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Effect of Carbohydrate Intake on Central Fatigue in Elite Badminton Athletes Running for a Long Time Under Moderate Hypoxia

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1. INTRODUCTION

Exercise-induced fatigue and its recovery process remain topical issues in the field of current sport scientific research and it is divided into the central fatigue and peripheral fatigue in accordance with different parts of fatigue. And the primary part that causes fatigue is the brain, which is also an organ that is most prone to fatigue.

The rather long game time and high intensity in the badminton competition will make the athlete in hypoxia. Then, the athlete is prone to be in a fatigue state. And central fatigue will challenge elite athletes' anticipation, reaction as well as technical and tactical thinking. Therefore, it is of extreme importance for badminton players to involve in the anti-fatigue action in the process of competition.

As an endurance sport, the fatigue caused by the badminton is affected by time and intensity. And the fatigue may originate from the muscles and the center. As for the fatigue caused by the muscles, it is the peripheral one, which occurs usually in the short-term exercise with high-intensity such as the short-term high-intensity counterattacks in badminton games. Additionally, the central fatigue happens in long-term sport with high-intensity. Compared with other sports, the event of sports is also a factor lead to the central fatigue. And the weight-bearing full-body exercise will cause the fatigue to a greater level.

The reason of central fatigue mainly relates to the hypoxia. In the whole process of fatigue, the degree of hypoxia matters. For example, the mild hypoxia accelerates the peripheral fatigue process. And the moderate to severe fatigue reduces athletes' athletic performance through the mechanism of central inhibition.

The main mechanism is the serotonin fatigue hypothesis that is similar to the long-term exercise and central fatigue is serotonin fatigue hypothesis. This model assumes that the proportion of free tryptophan (f-TRP) converted to branched-chain amino acids (BCAA) will change the serotonin level and cause the fatigue development. f- TRP is controlled mainly by the circulation concentration of free fatty acids (FFA). Specifically, the serotonin fatigue hypothesis hypothesizes that prolonged exercise enables the FFA increase, releases TRP from the albumin, and allows nascent f-TRP to cross the blood-brain barrier so as to convert to the serotonin. Studies have shown that athletes who took the serotonin reuptake inhibitor significantly shortened the time to fatigue compared to those with the placebo. Therefore, f-TRP surpasses BCAA in crossing the blood-brain barrier. Thus, compared to BCAA, f-TRP, which is more sensitive to the amino acid concentration, better serves as the marker of central fatigue. FFA levels are up-regulated under hypoxia, so the serotonin fatigue hypothesis proves that interventions that reduce the ratio of f-TRP to BCAA will ease the level of central fatigue.

Research has found that by controlling the carbohydrate intake, the ratio of f-TRP to BCAA could be reduced. Currently, there are relevant studies focused on the analysis of the effect of carbohydrate intake on central fatigue. However, no relevant research has been applied in badminton. Therefore, based on the serotonin theory of fatigue, this study explores the effect of moderate-intensity exercise on badminton players under hypoxia, and further analyzes whether carbohydrate intake would change the mechanism of fatigue for athlete under hypoxia.

2. STATEMENT OF RESEARCH PROBLEMS

The rather long game time and high intensity in the badminton competition will make the athlete in hypoxia. Then, the athlete is prone to be in a fatigue state, which leads to the central fatigue. For athletes in central fatigue, their anticipation, reaction as well as technical and tactical thinking will reduce, which is fatal to elite athletes. Hence, effective relief of central fatigue of athletes during the competition becomes a hot topic of research. After reviewing the previous literature, it is found that the serotonin fatigue hypothesis believes that interventions that reduce the ratio of f-TRP to BCAA would alleviate the occurrence of fatigue, and carbohydrate intake enables the reduction of the ratio of f-TRP to BCAA, thus revealing a certain theoretical basis for improving the fatigue level of badminton players. The research problems of this study are mainly parted into two aspects: (1) long-term exercise with moderate-intensity may lead to hypoxia in elite badminton athletes; (2) carbohydrate intake changes the mechanisms of fatigue alleviation of athletes under hypoxia.

