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Boxing Practitioners Physiology Review: 3. Dietary Supplementation, Weight Control, Recovery and Altitude

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Abstract

The preceding parts of the review concerned kinanthropometric parameters, skeletal muscle recruitment, ergometry, systemic responses and adaptations. Main teachings of this third part of the whole review follow. At the 1996 Atlanta Olympic Game, most vitamin users (91 percent) were boxers. After 18 days of endurance training at the altitude of 1800 m, in boxers, 1) erythropoietin and reticulocytes values increased, 2) remained unchanged parameters of iron metabolism and maximal oxygen uptake values, 3) iron supplementation decreased total body hemoglobin values. Zinc supplementation and/or regularity while boxing influenced plasma levels of calcium, copper, iron, magnesium, phosphorus and zinc in boxers. Sodium bicarbonate ingestion increased punches frequency and time to fatigue in boxers. Boxing-induced thermal dehydration yielded 1) body and muscle masses decrease compensated by increased neural input to muscle, to maintain muscle strength, but 2) a 26.8 percent performance fall. In boxers, fluid and food intake restriction 1) changed neither blood vitamin status nor plasma glutathione levels, 2) yielded a) a negative mood profile and a performance decrease, when resulted in body mass fall by 5.16 percent but b) no performance decrease when fall was by three percent. Diet protein or protein and caloric components decrease increased, in boxers, protein catabolism and, for the same submaximal workload, heart rate and oxygen intake. In food-restricted boxers, myoprotein catabolism increased with decreasing meal intake frequency. Competition and no-competition boxers utilize massage. Massage increased perceptions of recovery after a whole boxing performance. High level of cardiorespiratory fitness accelerates recovery process between boxing rounds.

Keywords

Boxing, Integrative Physiology, Martial Arts, Molecular Physiology,

Musculoskeletal Physiology

1. Introduction

Writing the present review has been prompted by what wrote Thomas Reilly and Niels Secher in a late page of the edited book titled "Physiology of Sports", expressing the hope that the form of analysis they used in the book was going to help the specialists whose sports had not been examined. Boxing is among those sports. The contributors to the book have been acknowledged near the end of the present review.

Contrary to other forms of boxing (Thai boxing, American boxing or French boxing), boxing concerned in the present review is a combat physical activity in which both practitioners opposed by each other use exclusively their fists for hitting and/or landing light touches to the opponent while avoiding the latter's fists reach their own anterior and lateral surfaces of the head, the neck and the trunk, above an imaginary plane passing through the top of both iliac crests and parallel to the ring.

Boxing practitioners' physiology is a biological science that deals with reciprocal influences of boxing practice and boxing practitioners' bodily functions.

The review concerned here deals with physiology of boxing practitioners. The present article is the third of the whole review. The first part of the review has dealt with kinanthropometric parameters, skeletal muscle recruitment and ergometry [1]. The second part has dealt with boxing practice-derived systemic responses and adaptations [2]. Insofar as boxing practice is concerned, the present and third part is related to dietary supplementation, weight control, recovery and altitude.

This third part of the review is going to deal with reciprocal influences of boxing practice on the one hand, and on the other hand with dietary supplementation, weight control, recovery and altitude, in as far as the concerned information is available. It ends by advices that permit boxing practitioners to benefit from the analysis of available information, which is expected to contribute to an effective practice of boxing.

As shown in **Table 1**, when available and pertinent, the concerned information has previously been obtained by entering the keywords "boxing" and "physiology" in Google and Medline search engines as well as consulting other sources of information: books, journal papers…

2. Dietary Supplementation, Weight Control, Recovery and Altitude

2.1. Dietary Supplementation

Dietary supplementation may be seen in the fact that something has been added to the kind of food someone eats each day, in order to increase the food acceptability, to improve the diet or to make the diet complete [3].

Table 1. Literature Selection

Keywords "Boxing" and "Physiology", or Concepts Related to Those Keywords	
|	|
Google and Medline search engines	Printed documents (books, journal papers, …)
↓	↓
Journal papers abstracts and/or full-texts contents	Printed documents contents
|	|
Pertinence analysis	Pertinence analysis
↓	↓
Pertinent or not pertinent	Pertinent or not pertinent
↓	↓
Literature selection or rejection, respectively	Literature selection or rejection, respectively

2.1.1. Vitamins Supplementation

Vitamins are organic substances 1) needed by the human organism in very small quantities, 2) that the organism is unable to synthesize or that it synthesizes in insufficient quantities, 3) that the organism is thus obliged to find for the most part in the diet, and 4) which deficiency is likely to be harmful to health.

Most vitamins act as coenzymes, or parts of coenzymes, which permits them to ensure the organism growth and to keep the organism healthy [4].

Vitamins are supplements when they are added to the diet in the aim of increasing the suitability of the sportsperson for the objective this latter is striving to achieve.

