Human Performance Enhancement in Sports and Exercise: Nutritional Factors - Carbohydrate and Fluids

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Summary The property by which the human body undergoes an adaptation following subjection to a stress exceeding a particular prior normal level is referred to as "plasticity". Athletes display a tremendous degree of plasticity in response to exercise training. A critical factor that influences many aspects of the plasticity adaptation response of athletes is their nutritional practices. The intention of this article is to provide some practical guidelines concerning nutritional practices dealing with carbohydrate consumption and fluid intake. Following the research-based guidelines recommended in this article can help to optimize the exercise training and subsequent sports performance of athletes in a variety of sports.

INTRODUCTION

The human body displays a remarkable ability to accommodate when subjected to stress [2,6]. Exercise training and sports competitions are stressful events that require appropriate accommodation if adaptation and improvement in human performance are to occur[1,2,6]. Athletes spend a tremendous amount of time in training in an attempt to maximize their level of physiology adaptation. For example, it is not uncommon for top-level elite athletes to spend 10-25 hours a week in training activities. Such time commitments, however, are necessary to introduce the appropriate volume of training stimulus to overload the body's physiological systems so they can adapt and improve to an optimal level (Table 1 illustrates some of the common adaptations to an exercise training program) [1,8].

The intent of this article is to discuss theoretical and practical aspects related to the adaptation process and performance enhancement is athletes. With respect to the practical aspects, the discussion focuses upon nutritional practices that aid exercise training and sporting performance in a competitive situation. The term "athlete" is used throughout this paper, but the recommendations are applicable to not only persons involved in sports but anyone who is performing exercise training on a regular basis.

EXERCISE TRAINING ADAPTATION

The types of changes noted in Table 1 all increase the potential for the athlete (both men and women) to have improved performance capacity (*i.e.,* perform higher absolute physical workload for longer sustained periods of time, production of greater levels of muscular force, and an attenuation of the onset of muscular fatigue) [8]. These adaptations are crucial in competitive sports, and the ability to maximize such adaptive changes is what coaches and athletes are constantly striving to achieve in order to increase the likelihood of performing and competing at the highest level in sporting events.

The ability of the human body to undergo an adaptation (*i.e.,* process of change) in shape, size or characteristic when subjected to a stress exceeding a particular prior "normal" level is referred to as the property of "plasticity" [2]. The items summarized in Table 1 illustrate the human body's ability to perform a tremendous degree of plasticity in response to exercise training - this is especially true within the skeletal muscle tissue (*i.e.,* myo-plasticity). Figure 1 is a schematic illustration representative of the proposed model for the human plasticity property in skeletal muscle [2].

In exercise training, two major variables of training are critical in determining the training load-dosage for an athlete. These variables (also known as "acute training variables") are the "intensity" at which an exercise session is performed and the "volume" (*i.e.,* duration and frequency) of the exercise session(s) performed. This training load-dosage serves as the principal modulator of the degree of plasticity displayed and physiological adaptation observed (*i.e.,* phenotype; displayed characteristic) in athletes [1,2,8]. The ultimate extent to which this adaptation can be manifested is in-

Table 1. Examples of select, critical physiological changes occurring with exercise training [2]

