system [8, 43]. Although the role of serotonin in central fatigue has been well established, there is evidence that dopamine also affects central fatigue. Research shows that dopamine neurotransmission is associated with many physiological functions that can improve athletic performance, including arousal, motivation, reinforcement, and motor behavior control. In fact, various studies provide evidence that the activation of central dopamine plays an essential role in thermoregulatory mechanisms, which is also important in exercise [7, 8, 22, 27].

Analysis and interpretation of studies show that the dopaminergic system is likely to affect various neural pathways, including motivation and reward, and has a positive effect on physical function even in pathological conditions such as Parkinson's disease [8, 12, 22, 27]. On the other hand, evidence shows that inactivity of the dopaminergic system is related to the development of fatigue. Studies have also shown that central dopamine metabolism enhances during exercise in different brain regions [2, 7, 12], in the present study the tennis match significantly increased the plasma dopamine levels of tennis athletes in both interventions, which is consistent with the results of these studies.

Serotonin/dopamine ratio: Obviously, given the complexity of the function, a single neurotransmitter cannot be blamed for central fatigue. Therefore, in general, it can be acknowledged that the activity of dopaminergic and serotonergic systems in interaction with each other increases or decreases physical function. It is important to note that with the onset of exercise, both serotonergic and dopaminergic systems are gradually enhanced with a kinetic pattern; however, while serotonin concentration peaks at the fatigue point, dopaminergic activity decreases as the exercise progresses or returns to resting levels at fatigue [4, 6–8]. So, the modulatory effects on fatigue during exercise may be due to the interaction between these two neurotransmitters because there is evidence that dopamine receptor antagonists increase serotonergic activity and dopamine receptor agonists decrease serotonergic activity. It has also been shown that the use of serotonin agonists inhibits the increase in brain dopamine concentration caused by exercise, and conversely, by intervening through the administration of serotonin antagonists, central dopamine levels are maintained during fatigue. In addition, the dopamine precursor (tyrosine) competes with the serotonin precursor (tryptophan) to enter the brain [7, 22, 35]. Therefore, the existence of an inhibitory relationship between dopaminergic and serotonergic systems is undeniable and fatigue does not depend on just one of the two systems, but it is a function of increased serotonergic activity and decreased dopaminergic activity. Therefore, the higher serotonin/dopamine ratio, the weaker the exercise performance, and the lower this ratio is maintained, fewer signs of fatigue and weakness are seen in exercise performance [7, 8, 22, 35]. Therefore, it seems that the serotonin / dopamine ratio can be generalized to determine fatigue and that it is better than analysis and intervention on one of the two. The findings of the present study also proved this fact because the serotonin/dopamine ratio was significantly lower in DM intervention, moreover, in the study of the correlation between RPE and the measured fatigue indices, the highest correlation was observed between the serotonin/dopamine ratio with the rating of perceived exertion.

Conclusions

Despite the importance of nutrition in athletic performance and delaying fatigue, this study shows that many athletes do not follow a proper eating pattern. The present study showed athletes and researchers that diet modification, albeit short-term, can help alleviate tennis players' concerns regarding fatigue. Therefore, tennis players are advised to modify their diet as the first and most important step to maintain performance and delay fatigue. In this study, for the first time, the serotonin/dopamine ratio was considered an indicator of fatigue. The high correlation of this ratio with RPE pressure perception scores showed that among conventional fatigue factors, serotonin/dopamine ratio can be the most valid indicator. There were limitations in this research due to ethics issues in research and human subjects, which made it impossible to study the tissue and brain levels of the studied factors to compare blood levels with tissue levels; therefore, it is suggested that histological studies should be performed on laboratory animals to help understand whether blood levels can be generalized to tissues and the brain.