At the 1996 Atlanta and 2000 Sydney Olympic Games, Canada athlete participants were interviewed by Canadian physicians [5]. The interviews gave, among other results, 1) that vitamins were taken by 59% of men and 66% of women in Atlanta, and 65% of men and 58% of women in Sydney; 2) that mineral supplements were used by 16% of men and 45% of women in Atlanta, and 30% of men and 21% of women in Sydney; 3) that the most popular vitamins were multivitamins in both Olympics; 4) that the most popular mineral supplements were iron supplements; and 5) that among all sports, the highest prevalence of vitamin use occurred in boxing (91% of the practitioners) in Atlanta.

What may be the reliability of those vitamin supplementations?

While performance capacity impairment may result from vitamin deficiency [6], 1) boxers sometimes subject themselves to stringent dietary regimens, often combined with dehydration in an attempt to lose weight, with the resulting risk of poor vitamin status [6]; 2) exercise has been said to increase the need for the B-complex vitamins in athletes [6]; 3) doubling daily intake of A, C and E vitamins as well as that of selenium has been proposed for high-level sportspersons by the "Apports Nutritionnels Conseillés pour la population française" [Nutritional Supplies Recommended to French people] [7]; and 4) some vitamins (cobalamin and folate) are needed for erythrocytes production and protein synthesis, whereas other vitamins (thiamin, riboflavin, pyridoxine, niacin, pantothenic acid and biotin) are involved in energy production [6].

Although increasing exercise intensity parallels free radicals production [7] which may cause tissue lesions [7], antioxidant vitamins (A, beta carotene, C and E) protect the organism against formation and propagation of free radicals [7].

Nonetheless, additional vitamins intake neither improve performance [6] nor is imperative [7] as long as sportsperson diet does not show the concerned vitamins deficiencies.

2.1.2. Iron Supplementation

Iron (Fe) is a biologically important trace element, a transition metal of atomic number 26, of relative atomic mass 55.85, present in hemoglobin, in myoglobin and in the cytochromes [8]. That permits iron to be absolutely essential for the transport of oxygen to the tissues [9]. That also permits iron to take part in electron transport during oxidative phosphorylation [4] [9], without which, life would cease within a few seconds [9]. Weakness may be observed as a result of iron deficiency [4].

During 18 days of endurance training at the moderate altitude of 1800 m, well-trained non-iron-depleted athletes members of the German national boxing team have been treated either with placebo or with ferrous-glycine-sulfate (1335 mg equivalent to 200 mg elementary iron) daily [10]. The concerned study gave, among other results, what follows: 1) only in the iron-treated group, total body hemoglobin values decreased; 2) in both iron- and placebo-treated groups, a) in the venous blood, parameters of iron metabolism values remained unchanged while erythropoietin values as well as reticulocytes values increased; and b) maximal oxygen uptake ($\dot{V}O_2$ max) values remained unchanged. Please see **Table 2**.

Comparing the results obtained from iron-treated group subjects with results obtained from placebo-treated group subjects, it may be observed that what could be expected occurred in both groups when have been concerned 1) the increase in erythropoietin levels, 2) the increase in reticulocytes values, 3) no increase in total body hemoglobin values and 4) unchanged maximal oxygen consumption values. Please see discussion in **2.4. Altitude**.

Table 2. Physiological variables in endurance-trained at moderate altitude and iron-supplemented but non-iron-depleted boxers.

Moderate altitude (1800 m)	Iron-treated group	Placebo group
Total body hemoglobin	decreased	unchanged
Venous blood		
* erythropoietin	increased	increased
* reticulocytes	increased	increased
* parameters of iron metabolism	unchanged	unchanged
Maximal oxygen uptake during incremental treadmill test	unchanged	unchanged

a. Iron supplementation have influenced only total body hemoglobin. b. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

However, an unexpected decrease in total body hemoglobin values was noticed only in iron-treated subjects, opposite to the placebo-treated group. That is surprising when one takes into account the fact that, iron being a constituent of hemoglobin [11], iron supplementation makes expect an increase in hemoglobin formation. But that is not surprising when one takes account of the following: 1) the concerned boxers were non-iron-depleted [10] and 2) any excess of iron taken orally is not absorbed but eliminated with the stools [12].

Thus, possibly, assuming that iron has been taken orally, in the non-iron-depleted but iron-treated boxers, total body hemoglobin decrease could have resulted from an overactive elimination of iron with the stools.

In the stools, the authors of the study here commented have searched for occult hemoglobin but not for iron. They also failed to search for possible iron losses through sweating. Such kind of losses is possible in athletes [11].

2.1.3. Zinc Supplementation

Zinc (Zn) is a biologically important trace element, a transition metal of atomic number 30, and of relative atomic mass 65.39 [8].