3. OBJECTIVE OF STUDY

The main aim of this study is to understand the effect of carbohydrate intake on central fatigue in elite badminton athletes under hypoxia

4. SIGNIFICANCE OF STUDY

The significance of this study is to improve the fatigue state of athletes through carbohydrate intake, which provides a new pattern of thinking and theoretical basis for the intervention of fatigue at the mechanism level. This study serves as a reference for the nutritional supplements of high-level badminton players with a theoretical reference for the research on the mechanism of fatigue under hypoxia.

5. DEFINITION OF TERMS

Hypoxia refers to a pathological process in which the metabolism, function and morphological structure of tissues are abnormally changed due to insufficient oxygen supply or dysoxidative hypoxia state in tissues. It is a very common pathological process in various clinical diseases and a major cause of death related to vital organs such as brain and heart. In addition, it can result from inadequate oxygen delivery to the tissues either due to low blood supply or low oxygen content in the blood (hypoxemia). Moreover, it refers to the lack of endogenous oxygen, which is oxygen bound to cells.

Sports fatigue: sports fatigue refers to the exercise induced physiological phenomenon of a temporary decrease in the maximum muscle contraction or maximum output. And the decreased muscle performance is the basic sign and essential feature of exercise-induced fatigue. In the past 20 years, researchers have carried out the research on exercise-induced fatigue from different perspectives, and proposed that the negative effects of exercise-induced metabolic enhancement may be the fundamental reason of exercise-induced fatigue, such as the depletion of metabolic substrates, the accumulation of metabolites, acidification of the metabolic environment. The above factors may change the muscle fiber structural integrity, energy supply, neurohumoral regulation, etc. through multiple channels, thus leading to the dysfunction of motor muscle contraction and relaxation. Therefore, the decline of exercise capacity, namely, the occurrence of fatigue, is an inevitable outcome.

Central fatigue: instead of signs of physical fatigue, the muscle pain, sweating, flushing, etc. after exercise all belong to signs of brain fatigue, which is medically known as the central fatigue. Studies have shown that there are many elements that lead to central fatigue. However, the mechanism of the regulatory response that both 5-hydroxytryptamine and dopamine are involved in causing central fatigue remains unsolved.

Carbohydrates: carbohydrates are composed of three elements, that is, carbon, hydrogen and oxygen. They are the most abundant organic compounds in nature with a broad spectrum of chemical structures and biological functions. Because their ratio of hydrogen and oxygen is two to one, which is same with that ratio of the water, it is named with the carbohydrate. And they provide thermal energy to the human. Carbohydrates in food are divided into two categories: effective carbohydrates that can be absorbed and utilized by humans and indigestible carbohydrates. Carbohydrates are the main source of energy for all living organisms so as to sustain the vital movement. They not only serve as a nutrient, but also present special physiological activities.

6. LITERATURE REVIEW

Title: Research Progress on the Effect of Glucose on Central Fatigue

Effective methods in alleviating sports fatigue have been a subject of great concern in the field of sport. Since the beginning of Mosso's study of human fatigue in 1880, two parts of fatigue occurrence were brought up firstly: one is in the central nervous system, which is the central fatigue; and the other is in the periphery (i.e. spinal motor nerve, neuromuscular junction and skeletal muscle), which has been widely studied. In recent years, an increasing number of researchers have been attaching more and more attention to exercise-induced central fatigue. At present, scientists have embarked on studying the impact of nutritional intervention mechanism on central fatigue. Currently, research on nutritional intervention focuses more on the impact of supplementing carbohydrate and amino acids on central fatigue.

Carbohydrate is not only the main energy substance to maintain the athletic ability, but also the main energy of the central nervous system. If the central nervous system cannot obtain enough glucose in time, it will lead to central fatigue and central dysfunction. The amount of glycogen reserved in the body is closely related to sport performance and the occurrence of sports fatigue. A large number of studies believe that carbohydrate supplementation during exercise can delay the occurrence of central fatigue, and carbohydrate supplementation after exercise can accelerate central fatigue and the synthesis of glycogen, thus improving the sugar reserve in the body.

Carbohydrate is one of the three major energy substances in the human body, which plays a crucial role in maintaining exercise ability during exercise. Blood glucose is the main energy substance for the central nervous system. And insufficient blood glucose will cause the dysfunction of the central nervous system and central nervous system fatigue. Carbohydrate supplementation during and after exercise will leave a positive impact on central nervous system fatigue.