References

1. Ali A., Williams C. Carbohydrate Ingestion and Soccer Skill Performance During Prolonged Intermittent Exercise. *Journal of Sports Sciences*, 2009, vol. 27, no. 14, pp. 1499–1508. DOI: 10.1080/02640410903334772

2. Balthazar C.H., Leite L.H.R., Rodrigues A.G., Coimbra C.C. Performance-Enhancing and Thermoregulatory Effects of Intracerebroventricular Dopamine In Running Rats. *Pharmacology Biochemistry and Behavior*, 2009, vol. 93, no. 4, pp. 465–469. DOI: 10.1016/j.pbb.2009.06.009

3. Bangsbo J., Hostrup M. Lactate Production Contributes to Development of Fatigue During Intense Exercise in Humans. *Ugeskrift for laeger*, 2019, vol. 181, no. 8.

4. Basso J.C., Suzuki W.A. The Effects of Acute Exercise on Mood, Cognition, Neurophysiology, and Neurochemical Pathways: A Review. *Brain Plasticity*, 2017, vol. 2, no. 2, pp. 127–152. DOI: 10.3233/bpl-160040

5. Carvalho-peixoto J., Alves R.C., Cameron L.C. Glutamine and Carbohydrate Supplements Reduce Ammonemia Increase During Endurance Field Exercise. *Applied Physiology, Nutrition, and Metabolism*, 2007, vol. 1190, pp. 1186–1190. DOI: 10.1139/H07-091

6. Chuckravanen D., Bulut S., Kürklü G.B., Yapali G. Review of Exercise-Induced Physiological Control Models to Explain the Development of Fatigue To Improve Sports Performance and Future Trend. *Science & Sports*, 2018, vol. 34, no. 3, pp. 131–140. DOI: 10.1016/j.scispo.2018.10.017

7. Coimbra C.C., Soares D.D., Leite L.H. The Involvement of Brain Monoamines in the Onset of Hyperthermic Central Fatigue. *An International Perspective on Topics in Sports Medicine and Sports Injury*, 2012, pp. 275–306. DOI: 10.5772/26191

8. Cordeiro L.M.S., Rabelo P.C.R., Moraes M.M., Teixeira-Coelho F. Physical Exercise-Induced Fatigue: the Role of Serotonergic and Dopaminergic Systems. *Brazilian Journal of Medical and Biological Research*, 2017, vol. 50, no. 12, pp. 1–13. DOI: 10.1590/1414-431x20176432

9. Fernandez-Fernandez J., Mendez-Villanueva A., Fernandez-Garcia B., Terrados N. Match Activity and Physiological Responses During a Junior Female Singles Tennis Tournament. *British Journal of Sports Medicine*, 2007, vol. 41, no. 11, pp. 711–716. DOI: 10.1136/bjsm.2007.036210

10. Fernandez-Fernandez J., Sanz-Rivas D., Fernandez-Garcia B., Mendez-Villanueva A. Match Activity and Physiological Load During a Clay-Court Tennis Tournament in Elite Female Players. *Journal of Sports Sciences*, 2008, vol. 26, no. 14, pp. 1589–1595. DOI: 10.1080/02640410802287089

11. Fernandez-Fernandez J., Sanz-Rivas D., Mendez-Villanueva A. A Review of the Activity Profile and Physiological Demands of Tennis Match Play. *Strength and Conditioning Journal*, 2009, vol. 31, no. 4, pp. 15–26. DOI: 10.1519/SSC.0b013e3181ada1cb

12. Foley T.E., Fleshner M. Neuroplasticity of Dopamine Circuits after Exercise: Implications for Central Fatigue. *NeuroMolecular Medicine*, 2008, vol. 10, no. 2, pp. 67–80. DOI: 10.1007/s12017-008-8032-3

13. Fonseca A., Bernardo M.A., Mesquita M.F.D., Brito J. Effect of 6% Maltodextrin Intake on Capillary Lactate Concentration in Soccer Players. *Medical Sciences Forum*, 2021, vol. 5, no. 1, p. 42. DOI: 10.3390/msf2021005042

14. Heater H.F., Alan E.M. *Practical Application in Sports Nutrition*, 5th Edition. Massachusetts, Jones and Bartlett Publisher, 2018. pp. 302–306.