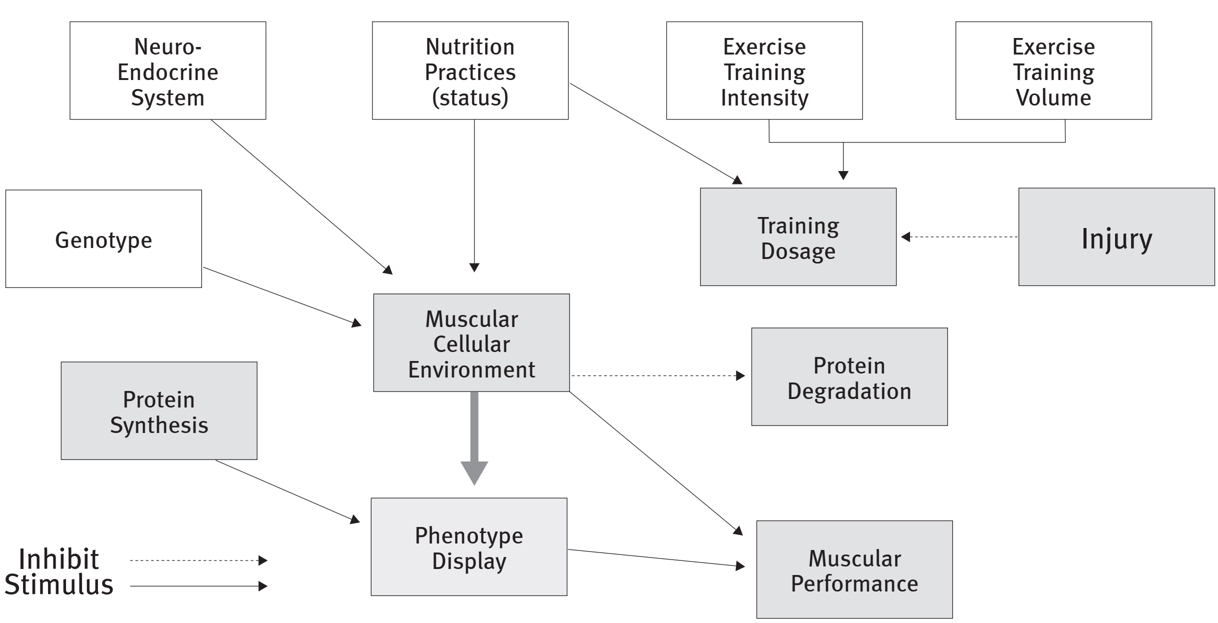
↑ Glycolytic enzyme activity within skeletal muscle
↑ Oxidative enzyme activity within skeletal muscle
↑ Mitochondria density within skeletal muscle
↑ Skeletal muscle fiber cross-sectional area
↑ Anabolic hormonal receptors number
↑ Hormonal receptor sensitivity
↑ Maximal oxygen uptake capacity
↑ Cardiac Output
↑ Stroke Volume
↑ Skeletal Muscle strength capacity
↑ Skeletal Muscle endurance capacity
↓ Depot body fat stores

↑ *denotes increase*; ↓ *denotes decrease*

turn determined by the genetic profile (*i.e,* genotype; heredity degree to which a characteristic can develop) of individual athletes [2,8]. Obviously, the manipulation of training variables and overall training load-dosage an athlete subjects themselves too is completely dependent upon the goals and level of performance they lay out and plan. A person interested in becoming more "healthy" and wanting to improve their physical fitness level will subject themselves to a much lower training load-dosage than a person wanting to improve their "sporting competitive" performances [1]. Each of these different intentions for exercise training places a varying degree of stress upon the human body and thus the degree of stimulus to the plasticity and the subsequent adaptation response varies enormously[1]. Exercise training to improve sporting competitive performance produces the greatest degree of adaptive responsive in the human physiological systems, but to maximize these adaptations is a complicated process requiring the athlete-coach-trainer work as a team and be in constant dialogue about the physiological and psychological state of the athlete. Most certainly there is a need for scientific and logic based actions and steps in the process, but there is also room for intuitive and instinctive adjustments in the training approach and development. For this reason, some people propose that the training of an athlete for sport is in many respects more "an art than it is a science".

In addition to the development components of training such as "intensity" and "volume", there are other

Figure 1. The figure is a schematic representation of the plasticity model of adaptation and the impact of critical components, which influence the human body, and are essential to the performance of exercise (modified from reference 2).



important factors that can impact upon sporting performance. In particular a critical factor that influences many aspects of plasticity adaptation is the nutritional practices (*i.e.*, status) of the athlete (see Figure 1) [2,7]. There are numerous research studies showing that the selection of macro-nutrient amount and variety can significantly improve or hinder select types of exercise performances and sporting activities [4,7]. The major intents of this article is to provide some key, but uncomplicated, nutritional practices a coach or athlete can do to enhance exercise training capacity and sporting performance.

DIETARY CARBOHYDRATE INTAKE

Exercise capacity and intensity are directly influenced by the levels of blood glucose and glycogen stores (*i.e.,* carbohydrate) available within the body. The depletion of either glucose or glycogen can compromise muscle function and lead to fatigue, especially in exercise of a prolonged duration [2,5]. Additionally, there are many tissues which rely on glucose as a major energy source whether a person is exercising or in a resting basal state. Regrettably, the human body has very limited storage capacity for carbohydrate. This limited capacity necessitates that we consume large amount of carbohydrate on a daily basis in order to meet the physiological needs of the body, this is especially true if exercise training is part of the daily routine.