(1) Carbohydrate supplementation before exercise and exercise-induced central fatigue. A large number of literature agree that carbohydrate supplementation before exercise is beneficial and may delay exercise-induced central fatigue. Bequet and others trained the murine model to run on high-intensity treadmills. During the training, microdialysis was applied to observe the effect of direct injection of glucose into the hippocampus of the murine model on serotonin metabolism (5-HT, 5-HIAA (5-hydroxyindoleacetic acid), TRP). The results showed that glucose induced the decrease of 5-HT and 5-HIAA in the murine model's brains and prevented the increase of training-induced 5-HT and 5-HIAA, but the TRP in the murine model's brains did not decrease with the glucose injection. The study showed that cerebrose could affect serotonin metabolism and prevent the exercise-induced 5-HT increase; it also showed that extracellular cerebrose did not affect the synthesis pathway of 5-HT, but might affect the release and reuptake system of 5-HT, so as to delay central fatigue. Studies have shown that in cycling with intensity of 2h, 70% ~ 75% Vo2max, carbohydrate supplementation could avoid the oxidation of branched chain amino acids (BCAA), so as to weaken the increase of NH in plasma and delay central fatigue. LARS NYBO DENMARK research shows that in the long exercise, carbohydrate intake can improve endurance, maintain blood glucose concentration homeostasis and delay central nervous system fatigue. (2) The mechanism of carbohydrate supplement to delay exercise-induced central fatigue. Under normal circumstances, the oxidation of carbohydrate in blood is the only energy source of the nervous system. When the blood glucose concentration is lower than the key value of 3.6mmol/L, the brain's intake of glucose will be reduced. And the further decline of blood glucose concentration will lead to cognitive dysfunction and central fatigue. Carbohydrate supplementation can effectively maintain the concentration of blood glucose and delay central fatigue. The mechanism of exercise-induced central fatigue shows that due to the increase of TRP in blood, the TRP entering the central nervous system increases, resulting in the increase of 5-HT in the central nervous system. During exercise, carbohydrate, as an energy substance, is firstly adopted. If the blood glucose is sufficient, there are relatively few free fatty acids (FFAS) in the blood, which is unable to compete with TRP for the binding protein, so that there is less free tryptophan (f-TRP) in the blood. When the f-TRP/BCAA ratio is at a low level, the production of 5-HT in the brain is reduced accordingly, so as to delay the occurrence of central fatigue. This paper believes that during exercise, carbohydrate supplementation can maintain a certain blood glucose level and keep the blood glucose at a level above 3.6mmol/L, so as to ensure the energy supply of the body and avoid the central nervous system dysfunction caused by lack of carbohydrate and energy substances in the central nervous system. Moreover, keeping blood glucose at a certain level benefits in maintaining a relatively less free fatty acids (FFAS) in the blood so as to make them unable to compete with TRP for the binding protein. With relatively less TRP entering the central nervous system, the production of 5-HT will decrease accordingly. Hence, the occurrence of central fatigue is delayed. (3) The way of supplementing carbohydrate during exercise. At present, evidence shows that at least 200 grams of the carbohydrate should be supplemented four hours before the game (pay attention to individual differences). The traditional view on the adaptability of supplementing carbohydrate before the competition is that in some events with high intensity and dominated by anaerobic metabolism, that is, events dominated by aerobic metabolism

greater than 80% VO2, athletes should not be given special carbohydrate supplementation before the game, because improper carbohydrate supplementation may damage the athletic ability. During the game, athletes should intake 30-60 grams of carbohydrate per hour. At the same time, it is found that a large amount of carbohydrate supplementation can lead to the increase of insulin secretion in the blood, which will reduce the blood glucose concentration, and cause the advance of fatigue. In order to avoid the insulin effect’s increasingly tendency to supplement fructose-1,6-diphosphate and oligosaccharides, the American College of Sports Medicine proposes that for high-intensity exercise which is longer than 1h, carbohydrate supplementation shall be conducted at the rate of 30-60 grams per hour, that is, drinking 600-1000 ml of 4-8% carbohydrate solution per hour. The prime consideration of carbohydrate supplementation is the osmotic pressure, which shall be 250-370 mmol/l. The secondary consideration should be the carbohydrate concentration. The carbohydrate concentration should be lower than 8%, which is conducive to the absorption function of the small intestine. The number of transportable carbohydrates in the solution should also be taken into consideration. The ideal combinations of transportable carbohydrates are 23.