Zinc is involved in reproduction, digestion, wound healing and metabolism as it is essential part of more than 100 enzymes [11]. Among the concerned enzymes, there are alcohol dehydrogenase, carboxypeptidase and carbonic anhydrase [13]. Another enzyme is lactic dehydrogenase that makes zinc important for the inter-conversions between pyruvic acid and lactic acid [9]. In the peripheral capillary blood, carbonic anhydrase present in the red blood cells is responsible for rapid combination of carbon dioxide with water while in the pulmonary capillary blood, carbonic anhydrase present in the red blood cells is responsible for rapid release of carbon dioxide from the pulmonary capillary blood into the alveoli [9].

Regularity while boxing training, oral zinc supplementation as well as combination of both things may influence plasma levels of calcium, copper, iron, magnesium, phosphorus and zinc in pubescent amateur boxers [14], as shown in **Table 3**.

What may justify zinc supplementation and what may underlie the resulting effects?

In boxers, zinc supplementation could be justified as lower zinc intakes could be expected in them. In fact, whereas zinc, iron, magnesium and calcium intakes in athletes increase with higher energy intakes [6], boxers are among the athletes who at times subject themselves to stringent dietary regimens, often combined with dehydration, in an endeavor to lose weight and thus to obtain a lower weight classification, being hence at considerable risk of marginal nutrition and consequently of poor vitamin mineral status [6].

Out of preparation for any competition and thus out of the aforementioned stringent dietary regimens, a decrease in some minerals has been shown by boxers, simultaneously with an increase in other minerals (please see **Table 3**). However, the influence of zinc supplementation on levels of zinc already present

Table 3. Influence of zinc supplementation on plasma levels of calcium, copper, iron, magnesium, phosphorus and zinc in pubescent amateur boxers.

Element present in the plasma	After a one hour boxing training program	After 4 weeks of only regular boxing training	After 4 weeks of regular boxing training with 50 mg oral zinc pills supplementation
Calcium	↓	↑	↑
Copper	↓		↓
Iron			↑
Magnesium			↓
Phosphorus	↑		↑
Zinc	↓	↓	

a. Regularity while boxing training, oral zinc supplementation as well as combination of both things have influenced plasma levels of calcium, copper, iron, magnesium, phosphorus and zinc. b. "↓" means "decreases". c. "↑" means "increases". d. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

in the plasma has not been signaled, making impossible to assess the concerned influence.

The results obtained from the study here commented make expect what mentioned below concerning the increases and decreases in the levels of the minerals concerned in the boxers plasma.

When calcium has been concerned, the response to one hour boxing training has been the decrease in boxers plasma levels while the adaptation to 4 weeks of only regular boxing training has been the increase in the plasma levels, as if the adaptation occurred to prevent 1) low levels of calcium-caused spontaneous discharge of nerve fibers, resulting in tetany [9], as well as 2) a slower growth and a possible bone resorption [4]. Oral zinc supplementation combined with 4 weeks of regular boxing training did not affect the results from 4 weeks of only regular boxing training. Alone, 4 weeks of only regular boxing training seems to be sufficient to have inverted the calcium levels decrease one hour of boxing training-caused.

When zinc has been concerned, 4 weeks of only regular boxing training caused a decrease in zinc plasma values, as has been the case with only one hour of boxing training: adaptation did not occur. The decrease is not surprising as it has been signaled an increase in zinc elimination after intense or prolonged exercises as well as during regular training periods [15]. In the case that the decrease yields zinc deficiency, the result may be ulcers and hypo-gonadal dwarfism [16], may be depressed immune responses [4] [16] may also be slower growth, a scaly skin, disorders of fertility as well as loss of taste and smell [4].

Moreover, zinc deficiency may possibly affect negatively boxing performance and fatigue delay, being zinc component of lactic dehydrogenase and carbonic anhydrase, respectively.

Component of lactic dehydrogenase, zinc contributes to the reciprocal conversions between pyruvic acid and lactic acid [9]; what may contribute to ATP regeneration via anaerobic glycolysis towards total energy expenditure. During boxing performance, that expenditure depends by a 70% on anaerobic processes [17].

Component of carbonic anhydrase, zinc contributes to rapid combination of carbon dioxide with water in the red blood cells of the peripheral capillary blood and for rapid release of carbon dioxide from the pulmonary capillary blood into the alveoli [9]. That may help counteract fatiguing action of acidity carbon dioxide-produced: 1) expiration of carbon dioxide keeps the blood hydrogen ion (H^+) concentration low [6] and 2) acidosis [higher than normal hydrogen ion (H^+) concentration] may impair the contraction process at several levels and may contribute both to central and peripheral fatigue [18].

When copper has been concerned, the response to one hour boxing training has been the decrease in boxers' plasma levels, decrease that has not been influenced by oral zinc supplementation combined with 4 weeks of regular boxing training. As the trend of boxer plasma levels of copper after 4 weeks of only regular boxing training has not been signaled, it is impossible to assess the effect of oral zinc supplementation combined with the aforesaid regular training. That is also the case for phosphorus levels in the boxer plasma levels where there have occurred increases after both one hour training and 4 weeks regular training combined with oral zinc supplementation.

