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PHYSIOLOGICAL AND MEDICAL STRATEGIES IN POST-COMPETITION RECOVERY–PRACTICAL IMPLICATIONS BASED ON SCIENTIFIC EVIDENCE

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Abstract Recovery from exercise is an important factor in the performance. During competition, where athletes may compete numerous times over a few days, enhancing recovery may provide a competitive strategy. Nutrition significantly influences sports recovery; however, the efficacy of any nutritional supplement should be carefully considered in relation to the event on the one hand, and the sex, training and nutritional status of the athletes on the other. In addition to the replenishment of muscle glycogen, there are other major objectives of post-competition recovery that have been examined in scientific literature and applied in the field. These include restoration of body fluid balance, improved performance (or training stimulus) in subsequent exercise tasks, increased protein synthesis, attenuated protein degradation, and attenuated muscle damage/muscle soreness. However, each new recovery strategy should be practised in training before it is used in competition.

Key words: fatigue, exercise-induced muscle injury, protein, sleep, probiotics

INTRODUCTION

Recovery (R) from exercise is an important factor in performance (Pe). During competition (C), where athletes may compete numerous times over a few days, enhancing R may provide a competitive strategy. Athletes spend a much greater proportion of their time in R than they do in training. Yet, much more attention has been given to training and/or C, with very little scientific evidence of R.

Thus, the objective of this article is to review the research into this area of training and scientific findings, which are to be incorporated into the coach's own thought processes with practical implications. R is essential to optimal Pe and its improvement, which often involves a protein synthesis. In order to maximize R, it is important to maintain the muscular pool and blood levels of various amino acids that are substrates for the synthesis of muscle proteins (P), and to know which different methods to apply in practice, during and especially after C.

The R process can be categorized in two terms:

A. Intra-sessions R, when coaches, medical doctors and scientists apply immediate R between exertions and/or short-term R between repeats, e.g., between resistance sets or interval bouts, and intra-C.

B. Inter-training sessions R (R between workouts and between C), commonly known as post-C R or post-training R.

Nutrition significantly influences sports R. However, the efficacy of any nutritional supplement should be carefully considered in relation to the event itself and the sex, training and nutritional status of the athletes.

On the other hand, causes of fatigue (F), the mechanism of action, safety and legality of the supplement, together with the scientific evidence from studies with an appropriate experimental design, should all be taken into account before being incorporated into the R diet.

In addition to the replenishment of muscle glycogen, there are other major objectives of post-C R that have been examined in the scientific literature applicable in the field. These include restoration of body fluid balance, improved Pe (or training stimulus) in subsequent exercise tasks, increased P synthesis, attenuated P degradation, and attenuated muscle damage/muscle soreness. Whereas nutritional manipulations have customarily been focused on preventing P degradation, muscle damage, and oxidative stress, recent evidence suggests that these processes may be critical for the optimal adaptive response to training and R from intense training [5], and more recently there has been information about immunologic (I) R [19]. Consequently, each nutritional strategy should be tested in training before it is used during a competition.

TYPES OF FATIGUE AND FATIGUE MECHANISMS

F could be classified into two types, Central F and Peripheral F, while the main F mechanisms are [1, 3, 7, 8, 18, 27, 29, 30, 31, 32, 34]:

1. Substrate depletion: Glycogen, ATP-PCr;
2. Metabolites accumulation: Hydrogen ions, Lactate, Inorganic Phosphate, NH4;
3. Temperature elevation;
4. Exercise-induced muscle damage;
5. Hydro-electrolyte alterations (water, Na, K, etc.);
6. Branched chain amino acids changes;
7. Free radicals;
8. Exercise-induced muscle damage prevention; and
9. Immunity maintenance.

SUBSTRATE DEPLETION

Glycogen

Consumption of macronutrients, particularly carbohydrate (CHO) and possibly a small amount of P and leucine [15] in the early R phase after endurance competition can enhance muscle glycogen resynthesis rates.