In conclusion, supplementing carbohydrate during exercise can delay the central fatigue, while some literature suggested that carbohydrate supplementation after exercise will cause central fatigue, which can lead to the enhancement of muscle glycogen synthesis and result in glycogen reserve increase. On the basis of previous studies, this study proposes that there is a certain theoretical basis for supplementing glucose to alleviate the degree of central fatigue in elite badminton players before the game. On this basis, this paper will further explore its mechanism.

7. RESEARCH METHODOLOGY

7.1 Literature Review

With keywords such as hypoxia, central fatigue, glucose, badminton, domestic and foreign related researches, online and offline literature from the CNKI, Libraries, Wanfang, VIP, web of science, NBIC, etc. have been gathered. Then, analysis of the status quo of related research has been conducted.

7.2 Experimental Research

7.2.1 Experiment Subjects

This study involved 12 elite male badminton athletes at the first level, who had completed the endurance training with the training frequency of at least five times a week.

Inclusion and exclusion criteria: (1) Studies have shown that there are differences in the anti-fatigue mechanism of women and men, so women are not included in this study; (2) athletes with recent endocrine disorders are excluded; (3) male athlete encountered with any athletic injury in the past 3 months are excluded.

7.2.2 Experiment Design

All athletes would take the experiment on the treadmill. The first experiment was an incremental load running test under normoxia so as to determine maximal oxygen uptake (VO2max). Subjects with qualifying VO2max values, namely, VO2max ≥ 55ml/kg, would be included in the study. All subjects are familiar with the experiment procedures, including maximal voluntary muscle contractions (MVCs) of the lower extremities and magnetic stimulation techniques in quantifying central and peripheral fatigue. Then, the second test is consisted with a 1-hour running under normoxia at 65% of VO2max. And at 15, 30 and 45 minutes of the running, the subjects intake a non-caloric sweetener (NORM-PLA) as a control group. In the third test, subjects perform a 1-hour running under hypoxia (a simulation of the 3000 plateau) at 65% of the VO2 max intensity under normoxia. At 15, 30 and 45 minutes, subjects consume a carbohydrate drink (HYP-CHO) whose sweetness matched to that of the previous placebo. Before and after the second and third tests, blood samples are taken from the vein every minute for 30 minutes. Moreover, the blood glucose, FFA, f-TRP, and BCAA are measured approximately 5 minutes after exercise to evaluate the central and peripheral fatigue. Test 1: Subjects’ resting ventilation and metabolic data for 3 minutes at rest are collected. Then, after resting for enough time, under a fixed temperature, participants ran for 3 minutes at 12.1, 12.9, 13.8, and 14.9 km/h with the slope of 0%. After the third running test, participants run at 14.9 km/h for one minute. Meanwhile, the treadmill incline increases to 2% over the next 2 minutes and continued to increase by 2% every 2 minutes until the occurrence of volitional fatigue (i.e. the participant volunteered terminate the test). The test of VO2max is performed under the gold standard. During the first test, subjects would be familiar with the MVC procedure as well as the magnetic stimulation of the femoral. When it comes to the second and third tests: subjects run on a treadmill for 1 hour at a fixed speed while breathing normoxic or hypoxic gas. Upon arrival at the laboratory, participants are weighed and the corresponding adequate hydration is confirmed by urine refractometer. If the subject arrives at the laboratory with a urine specific gravity of 1.02, then he drinks 300 ml of water. In terms of hydration assessment, participants complete their training diaries and a 24-hour diet record. Moreover, subjects must adhere to a 12-hour fasting because muscle glycogen depletion affects the occurrence of fatigue. The speed of the treadmill (average speed 13.0km/h) has been determined in accordance with relevant studies.

7.3 Mathematical Statistics

The data of this test were entered in Excel. Each group of data after processing is presented as the mean ± standard deviation. And the statistical analysis is conducted by means of descriptive statistics. Certain data are analyzed by paired-samples T test. $P<0.05$ indicates the statistically significant difference.

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