The decreased values of copper in the boxers plasma levels may have as a contributing factor the signaled increase in copper elimination after intense or prolonged exercises as well as during regular training periods [15]. When copper deficiency happens, one may expect the occurrence of anemia and bone modifications [4] [16] as well as cardiovascular modifications [4]. As for extreme excess of phosphorus, it causes not any known problem [4].

The paper here commented displays an increase in iron and a decrease in magnesium plasma levels only for 4 weeks of regular boxing training combined with oral zinc supplementation. However, no values have been signaled concerning only 4 weeks of regular training or one hour boxing training. It is hence impossible to assess the influence of zinc supplementation on both kinds of training when iron and magnesium have been concerned.

Iron is essential to the working of the heme, the hemoglobin part with which oxygen binds [4]. Nonetheless, extreme excess of iron may cause liver lesion and hemochromatosis [4]. As for magnesium, low concentration has been signaled to cause increased irritability of the nervous system, peripheral vasodilation and cardiac arrhythmias [9]. Magnesium deficiency has also been said responsible for tremors, muscular weakness, hypertension and sudden death cardiac arrest-caused [4].

2.1.4. Sodium Bicarbonate Supplementation

Also called sodium hydrogenocarbonate, sodium bicarbonate is a chemical compound of formula $NaHCO_3$, of molar mass 84.0066 $g{\cdot}mol^{-1}$ [19]; a salt that breaks down in water to form a sodium cation (Na^+) and a bicarbonate anion (HCO_3^-), making the aqueous solution alkaline, and thus able to neutralize acid [20]. The alkalizing agent sodium bicarbonate 1) counteracts low pH and 2) may be naturally formed in the human organism, as it may be found in baking soda [21].

A strong positive relationship links the ability to regulate hydrogen ions (H^+) [muscle buffering capacity (MBC)] with exercise performance (repeated sprint ability, high-intensity exercise capacity…) [21]. In fact, high intensity anaerobic exercise performance may be adversely affected by the reduction of pH within the concerned skeletal muscle, reduction coupled with a large accumulation of hydrogen ions (H^+) within the muscle [21].

Sodium bicarbonate supplementation regulates intramuscular pH by creating a pH difference between the inside and the outside of muscle cells, what causes an accelerated movement of H^+ out of the contracting muscle, pH difference being due to sodium bicarbonate action of increasing the blood pH [22]: in particular during maximal workouts lasting from one to 7 minutes, ingestion of sodium bicarbonate could tend to increase physical performance, work output, an effect that could be attributable to increased efflux of lactate and H^+ from the intracellular compartment of the working muscle to the extracellular fluid [6]. Acidosis is hence among the factors that reduce endurance [18]. Acidosis also reduces the power of ATP generation [18].

Acidosis may impair the contraction process at several levels and may contribute both to central and peripheral fatigue [18]. On the one hand, while increases in the products of ATP hydrolysis (ADP, Pi and H^+) negatively influence contractile parameters and therefore are likely involved in the fatigue process during high-intensity exercise [18], it has been shown that when power or capacity of the ATP generating processes is improved there is a delayed onset of fatigue [18].

On another hand, lactate generated within a skeletal muscle cell may be used as a source of energy after being 1) funneled into the citric acid cycle in the cell where it was produced, 2) imported by and metabolized in a neighboring cell or 3) transported by the bloodstream to some distant cell and a) metabolized or b) turned into glucose by the process called gluconeogenesis [22]. In each of the three cases, lactate transporters permit lactate enters the concerned cells [22].

All above mentioned about hydrogen ions (H^+) and lactate may explain what follows.

A significant increase in the number of punches performed has been signaled in a study that included 10 amateur boxers who ingested 0.3 $g \cdot kg^{-1}$ body weight of sodium bicarbonate 90 minutes before 4 three-minute boxing rounds interspersed with one-minute rest [23] [24].

A significant increase in time to fatigue has been signaled in another study that enrolled 7 elite male professional boxers [24] [25] who performed two pairs of exertions. The first pair was made from a boxing specific high intensity interval running protocol followed by a first high-intensity run to volitional exhaustion. The second pair comprised a second high-intensity run to volitional exhaustion followed after a 75-minute rest by a boxing specific punch combination protocol. Sodium bicarbonate ingestion (0.3 $g \cdot kg^{-1}$ body weight) took place 65 minutes after the first high-intensity run to volitional exhaustion.

Most of sodium bicarbonate performance-improving effect was due to a range of its physiological effects but a portion of the ergogenic effect still seems to be placebo-driven [24].

2.2. Body Weight Control

Weight is how heavy something is when it is measured [3]. Weight control refers here to the means set about for a sportsperson not to get too heavy when the person is weighed.

Practicing a weight category sport, boxers generally attempt to gain a competitive advantage by showing the lowest weight possible of the category to which they belong [26].

2.2.1. Exercise-Induced Thermal Dehydration

Dehydration refers here to the fact of making the body lose water [3].