Scientific Evidence

A target of at least 1.2 g•kg body weight-1•h-1 CHO (over several hours) is suggested. Recent findings challenge the dogma that athletes always benefit from attempts to enhance muscle glycogen synthesis following endurance training. The "train low, compete high" concept of muscle glycogen has been put forward since multiple markers (resting glycogen, oxidative enzymes) suggesting improved training adaptation were observed when muscle glycogen was kept below normal during training sessions in untrained subjects; however, this has not yet been verified in trained subjects. When training is performed with low glycogen stores, more “performance" genes are activated. Two targets of this transcriptional activation are the GLUT4 and PGC-1 genes [2]. GLUT4 catalyses the rate-limiting step in glucose uptake and glycogen synthesis, the transport of glucose into the muscle cell, while PGC-1 coordinates the nuclear and mitochondrial genes needed for mitochondrial biogenesis. One result of this is an increase in the capacity to take up and either oxidize or store glucose, the main fuel used during maximal Pe, and the other is an increased capacity to generate ATP from fat and spare glycogen during lower intensity exercise [1].

PRACTICAL IMPLICATIONS

This rate of CHO intake could be sustained with liquid, gel, or solid food rich in CHO to maximize muscle glycogen. Advantages of added P and leucine with CHO also lie in the increase in P resynthesis, and probably in reducing muscle damage from intense exercise. To summarize, in order to replenish glycogen after C, CHO, proteins and leucine should be ingested as soon as possible. Timing, muscle glycogen levels, dosage, the glycemic index and caloric content are the most important factors. Whether small increases in muscle glycogen resynthesis can be sustained after 4 h and into the next day also remain to be verified. Using milk-based products or other P-containing beverages or foods are other options which athletes could consider during R from training or C.

Future Investigations

An examination into signalling mechanisms within muscles should be conducted in parallel with translational evidence in humans [2].

ATP - PCr

Creatine (Cr) is one of the most popular dietary supplements on the market worldwide. Athletes from many different sports have been known to supplement Cr. The Cr that is normally present in human muscle may come from two potential sources, dietary (animal flesh), and/or internal.

Scientific Evidence

A study published in 1992 demonstrated approximately 20% increase in total Cr stores in subjects fed 20 g of Cr per day for several days [11]. This increase appeared to be the upper limit and it remained such even over a course of a few days, while a progressively increasing percentage of supplemented Cr ended up in urine [11]. The ingestion of large amounts of Cr for 4-6 days increased skeletal muscle Cr and phosphocreatine contents, accompanied by improved soccer-specific skill performance compared with ingestion of placebo [24]; it also improved R during high intensity exercise repetitions, while low-dose supplementation with Cr monohydrate did not produce laboratory abnormalities for the majority of health parameters [26].

Practical Implications

Scientific knowledge suggests that Cr supplementation can improve short-term exercise R and Pe, especially in sports with repeated short-term sprints. It may also augment the accretion of skeletal muscle when taken in combination with a resistance-exercise training program and R during resistance training.

Other Substrates

Medium-chain triglycerides (MCTs) are fats with an unusual chemical structure that allows the body to digest them easily. Most fats are broken down in the intestine and remade into a special form that can be transported in the blood. But MCTs are absorbed intact and taken to the liver, where they are used directly for energy. In this sense, they are processed very similarly to CHO. Branched-chain amino acids (BCAA) include leucine, isoleucine as well as valine.

Scientific Evidence

The findings from studies investigating the effects of ingesting MCTs and BCAAs, either on their own or in combination with CHO, on endurance Pe and R have been equivocal and therefore would not be recommended [21].

Practical Implications

There is not enough scientific evidence to accompany applied R strategies with these amino acids after C.

Future Investigations

There is a need for future investigations in this field.

Metabolites Accumulation

Hydrogen ions (Buffering capacity), Lactate, Inorganic phosphate, NH4

Carnosine and anserine have high muscle buffering capacity. Supplementations of those dipeptides and/or the precursor beta-alanine could increase the muscle buffering capacity.

Scientific Evidence

Recent studies [12] have shown that supplementation with beta-alanine would increase the amount of intramuscular carnosine and muscle buffering capacity. Many studies have reported Pe increases in laboratory-based cycling tests and simulated running races in the field following sodium bicarbonate ingestion where the need for ATP from substrate phosphorylation is high. However, other studies have reported no benefit while the incidence of negative side effects is high. Besides, its effect on R is not clear.