The recommended amount of carbohydrate for an athlete or a person involved with regular exercise to consume on a daily basis is equivalent to 60% or greater of their caloric intake [3,4,7]. For example, if a person consumed 3000 kcal of food daily then 1800 kcal of that should be carbohydrate (there are ~4 kcal per gram of carbohydrate, thus 1800 kcal equals consumption of 450 grams of carbohydrate daily). Knowing total daily caloric intake typically requires a dietary assessment by a trained professional such as a dietician. This is not always practical or available to the athlete. Therefore, as an easier alternative to achieve adequate intake is to recommended athletes attempt to consume a set amount of carbohydrate based upon their body mass. Table 2 lists to the specific grams per kilogram of body weight values proposed for men and women who exercise [2,3,7].

Table 2. The recommendation for amount of daily carbohydrate (CHO) intake as based upon body mass in kilograms [2,3,4,6]
Males - 7 to 10 g/kg body mass/day
Females - 5 to 8 g/kg body mass/day
Example: Male athlete, 70 kg body mass 70 kg x 7 g/kg body mass/day = 490 g CHO per day 70 kg x 10 g/kg body mass/day = 700 g CHO per day

The type of carbohydrate recommended for consumption is the complex polysaccharide variety [4,7]. Examples of foods which contain such carbohydrates would include, but not limited to, the following: breads, cornmeal, whole-grain cereals, whole grains, crackers, corn, lentils, potatoes, rice, and pasta. Such foods are readily accessible to most individuals and easily incorporated into daily diets without to much difficulty. The challenger however is to achieve enough carbohydrate on a daily basis. The may require that the athlete not only eat three regular meals daily, but incorporate consumption of small snacks during the day.

In addition to focusing on just the total daily carbohydrate content of the diet, athletes should also be mindful of special considerations with their carbohydrate consumptions immediately after competing a training session or competition. Specifically in the first four hours after ending exercise it is critical for the athlete to start the muscle glycogen repletion process. Therefore, it is recommended that the athlete consume between 1.0-1.2 grams of carbohydrate per kilogram body mass each hour for the first four into recovery [3,4,7]. This can be simple mono-, disaccharide forms of carbohydrate or it can be complex. Then throughout the remainder of the day until then next exercise session, they can complete their target goal for total daily consumption. Because fluid replenishment (see next topic of discussion) is critical for athletes, it may be advisable to use sports drinks (*e.g.,* Gatorade) as a means for getting some of the carbohydrates ingested in the first four hours after exercise.

A final important consideration with carbohydrate concerns eating before exercise or a sporting competition. Eating a meal high in carbohydrate to close to the time before an exercise session can result in starting the exercise in a hyperinsulinemic state [5]. Starting exercise in this state can increase the risk of developing an exercise-induced hypoglycemia (*i.e.,* low blood sugar levels) which is associated with an early onset of fatigue during exercise. For this reason it is advisable to consume any pre-exercise meal or snack 1-3 hours before the exercise (exactly how long before depends upon individuals preference and exact meal composition). Athletes should experiment on themselves and find what length of time works best for them, what the size of the meal should be and what composition it should contain. Although relative to composition, it should consist primarily of carbohydrate and only small amounts of protein of fat.

DAILY FLUID INGESTION

Approximately 60% of the human body is comprised of water. This water is divided into the intra-cellular and extra-cellular components, which can each be divided into sub-compartment. A sub-compartment of the extra-cellular component is the plasma water of the blood which gives the blood its fluidity. Humans gain and lose water throughout the day. The rates of gain or lose are affected by behavior, environment, and physical activity level [2]. In athletes a principle means for daily water loss is through the sweating mechanism. Sweating is a required process for allowing evaporative cool which prevents the core temperature of the body from becoming dangerous elevated. It is not uncommon for athletes to sweat at a rate of 1.0 to 2.0 liters per hour during exercise. In hot and humid environmental conditions, these sweat rates can be doubled. Sweat water loss can result in the total water content of the body to be reduced, resulting in a condition called "dehydration". Typically humans can tolerate approximately a 2% fluctuation in water content without severe, adverse detrimental affects on exercise capacity or performance. However, once water loss starts to become great that 2% (*i.e.*, a water loss equal to –2% loss of body mass) significance physiologic changes start to occur [2,4,7]. Table 3 presents a summary of critical physiological changes that various levels of dehydration can produce. It is important to note that the effects of dehydration also impact on mental function as well as physiology. This means the dehydrated athlete could not only have compromised muscular function but make poor judgments and actions during the course of their sporting competitions.