At a certain level of exercise intensity, faster metabolism in contracting muscles generates heat, what may produce dehydration due to compensatory sweating initiated to help dissipate some of the heat load [27]. That may support why dehydration has been expressed as a percentage of body weight loss [27] [28].

A recent study using one professional male boxer as his own control made the boxer to participate in two matches as welterweight and as super welterweight, successively [29]. The authors of the study found that neural input to the muscle increased to compensate for body weight and muscle mass decreases and to maintain muscle strength during rapid weight loss, while neuromuscular characteristics were not markedly changed when no significant weight loss occurred. Where rapid weight loss took place in the study, it was accompanied by total body water decrease, what made the authors of the study think that weight loss may have represented an acute decrease in body water.

What may support those findings?

Sixty% and 50% of body mass consist of water, respectively in a male and a female, both aged 25 years and showing 70 kg total body mass [27], what makes body mass decrease possible with dehydration increase.

Evaporation of sweat is the chief method of excess heat dissipation during exercise [27], what makes possible exercise-induced thermal dehydration.

Progressive dehydration impairs work capacity [6]: an individual tolerates heavy physical exercise less well if subjected to a water deficit, even if the water loss is only about 1% of the body weight [6].

The muscle mass and the ability of the central nervous system to recruit it mainly determine the potential for developing strength [6]. That may explain 1) why old age-related loss of skeletal muscle mass decreases strength [6] and 2) why old age-related total muscle mass reduction is concomitant of muscle strength decline [6].

One could thus expect from the study here commented a decrease in muscle strength due to muscle mass and body weight decreases. But that was not the case: muscle strength was maintained despite muscle mass and body weight decreases [29]. Possible explanations may be, for instance, 1) as presented by the authors of the study, an increase in neural input to the muscle so as to compensate for muscle mass and body weight decreases, and/or 2) that the here concerned dehydration was not a sufficient stimulus for the attainment of the threshold from which a decrease in muscle strength is noticeable. In fact, both total body water and skeletal muscle mass decreased by ~1% - 2% [29].

Carried out by other research workers, a former study displayed the following results.

Seven novice amateur boxers completed three three-minute rounds of simulated boxing on a prototype boxing ergometer in an euhydrated state and after exercise-induced thermal dehydration [30].

Comparing the values recorded in euhydrated state with the values recorded in dehydration state, it appears that rapid body mass loss produced what follows: 1) a body mass loss by a 3.8 (SD ± 0.3) % [77.3 (SD ± 11.3) to 74.4 (SD ± 10.7) kg, $p < 0.001$], 2) inconsistent and not statistically significant ($p > 0.05$) plasma volume changes, 3) no blood lactate difference, 4) no heart rate difference, and 5) boxing performance mean value fall by a 26.8% [30].

What may underlie those results?

Body mass loss due to exercise-induced thermal dehydration has been possible and may be explained by heat dissipation which occurs mainly through sweet evaporation during exercise [27]. For evaporative heat loss, through sweating, body water and some of the blood volume are sacrificed [27]. A decrease in plasma volume may thus be expected. But here, where dehydration-caused body mass fall has been 3.8%, the authors found no significant change in the plasma volume of the boxers enrolled in the concerned study. That is consistent with what has been signaled by Borer [27]: in the range of 3.6% to 6.4% of total body water, plasma volume expressed as percentage of total body water loss does not change, staying at the value of 10%.

Blood lactate displayed no difference when comparison has been held between euhydrated state values and dehydrated state values. That is not surprising 1) as no plasma volume change has been found [30] and 2) if the lactate threshold has not been attained, in the concerned subjects. Another possibility is that exercise-induced significant increase in blood lactate values has been counteracted by the clearance of lactate from the bloodstream to the liver for the sake of gluconeogenesis [31].

Boxing task-related heart rate did not differ between euhydrated state values and dehydrated state values. Boxer organisms may have considered the dehydrated state not to be an overtaxing one when compared with the euhydrated state. A dehydration-caused heart rate increase could have occurred if the boxing task was more overtaxing in the dehydrated state than in the euhydrated state. In fact, heart rate has been found to increase with increasing submaximal workload [6]. That may have been the case in the here concerned situation where the boxers only simulated boxing.

The subjects concerned with the study here commented have shown a decrease in boxing performance, contrary to their counterparts concerned with the study just above commented. Here, body mass loss has reached 3.8% [30] while there, the decrease has been by ~1% - 2% [29]. All that suggests that exercise-induced thermal dehydration must reach a threshold before causing decrease in boxing performance.

2.2.2. Fluid and Food Intake Restriction

Here, fluid and food intake restriction refers to the fact of allowing oneself to consume only part of what must be drunk and what must be eaten [3].