PRACTICAL IMPLICATIONS

The ingestion of sodium bicarbonate before intense exercise decreases the blood [H^+] to potentially assist the efflux of H^+ from the muscle and temper the metabolic acidosis associated with intense exercise.

FUTURE INVESTIGATIONS

Very little is known about the physiological or nutritional treatment to recover from the increases in inorganic phosphate and/or NH4. The supplementation with beta-alanine and its effect on R is not clear.

TEMPERATURE ELEVATION

Scientific Evidence

Hyperthermia, an increase in core temperature (Tcore) above 38°C induced by intense exercise, causes central fatigue [23], such as demonstrated in a recent study in triathletes during a 226 km Ironman triathlon, where Tcore was 38.1±0.3 degrees [16]. Moreover, time to exhaustion in cyclists with fever is reduced [10] and alter prefontal cerebral area activity [23].

In addition, marked elevations in Tcore (2-3°C) and skin blood flow (4-fold) resulted in significant reductions in cardiac output due to a substantial decline in SV, yet whole body O_2 was unaltered.

PRACTICAL IMPLICATIONS

Recently Wilkinson et al. [35] reported that a gastrointestinal temperature pill ingested immediately prior to physical activity can be used to measure Tcore accurately in all individuals for 30/60 min after ingestion of cool fluids during the following 8 h period.

Any strategy to decrease Tcore, including proper hydration and the use of cooling jackets, would be of importance for R in temperature-induced F.

FUTURE INVESTIGATIONS

Thus it is possible that endurance performance during competition is affected by hyperthermia. Further studies in endurance athletes are required to prove these suggestions.

EXERCISE-INDUCED MUSCLE DAMAGE

Presently more attention should be paid to exercise-induced muscle damage and resynthesis processes that repair muscle and connective tissue. Mainly the collagen and muscle protein synthesis after exercise, must be considered.

Scientific Evidence

Recovery modalities have largely been studied with regard to their ability to reduce the severity and duration of exercise-induced muscle injury and delayed onset muscle soreness (DOMS). Neither of these reflects the circumstances of between-training session R in elite athletes. The majority of studies examining exercise-induced muscle injury and DOMS have used untrained subjects undertaking large amounts of unfamiliar eccentric exercise. This model is unlikely to closely reflect the circumstances of elite athletes.

PRACTICAL IMPLICATIONS

Modalities reviewed were nutrition, massage, active R, cryotherapy, contrast temperature water immersion therapy, hyperbaric oxygen therapy, nonsteroidal anti-inflammatory drugs, compression garments, stretching, electromyostimulation and combination modalities.

Future Investigations

Intense exercise can cause release of muscular P and muscle damage, due to inflammatory reactions induced by phagocyte infiltration that is triggered mechanical stress, oxidative stress? Increase in intracellular Ca?, there is no scientific evidence yet about this question.

NUTRITION

Nutrient intake before, during, and after C or training will influence the adaptations that occur in response to the exercise stimulus. The influence of P on these adaptations is receiving increasing attention from researchers.

Scientific Evidence

Evidence suggests that adaptations to training are due to changes in the types and activities of various P in response to each exercise bout. Thus, study of acute metabolic and molecular responses to exercise plus nutrition may provide valuable information about the expected influence on training adaptations. The type of P, timing of P ingestion relative to exercise, concurrent ingestion of other nutrients with P, as well as the type of exercise training performed will impact the adaptations to training with the intake of P. Traditionally, endurance athletes have focused on CHO intake, but recently P has been touted to be critical during and after endurance exercise. Whereas nutritional manipulations have customarily been focused on preventing protein degradation, muscle damage, and oxidative stress, recent evidence suggests that these processes may be critical for the optimal adaptive response to training and recovery from intense training [5].

Future Investigations

Recent evidence suggests that these processes may be critical for the optimal adaptive response to training and R from intense training [5].