15. Hopkins W.G., Marshall S.W., Batterham A.M., Hanin J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Medicine and Science in Sports and Exercise*, 2009, vol. 41, no. 1, pp. 3–12. DOI: 10.1249/MSS.0b013e31818cb278

16. Hornery D.J., Farrow D., Mujika I., Young W.B. Caffeine, Carbohydrate, and Cooling Use During Prolonged Simulated Tennis. *International Journal of Sports Physiology and Performance*, 2008, vol. 2, no. 4, pp. 423–438. DOI: 10.1123/ijspp.2.4.423

17. Hornery D.J., Farrow D., Mujika I., Young W. Fatigue In Tennis. *Sports Medicine*, 2007, vol. 37, no. 3, pp. 199–212. DOI: 10.2165/00007256-200737030-00002

18. Juzwiak C.R., Amancio O.M.S., Vitalle M.S.S., Pinheiro M.M. Body Composition and Nutritional Profile of Male Adolescent Tennis Players. *Journal of Sports Sciences*, 2008, vol. 26, no. 11, pp. 1209–1217. DOI: 10.1080/02640410801930192

19. Kim D.-H., Kim S.-H., Jeong W.-S., Lee H.-Y. Effect of BCAA Intake During Endurance Exercises on Fatigue Substances, Muscle Damage Substances, and Energy Metabolism Substances. *Journal of Exercise Nutrition and Biochemistry*, 2013, vol. 17, no. 4. DOI: 10.5717/jenb.2013.17.4.169

20. Kovacs M.S. Carbohydrate Intake and Tennis: Are There Benefits? *British Journal of Sports Medicine*, 2006, vol. 40, no. 5, pp. 1–6. DOI: 10.1136/bjsm.2005.023291

21. Kwak J., Yook J.S., Ha M. Potential Biomarkers of Peripheral and Central Fatigue in High- Intensity Trained Athletes at High-Temperature. *Journal of Immunology Research*, 2020. DOI: 10.1155/2020/4768390

22. Leite L.H., Rodrigues A.G., Soares D.D., Marubayashi U. Central Fatigue Induced by Losartan Involves Brain Serotonin and Dopamine Content. *Medicine and Science in Sports and Exercise*, 2010, vol. 42, no. 8, pp. 1469–1476. DOI: 10.1249/MSS.0b013e3181d03d36

23. MacLaren D., Morton J. *Biochemistry for Sport and Exercise Metabolism*. John Wiley & Sons, 2011. 265 p.

24. Maraga N., Duffield R., Gescheit D., Perri T. Playing Not Once, Not Twice but Three Times in a Day: the Effect of Fatigue on Performance in Junior Tennis Players. *International Journal of Performance Analysis in Sport*, 2018, vol. 18, no. 1, pp. 104–114. DOI: 10.1080/24748668.2018.1452110

25. McMahon G., Thornbury A. Ingestion of Carbohydrate Prior to and during Maximal, Sprint Interval Cycling Has No Ergogenic Effect: A Randomized, Double-Blind, Placebo Controlled, Crossover Study. *Nutrients*, 2020, vol. 12, no. 8, pp. 1–12. DOI: 10.3390/nu12082223

26. McRae K.A., Galloway S.D.R. Carbohydrate-Electrolyte Drink Ingestion and Skill Performance During and after 2 Hr of Indoor Tennis Match Play. *International Journal of Sport Nutrition and Exercise Metabolism*, 2012, vol. 22, no. 1, pp. 38–46. DOI: 10.1123/ijsnem.22.1.38

27. Meeusen R., Roelands B. Fatigue: Is It All Neurochemistry? *European Journal of Sport Science*, 2018, vol. 18, no. 1, pp. 37–46. DOI: 10.1080/17461391.2017.1296890

28. Mehrez A., Salesi M. *Sport Nutrition and Doping Knowledge, Eating Habits and Supplement Use in Tennis Athletes and Coaches.* Shiraz University, 2017.