1) *Vitamin Status and Plasma Glutathione Levels*

Food record checklists and blood samples have been obtained from elite male boxers, 7 of whom used as control group of the 10 who had to practice rapid weight loss during a pre-competition week that separated a weight maintenance week from a post-competition week [32]. From the results obtained, it has been concluded that in elite male boxers, regardless of participating in rapid weight loss or not, a) the diet was low-caloric and low-carbohydrate, b) intakes of vitamins A, E and folate were below recommended values throughout the three weeks and, however, c) blood vitamin status, as well as plasma glutathione levels did not change significantly [32].

It is not surprising that blood vitamin status did not change significantly despite intakes of vitamins A, E and folate below recommended values throughout three weeks. In fact, although vitamin deficiency impairs performance capacity, it takes a long time to develop such deficiency in an individual living on a deficient diet: an individual can be without any vitamin intake for a week or so without any detectable detrimental effect on work capacity [6]. The explanation may be that vitamins are stored to a slight extent in all cells and stored to a major extent in the liver [9]. That makes possible that a) the quantity of vitamin A stored in the liver may be sufficient to maintain a person for 5 to 10 months without any intake of vitamin A [9] and b) only rare instances of proved vitamin E deficiency have occurred in human beings [9].

Plasma glutathione levels have been said not to have changed significantly. But was that surprising? Additional information is needed in order to reply to that question.

In fact, while a) plasmatic glutathione levels have been declared to increase in the sportsperson aerobic-(exercise) trained [7] and b) in the human, everything is going as if training increases the ability to resist increased free radicals production (oxygen consumption increase) but without dramatically affect the activity of antioxidant enzymes [7], c) boxing training is not a pure aerobic exercise activity: it is an intermittent high-intensity activity, the training for which comprises aerobic as well as anaerobic exercise and, [17] whose total energy expenditure relies on both anaerobic processes and aerobic processes, by a 70% and by a 30%, respectively.

2) *Performance and Mood Profile at* 5.16% *Lower Body Weight*

Rapid weight loss may be accompanied by poor performance and a negative mood profile before the concerned boxers compete at their championship weight [9]. That is the conclusion that has been drawn from a study that enrolled 16 experienced amateur boxers whose average body weight reduction [5.16% (SD = 1.06%)] has been achieved through fluid and food intake restriction during one week, the week leading to competition.

On three different occasions with one week between two successive occasions, the boxers have been subjected to a test consisting of a circuit training task rather than a competitive boxing task such as shadow boxing, punching bag work or sparring: during 4 two-minute interspersed with one-minute recovery, the boxers performed a "burpee" (a press-up followed by standing up) and press-up being carried out continuously [9].

During the last of the three occasions, the boxers showed their championship weight. Then, apart from the poor performance, rapid weight loss was also accompanied by a negative mood profile that expressed itself in increased anger, fatigue and tension, as well as in reduced vigor [9].

What may be the possible causes?

Decrease in performance may result from both fluid intake restriction and food intake restriction.

In fact, as progressive dehydration impairs work capacity [6] and assuming that fluid intake restriction has resulted in dehydration, one may expect the contribution of fluid intake restriction to the performance decrease.

Furthermore, it has been noticed in ordinary people that precipitous deterioration of cellular functions occurs when, for energy, the amino acids of the blood are rapidly deaminated and oxidized due to the fact that after several weeks of starvation, the quantities of stored carbohydrates and fats have begun to run out [9]. Please note that regardless of participating in rapid weight loss or not, boxers have a low-caloric and low-carbohydrate diet [32]. All that may possibly explain performance decrease due to food intake restriction.

As for it, the negative mood profile that has accompanied the poor performance is not surprising in those subjects who have shown a rapid weight loss, assuming that their organisms have interpreted as unusual intense exercise the circuit training task to which they have been subjected. As a matter of fact, when carried out to excess, intense exercise can augment anxiety and produce changes in the hypothalamo-pituitary-adrenal function similar to those seen in depression, although many forms of low-intensity exercise can improve psychological mood [27].

Exercise, like psychological stresses that can elicit anxiety, fear or anger, can induce secretion of thyroid-stimulating hormone, growth hormone, prolactin, epinephrine and cortisol [27].

Cortisol secretion, a) which is directly proportional to exercise intensity [27], b) improves the mood (euphoria), but c) at high concentrations, can cause depression [27].

On the one hand, findings a) support the hypothesis that energy deficiency is a critical factor in fatigue, and b) show that when the power or capacity of the ATP generating processes is improved, there is a delayed onset of fatigue [18]. On the other hand, particularly with caloric restriction, people cannot lose substantial amounts of body mass without losing marked amounts of lean body mass [11]. But in the study here concerned [9], the food intake-restricted boxers showed a 5.16% average body weight reduction while an increased working muscle mass a) is an advantage during high-intensity exercise, since both the power and the capacity of anaerobic processes increase, and b) increases the amount of energy that can be produced by aerobic and anaerobic energy production processes [18]. That could contribute to the explanation of the poor performance and fatigue experienced by those boxers.