There are several simple but effective steps that athletes can take to prevent the complications of dehydration. In normal temperate weather conditions an athlete should consume 400-600 ml of fluid before exercise. If possible this should be at least 2 hours before the exercise. If the weather is hot and, or humid an additional 250-500 ml beyond that just noted should be consumed. It is also advisable to have the athlete consume water during exercise. Ideally fluid intake should match or exceed sweat rate. However the athlete is unlikely to know their sweat rate. Therefore, it is recommended that between 500 and 3000 ml of fluid be consumed per hour of exercise. This should be consumed in small portions of fluid every 15-20 minutes throughout the exercise [2,3,4,7].

The fluids need after exercise can be approximated by examining the body mass lost during an exercise session. By simply checking body mass before and after an exercise session and assuming the entire mass loss is water, you have an idea of how much fluid needs to be consumed to reach normal hydration levels (*e.g.*, in actuality some of the mass loss is from energy stores [carbohydrate and fat] metabolized to produce energy, however this is relatively small an only accounts for a few grams of the total mass loss). To insure that an adequate amount of fluid is consumed it is recommended that what ever the mass lost actually is, the fluid consumption should be approximately 150% of that amount [4].

The type of fluid to consume is an important consideration. Plain water is most certainly an excellent choice

Table 3. Influence of different levels of dehydration on the physiology of the human body [2,4,6]

Percent (%) of body mass loss	Signs and symptoms occurred at dehydration level
1%	Thirst threshold, and threshold for possible impaired exercise thermoregulation leading to slight decrement in muscular work capacity
2%	Stronger thirst, vague discomfort and sense of oppression, loss of appetite
3%	Dry mouth, increased viscosity of blood, reduction in urine output
4%	Potential decrement of 20-30% in muscular work capacity
5%	Difficulty in mental concentration, headache, impatience, sleepiness
6 %	Severe impairment in exercise thermo-regulation, increased respiratory rate, possible numbness in extremities
7%	Likely to collapse if combined with exercise in a hot and, or humid environment

and highly recommended [6]. It has an excellent gastric emptying rate which allows it to move into the blood stream rapidly. However, athletes have individual preferences for fluids they like to drink, which influences whether they will drink and how much they will drink. Sports drinks such as "Gatorade" are formulated to have small amounts of carbohydrate, electrolytes and water (some newer varieties of such drinks also have small amounts of protein or even caffeine within them). Thus, they are a good source of fluid as well as aiding in restoring carbohydrate stores within the body. These sports drinks also come in a variety of flavors which may make them more palatable for athletes to drink and result in more fluid being consumed. It is not advisable, however, for athletes to use fluids with high levels of osmolality (a factor that slow gastric emptying) such as soda-pop, colas, 100% fruit juices, or alcohol beverages as fluid replacement drink [2,4,7]. Also, caffeine containing beverages (coffee, tea, colas... etc.) should be minimized within the fluid replacement regime because of their potential diuretic capability which could result in increased urinary water loss [4].

CONCLUSIONS

The human body can undergo adaptation in shape, size or characteristics when subjected to a stress exceeding a particular prior normal level - such adaptation is referred to as the property of "plasticity". There is a tremendous degree of plasticity in response to exercise training such as that an athlete performs. There are many factors that affect the degree of the human plasticity response. One such factor that is highly critical is the nutritional practices of an athlete. Daily carbohydrate and fluid consumption are nutritional practices that the athlete should monitor and can easily manipulate to improve exercise performance in training and sporting competition. Following the guidelines outline in this article should aid the athlete to more optimally maximize their plasticity response and subsequent sporting performance.

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