PROTEIN SYNTHESIS

Very often the R process involves a P synthesis. In order to maximize R, it is important to maintain the muscular pool and blood levels of various amino acids that are substrates for the synthesis of muscle P.

Scientific Evidence

Not only the amount of P intake, but also the *timing* of intake is important for building muscles efficiently [14]. Eating a meal immediately after resistance exercise may contribute to a greater increase in muscle mass compared with ingesting a meal several hours later. Also, intake of CHO with P can accelerate the synthesis of muscle P via the actions of insulin, which increases P synthesis and inhibits its catabolism. In addition, it has been reported that the intake of amino acids and peptides is beneficial. Free amino acids and peptides do not need to be digested, so rapid absorption can be expected. Amino acids are not only utilized for the synthesis of muscle P, but some of these molecules also exert a variety of physiological effects.

Glutamine has also been reported to promote muscle growth by inhibiting P degradation. It is the most abundant free amino acid in muscle tissue and its intake leads to an increase in myocyte volume, resulting in stimulation of muscle growth. Glutamine is also found at relatively high concentrations in many other human tissues and has an important homeostatic role. Therefore, during catabolic states such as exercise, glutamine is released from skeletal muscle into the plasma to be utilized for the maintenance of glutamine levels in other tissues.

Arginine is a precursor of nitric oxide and Cr, and its injection promotes the secretion of growth hormone, which may lead to an increase in muscle mass and strength. Although the effect of oral arginine on P synthesis is equivocal, recent studies have indicated that combined intake of arginine with other compounds improves exercise R.

Various other food components have also been studied to determine their effects on muscle strength and mass. A meta-analysis of the studies done between 1967 and 2001 supported the use of two supplements, Cr and β-hydroxy-β-methylbutyrate (βHMB), to augment lean body mass and strength when performing resistance exercise. βHMB is a metabolite of the BCAA leucine, and it increases muscle bulk by inhibiting the degradation of P via an influence on the metabolism of BCAA.

PRACTICAL IMPLICATIONS

It has been reported that intake of 1.5 to 3.0 g/day of βHMB for 3 to 8 weeks achieved a greater increase in muscle mass and power compared with the intake of placebo.

HYDROTHERAPY

One method that is gaining popularity as a means to enhance post-game or post-training R is immersion in cold water. Much of the literature on the ability of water immersion as a means to improve athletic R appears to be based on anecdotal information, with limited research on actual Pe change.

Scientific Evidence

Water immersion may cause physiological changes within the body that could improve R from exercise. These physiological changes include intracellular-intravascular fluid shifts, reduction of muscle oedema and increased cardiac output (without increasing energy expenditure), which increases blood flow and possible nutrient and waste transportation through the body. Also, there may be a psychological benefit to athletes with a reduction or cessation of fatigue during immersion. Water temperature alters the physiological response to immersion and cool to temperatures may provide the best range for recovery. Ingram et al. [13] demonstrated that cold-water immersion following exhaustive simulated team sports exercise offers greater recovery benefits than hot water immersion or control treatments.

Future Investigations

In future it is necessary to study the responses to contrast bath or cool water immersion in different races.

IMMUNITY MAINTENCE

Intense exercise causes a temporary depression of various aspects of immune function (IF) (e.g., neutrophil respiratory burst, lymphocyte proliferation, monocyte TLR, and major histocompatibility complex class II P expression) that lasts 3–24 h after exercise, depending on the intensity and duration of the exercise bout.

Scientific Evidence

Postcompetition IF depression is most pronounced when the exercise is continuous, prolonged (>1.5 h), of moderate to high intensity (55–75% maximum O_2 uptake), and performed without food intake. Periods of intensified training or C (overreaching) lasting 1 wk or more can result in prolonged immune dysfunction. Although elite athletes are not clinically immune deficient, it is possible that the combined effects of small changes in several IF may compromise resistance to common minor illnesses such as URTI. Protracted immune depression linked with prolonged training may determine susceptibility to infection, particularly at times of major C. This is obviously a concern because of the potential impact of an infectious episode on exercise Pe.