29. Mendez-Villanueva A., Fernandez-Fernandez J., Bishop D., Fernandez-Garcia B. Activity Patterns, Blood Lactate Concentrations and Ratings of Perceived Exertion During a Professional Singles Tennis Tournament. *British Journal of Sports Medicine*, 2007, vol. 41, no. 5, pp. 296–300. DOI: 10.1136/bjsm.2006.030536

30. Mendez-Villanueva A., Fernandez-Fernández J., Bishop D., Fernandez-Garcia B. Ratings of Perceived Exertion-Lactate Association During Actual Singles Tennis Match Play. *The Journal of Strength & Conditioning Research*, 2010, vol. 24, no. 1, pp. 165–170. DOI: 10.1519/JSC.0b013e3181a5bc6d

31. Nybo L., Dalsgaard M.K., Steensberg A., Møller K. Cerebral Ammonia Uptake and Accumulation During Prolonged Exercise In Humans. *Journal of Physiology*, 2005, vol. 563, no. 1, pp. 285–290. DOI: 10.1113/jphysiol.2004.075838

32. Oršolić M., Barbaros Tudor P., Šarić A. Recommended Amounts of Macronutrients before and after Tennis Matches. *Hrana u zdravlju i bolesti,* 2020, vol. 9, no. 1, pp. 40–47.

33. Parker-Simmons S., Love P. Sports Nutrition for Tennis Players. *Tennis Medicine*, 2018, vol. 34, no. 1, pp. 563–572. DOI: 10.1007/978-3-319-71498-1

34. Phillips S. *Fatigue in Sport and Exercise*. London, Routledge, 2015. 271 p. DOI: 10.4324/9781315814858

35. Rabelo P.C.R., Almeida T.F., Guimarães J.B., Barcellos L.A.M. Intrinsic Exercise Capacity Is Related to Differential Monoaminergic Activity in the Rat Forebrain. *Brain Research Bulletin*, 2015, vol. 112, pp. 7–13. DOI: 10.1016/j.brainresbull.2015.01.006

36. Ranchordas M.K., Rogerson D., Ruddock A., Killer C. Nutrition for Tennis: Practical Recommendations. *Journal of Sports Science & Medicine*, 2013, vol. 12, no. 2, pp. 211–224.

37. Reid M., Duffield R., Dawson B., Baker J. Quantification of the Physiological and Performance Characteristics of On-Court Tennis Drills. *British Journal of Sports Medicine*, 2008, vol. 42, no. 2, pp. 146–151. DOI: 10.1136/bjsm.2007.036426

38. Rota S., Morel B., Saboul D., Rogowski I. Influence of Fatigue on Upper Limb Muscle Activity and Performance in Tennis. *Journal of Electromyography and Kinesiology*, 2014, vol. 24, no. 1, pp. 90–97. DOI: 10.1016/j.jelekin. 2013.10.007

39. Rusip G., Suhartini S.M., Suen A.B. Influence of Exercise on Plasma Ammonia and Urea after Ingestion Beverages of Carbohydrate Electrolyte. *IOP Conference Series: Earth and Environmental Science*, 2018, vol. 130, no. 1, pp. 12–20. DOI: 10.1088/1755-1315/130/1/012020

40. Schulz H., Heck H. Glycogen Depletion as Indication for Ammonia Determination in Exercise Testing. *European Journal of Sport Science*, 2003, vol. 3, no. 3, pp. 1–9. DOI: 10.1080/17461390300073303

41. Snow R.J., Carey M.F., Stathis C.G., Febbraio M.A. Effect of Carbohydrate Ingestion on Ammonia Metabolism During Exercise in Humans. *Journal of Applied Physiology*, 2020, vol. 88, no. 5, pp. 1576–1580. DOI: 10.1152/ jappl.2000.88.5.1576

42. Soraya S., Elias M., Saad H.A., Nasir M. Effects of Sports Nutrition Education Intervention on Sports Nutrition Knowledge, Attitude and Practice, and Dietary Intake of Malaysian Team Sports Athletes. *Malaysian Journal of Nutrition*, 2018, vol. 24, no. 1, p. 103.