Fatigue, weakness, dizziness and decreased concentration have been noted in athletes who have attempted to lose too much weight [11]. High work intensity in combination with short rest duration have, as for them, been said to result in increasing nervous tension and mounting emotional stress [6].

3) *Performance at* 3% *Lower Body Weight*

Energy and fluid restriction before boxing competition do not always lead to a significant decrease in performance. That is the conclusion to which came a research team that imposed energy and fluid intake restriction to 8 amateur boxers acting as their own controls before subjecting the boxers on each of two different days to three three-minute rounds of simulated boxing interspersed with one-minute recovery [33].

By comparison with the values shown during normal, the values shown during restricted diet trials were a) lower ($p < 0.05$) energy and fluid intake, b) 3% lower ($p < 0.05$) body mass each trial day, c) 3.2% lower one day and 4.6% lower the other trial day but both punching force decreases not significant, d) not significantly different end-of-bout heart rate, e) not significantly different 4 minutes post-performance blood glucose concentrations, and f) lower ($p < 0.05$) 4 minutes post-performance blood lactate concentrations [33]. Please see **Table 4**.

How a 5.16% body mass fall due to fluid and food intake restriction may have resulted in performance decrease has been discussed in the just above displayed commentary of the study by Hall and Lane [34].

In the study here concerned, the enrolled boxers showed the lower body mass fall of 3%. No performance decrease has been noticed in the boxers punching forces when they simulated boxing. The maintenance of performance when the body mass fall has been lower (3% versus 5.16%) suggests the existence of a threshold from which performance begins to decrease.

Table 4. Comparison between values shown during restricted with values shown during normal diet trials by amateur boxers.

Variables	Restricted compared with normal diet values
Energy and fluid intakes	lower ($p < 0.05$)
Body mass shown during each of the two days of boxing performance	lower (decrease by 3%, $p < 0.05$)
Punching force during the two days of boxing performance	lower (decreases by 3.2% and 4,6%; both not significant)
End-of-bout heart rate	not significantly different
Four minutes post-performance blood glucose concentrations	not significantly different
Four minutes post-performance blood lactate concentrations	lower ($p < 0.05$)

a. Punching force did not decrease significantly at 3% lower body weight. b. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

Furthermore, here, the boxers have been subjected to a less unusual task (simulated boxing bouts) rather than to a more unusual task (the concerned circuit training task). One of the results has been no significant change in the end-of-bout heart rate. That is consistent with what has been found by others: in stressful situations, the inexperienced subjects show heart rate values higher than those shown by experienced subjects [6].

What just above mentioned concerns the comparison that has been held between boxers who have shown different body mass fall percentages. Now, in the boxers here concerned, if comparison is held between the situation of not being with the situation of being subjected to fluid and food intake restrictions, no difference in end-of-bout heart rate may mean that intake restrictions have not overtaxed the concerned boxers.

What could explain the absence of difference in 4 minutes post-performance blood glucose concentrations, when have been compared with each other the values of both situations?

It has been argued that when exercise is sufficiently intense to produce fatigue within 5 minutes, maintaining blood glucose concentration is important to delay muscle exhaustion [6].

As for the absence of difference in 4 minutes post-performance lactate concentrations when comparison has been held between each of both situations, the cause may be that during the simulated boxing bouts as well as during recovery, the situation of fluid and food intake restrictions has made, more than normal diet situation, the concerned boxers rely on blood lactate utilization.

In fact, during high-intensity exercise in an energy-depleted state caused by a prolonged fast, a) plasma lactate is elevated [27], what may favors gluconeogenesis and b) rise in plasma glucose is possible only by gluconeogenesis [27].

However, after exercise, restoring glycogen stores in muscle is given precedence [35].

During the first hour of recovery from high-intensity exercise, in a previously exercised muscle, glycogen synthesis occurs, benefiting from muscle glucose uptake made possible by hepatic glucose output contributed by both glycogenolysis (60%) and gluconeogenesis (40%) [27]. Hepatic glucose output as well as gluconeogenesis are greater than during intense exercise [27].

Thus, no significant difference of the values concerned with 4 minutes post-performance blood glucose and 4 minutes post-performance blood lactate concentrations may reflect both a) hepatic glucose output to blood which is increased during the first hour of recovery from high-intensity exercise, output that helps complete glucose missing in the blood, but for the final sake of muscle glycogen synthesis, and b) muscle gluconeogenesis that helps decrease excessive blood lactate produced by high-intensity exercise in the situation of fluid and food intake restriction.

2.2.3. Various Protein Diets

Protein diet is the proportion of proteins in the food eaten. The dietary proteins are chemically long chains of amino acids bound together by peptides linkages [9].

During weight reduction period, there may exist a threshold from which decreasing the diet protein component or diet protein and caloric components is accompanied in the concerned boxers 1) by protein catabolism increase as well as, 2) for the same submaximal work load, by increases in heart rate and oxygen intake. That is suggested by the results of a study which purpose was to provide information on the requirement of nutrition [36].