Recent studies from Bente Pedersen's group in Copenhagen [25] indicate that the release of IL-6 from contracting muscle can be attenuated by long-term antioxidant supplementation. High levels of circulating IL-6 stimulate cortisol release, and this study provides some strong evidence that the mechanism of action of the antioxidant supplementation was via a reduction in IL-6 release from the muscle fibers of the exercising legs. Attenuating the IL-6 and cortisol response would be expected to limit the exercise-induced depression of IF, and this may be the mechanism that could explain the reported lower incidence of URTI symptoms in ultramarathon runners supplemented with vitamin C (alone or in combination with other antioxidants) compared with placebo.

Consumption of CHO during exercise also attenuates increases in plasma IL-6, catecholamines, ACTH, and cortisol. CHO intake during exercise also attenuates the trafficking of most leukocyte and lymphocyte subsets, including the rise in the neutrophil-to-lymphocyte ratio, prevents the exercise-induced fall in neutrophil function, and reduces the extent of the diminution of mitogen-stimulated T-lymphocyte proliferation following prolonged exercise.

Pedersen's group, however, have argued that the reduction in the IL-6 response to exercise may be a double-edged sword, as IL-6 has several metabolic effects and shared mechanisms exist regarding IF and training adaptation. Attenuating the IL-6 response to exercise will also inhibit lipolysis, reduce the anti-inflammatory effects of exercise, and attenuate the expression of a number of metabolic genes in the exercised muscle. In other words, it is possible that antioxidant supplementation and/or CHO ingestion (train low, compete high) during exercise sessions could limit adaptation to training. However, it can also be argued that CHO intake during training allows the athlete to work harder and longer, and as yet there has been no evidence that physiological and P adaptations are impaired by CHO intake during training sessions. Further research is needed to determine how nutrient intake might affect the transcriptional regulation of metabolic genes in skeletal muscle and what, if any, consequences this has for training adaptation or even long-term health benefits. The concern for athletes is that, although these nutritional interventions may reduce their risk of infection, another effect may be to limit their hard-earned adaptation to training.

Dietary deficiencies of P and specific micronutrients have long been associated with immune dysfunction. An adequate intake of iron, zinc and vitamins A, E, B6 and B12 is particularly important for the maintenance of IF, but excess intakes of some micronutrients can also impair IF and have other adverse effects on health. IF depression has also been associated with an excess intake of fat. Convincing evidence that so-called 'immune-boosting' supplements, including high doses of antioxidant vitamins, glutamine, zinc, probiotics and echinacea, prevent exercise-induced immune impairment is currently lacking [9].

Future Investigations

Further research is needed to evaluate the effects of other antioxidants and dietary immunostimulants such as probiotics (Pr) and echinacea on exercise-induced immune impairment [4].

PROBIOTICS (PR)

Pr are dietary supplements and live microorganisms containing potentially beneficial bacteria or yeasts. Pr bacteria are defined as live food ingredients that are beneficial to the health of the host. Pr occur naturally in fermented food products such as yogurt, kefir, sauerkraut, cabbage kimchee, and soybean-based miso and natto. Numerous health benefits have been attributed to Pr, including effects on IF.

Scientific Evidence

Recently [22], the use of Pr foods have been recommended for sports R and maintenance of I. Pr bacteria are defined as live food ingredients that are beneficial to the health of the host. A systematic review of the medical literature failed to identify any studies that directly investigated the potential ergogenic effects of Pr on athletic Pe. Two published articles suggest that Pr may enhance the IF of fatigued athletes.

PRACTICAL IMPLICATIONS

In summary, although scientific evidence for an ergogenic effect of Pr is lacking, Pr may provide athletes with secondary health benefits that could positively affect athletic Pe through enhanced R from F, improved immune function, and maintenance of healthy gastrointestinal tract function.

HOMOCYSTEINE

Homocysteine (Ho) is an amino acid in the blood [17]. Plasma Ho levels are strongly influenced by diet, as well as by genetic factors. The dietary components with the greatest effects are folic acid and vitamins B6 and B12. Folic acid and other B vitamins help break down Ho in the body.

Scientific Evidence

Epidemiological studies have shown that too much Ho in the blood (plasma) is related to a higher risk of coronary heart disease, stroke and peripheral vascular disease.