43. Sutoo D., Akiyama K. Regulation of Brain Function by Exercise. *Neurobiology of Disease*, 2003, vol. 13, no. 1, pp. 1–14. DOI: 10.1016/S0969-9961(03)00030-5

44. Thomas D.T., Erdman K.A., Burke L.M. American College of Sports Medicine Joint Position Statement Nutrition and Athletic Performance. *Medicine and Science in Sports and Exercise*, 2016, vol. 48, no. 3, pp. 543–568. DOI: 10.1249/MSS.0000000000000852

45. Thomas D.T., Erdman K.A., Burke L.M. American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Medicine and Science in Sports and Exercise*, 2016, vol. 48 (3), pp. 543–568. DOI: 10.1249/MSS.0000000000000852

46. Vergauwen L.I.E.V.E.N., Brouns F.R.E.D., Hespel P. Carbohydrate Supplementation Improves Stroke Performance in Tennis. *Medicine and Science in Sports and Exercise*, 1998, vol. 30, no. 8, pp. 1289–1295. DOI: 10.1097/ 00005768-199808000-00017

47. Wilkinson D.J., Smeeton N.J., Watt P.W. Ammonia Metabolism, the Brain and Fatigue; Revisiting the Link. *Progress in Neurobiology*, 2010, vol. 91, no. 3, pp. 200–219. DOI: 10.1016/j.pneurobio.2010.01.012

48. Zimmer P., Stritt C., Bloch W., Schmidt F.P. The Effects of Different Aerobic Exercise Intensities on Serum Serotonin Concentrations and Their Association with Stroop Task Performance: a Randomized Controlled Trial. *European Journal of Applied Physiology*, 2016, vol. 116, no. 10, pp. 2025–2034. DOI: 10.1007/s00421-016-3456-1

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ВЛИЯНИЕ КРАТКОВРЕМЕННОЙ СМЕНЫ ДИЕТЫ НА ПОКАЗАТЕЛИ УТОМЛЯЕМОСТИ У ТЕННИСИСТОВ

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Цель. Целью данного исследования было определение влияния кратковременной смены диеты на плазменные показатели утомляемости (плазменные концентрации серотонина и дофамина, соотношение серотонин / дофамин, содержание аммиака и лактата) после часового теннисного матча. **Материалы и методы.** Рандомизированное перекрестное исследование с участием 32 полупрофессиональных теннисистов, поделенных на две группы в зависимости от режима питания (со сменой диеты и без смены диеты). Все участники исследования сыграли двухчасовую партию в теннис. До и после теннисной партии у всех участников были определены плазменные показатели утомляемости и показатели субъективно воспринимаемой напряженности. **Результаты.** Результаты исследований показывают статистически значимый прирост ($p < 0,001$) плазменных концентраций серотонина, дофамина, лактата и аммиака в обеих группах по сравнению с исходными значениями, при этом статистически значимое ($p < 0,001$) увеличение соотношения серотонин / дофамин было зарегистрировано только в группе без изменения диеты. Увеличение концентраций аммиака ($p < 0,001$) и серотонина ($p < 0,05$), а также увеличение соотношения серотонин / дофамин ($p < 0,05$) в группе со сменой диеты было значительно ниже по сравнению с показателями контрольной группы. Хотя концентрации лактата и дофамина после партии в группе со сменой диеты были выше на 21 и 8 % соответственно, данные изменения не были статистически значимыми. Сильная и умеренная корреляция была зарегистрирована между показателями субъективно воспринимаемой напряженности и соотношением серотонин / дофамин ($p < 0,001$) и прочими переменными ($p < 0,001$) соответственно, при этом для дофамина была обнаружена отрицательная корреляция ($p < 0,05$). **Заключение.** По результатам исследования было установлено, что кратковременная смена диеты может повлечь изменения большинства показателей утомляемости. Таким образом, изменение режима питания может быть рекомендовано для контроля утомляемости и поддержания результативности теннисистов. Наиболее информативным показателем утомляемости может считаться соотношение концентраций серотонина и дофамина.

Ключевые слова: *утомляемость, теннис, смена режима питания, лактат, аммиак, дофамин, субъективно воспринимаемая напряженность.*

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