Several studies have found that higher blood levels of B vitamins are related, at least partly, to lower concentrations of Ho. Other recent evidence shows that low blood levels of folic acid are linked with a higher risk of fatal coronary heart disease and stroke.

Ho could be elevated after intense repeated exercise (competitions). Elevated plasma Ho is associated with an increased risk of myocardial infarction, stroke, and venous thromboembolism.

PRACTICAL IMPLICATIONS

Folic acid and B12 vitamin lower plasma Ho levels.

Future Investigations

Ho-lowering therapy could probably be justified in certain athletes after C [17].

EICOSAPETAENOIC ACID

Eicosapentaenoic acid (EPA or also icosapentaenoic acid) is an *omega-3 fatty acid*. In physiological literature, it is given the name of 20:5(n-3), but it is also known as timnodonic acid. In its chemical structure, EPA is a *carboxylic acid* with a 20-*carbon* chain and five *cis* double bonds, the first of which is located at the third carbon from the omega end.

Scientific Evidence

Loss of lean tissue mass is a common finding after several intense C. The mediators responsible for these changes are thought to be proinflammatory cytokines, the neuroendocrine system, and certain tumour specific factors such as proteolysis inducing factor (PIF). Cytokines increases have been described after very intense exercise [28].

EPA has been shown to have anticachectic effects. The effects of EPA have been related to inhibition of PIF induced upregulation of key regulatory components of the ubiquitin-proteasome proteolytic pathway.

PRACTICAL IMPLICATIONS

These benefits may be related to the effect of EPA on PIF but might also be related to downregulation of proinflammatory cytokine production. Whatever the mechanism, to recover the lean tissue lost in the intense exercise catabolic process [6].

SLEEP

Sleep (S) is a *natural* state of *bodily rest* observed throughout the *animal kingdom*. In humans, other mammals, and a substantial majority of other animals which have been studied, sleep is essential for survival.

Scientific Evidence

Ensuring that athletes achieve an appropriate quality and/or quantity of S may have significant implications for Pe and R and reduce the risk of developing overreaching or overtraining. Indeed, S is often anecdotally suggested to be the single best R strategy available to elite athletes.

PRACTICAL IMPLICATIONS

A number of nutritional factors have been suggested to improve S, including valerian, melatonin, tryptophan, a high glycaemic index diet before bedtime, and maintenance of a balanced and healthy diet. Conversely, consumption of alcohol and caffeine and hyper-hydration may disturb S. Strategies such as warming the skin, hydrotherapy, and adoption of appropriate S hygiene (maintenance of good S habits and routines) are other tools to aid in S promotion. Ensuring athletes gain an appropriate quality and quantity of S may be important for optimal athletic Pe.

CONCLUSIONS AND PRACTICAL APPLICATION

- For proper recovery from sport fatigue it is absolutely necessary to know.
- The type of fatigue and, if possible, the mechanisms that are producing that fatigue. In other words we have to know the type of fatigue that we need to recover from.
- The exercise-induced muscle injury and resynthesis processes to repair muscle and connective tissue after intense exercise and competition.
- The timing of using the recovery treatments; the individual response to recovery treatments (the different targets of this transcriptional gene activation); the activation of genes depending on type of nutrition and training; and the maintenance of immunity.
- Nutrient intake after competition will influence the adaptations that occur in response to the exercise stimulus.
- The influence of protein on these adaptations is receiving increasing attention from researchers.
- Evidence suggests that adaptations to training are due to changes in the types and activities of various proteins in response to each exercise bout.
- Study of the acute metabolic and molecular responses to exercise plus nutrition may provide valuable information about the expected influence on training adaptations.
- The type of food, timing of ingestion relative to exercise, concurrent ingestion of other nutrients, as well as the type of exercise performed will impact the adaptations.
- Ensuring athletes achieve an appropriate quality and/or quantity of sleep may have significant implications for performance and recovery and reduce the risk of developing overreaching or overtraining.
- Other nutritional aids as creatine, alanine, eicosapentaenoic acid, probiotic foods, could be of benefit for post-competition recovery.

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