In fact, as shown in **Table 5**, both high protein and ordinary protein diets have been able to prevent the aforementioned consequences resulting from lower protein and energy intakes at the end of 9 days of a weight reduction period. It is worth signaling that high and ordinary protein diets were imposed to the boxers

Table 5. Protein metabolism and physical performance resulting from various protein diets during weight reduction.

Groups	Calorie intake (kcal·day^{-1})		Protein intake (g·kg^{-1}·day^{-1})		Nitrogen balance	Both HR and ($\dot{V}O_2$)
	Weight reduction period					
	First half	Second half	First half	Second half	End	End
Low protein diet		883		0.9	negative	increased
Ordinary protein diet	2000	1200	1	1	unchanged	unchanged
High protein diet	2000	1200	2	1.5	unchanged	unchanged

a. Low calorie and low protein intakes have made the nitrogen balance negative and both heart rate and oxygen intake increased. b. "HR" means "heart rate". c. "$\dot{V}O_2$" means "oxygen intake". d. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

while what resulted to be the lowest protein and caloric diet was the outcome of a free diet, boxers having taken food ad libitum.

In the study here commented [36], weight reduction period has comprised two halves. Protein intake value in the free diet group has not been recorded during the first half of the period, contrary to during the second half. However, in the high protein diet and in the ordinary protein diet groups, protein intake values have been recorded during each of the halves of the period.

Every individual, performing exercise or not, aged 19 years and older, is required to have in the diet 0.8 g protein·kg^{-1}·day^{-1} [37]. Each of the subjects enrolled in the concerned study has hence eaten protein more than what required, whichever the half of the weight reduction period. However, in the free diet group, 1) protein consumption has shown the least value and 2) heart rate and oxygen intake at the submaximal workload have increased significantly while no noticeable changes have been observed in the other diet groups [36].

Lowest protein and energy intakes in the free diet group may have made more overtaxing the same submaximal workload for the concerned subjects when comparison has been held with the subjects of the other diet groups.

In fact, comparing ergometry modes during submaximal work, Eston and Brodie [38] concluded that at each of different outputs (49, 73.5 and 98 W), 1) heart rate as well as oxygen intake values have been significantly ($p < 0.01$) higher in arm ergometry than in leg ergometry, and significantly ($p < 0.01$) higher in arm ergometry than in combined arm and leg ergometry and 2) gross mechanical efficiency has been significantly ($p < 0.01$) lower in arm ergometry than in leg ergometry and significantly ($p < 0.01$) lower in arm ergometry than in combined arm and leg ergometry: an inverse linear correlation seems to exist between on the one hand gross mechanical efficiency and, on the other hand, heart rate as well as oxygen intake values.

What above mentioned suggest the existence, in the concerned subjects of the study here commented [36], of a possible inverse linear correlation between protein and/or calorie intakes on the one hand, and in the other hand, heart rate as well as oxygen intake values: decreasing calorie and/or protein intake could parallel increasing heart rate and oxygen intake values.

In the study just aforementioned, at the end of the weight reduction period, nitrogen balance had changed to a negative value only in the lowest protein and calorie intakes group [36]. That means that it was only in that group where occurred daily decrease in body stores of protein, daily intake of protein being less than daily breakdown of protein [9].

At the end of the period, in the urine of the lowest protein and energy intakes group, it has been found significant increases in 3-methylhitidine and in the ratio of 3-methylhistidine to creatinine. That is consistent with the reported evidence that 1) the urinary excretion of 3-methylhistidine may be used as an index of skeletal muscle breakdown in human subjects and that 2) the fractional turnover of muscle protein may be reflected in the excretion ratio of 3-methylhistidine to creatinine as 3) creatinine excretion rate allows to estimate the total body pool of skeletal muscle [39]. In the high protein and ordinary protein diet groups, no nitrogen balance negative value seems to have resulted from a lesser protein breakdown, when compared with protein breakdown in the lowest protein and energy intakes group. In the two former groups, lesser protein breakdown may have been reflected in the increased urine 3-methylhistidine and ratio of 3-methylhistidine to creatinine.

As for it, increased urine urea nitrogen in the lowest protein and energy intake group is in contradiction with what has been observed by Pérez *et al.* [40] in a study aimed to assess the usefulness of urine urea nitrogen measurement as a marker of protein restriction: 1) 24 h urea nitrogen excretion significantly decreased after 14 days with a protein-restricted diet (0.6 $g \cdot kg^{-1} \cdot day^{-1}$ versus, for the control subjects, 1 $g \cdot kg^{-1} \cdot day^{-1}$) in participants with normal kidney function, and 2) a reduction in 24 h urea nitrogen excretion, corrected to creatinine, indicated that there was a high probability that a reduction in protein intake really occurred. However, attention must be drawn to the following: in the study here concerned [36], protein-restricted subjects were also energy-restricted while in protein-restricted subjects enrolled in the study carried out by Pérez *et al.* [40], missing protein calories have been substituted by carbohydrates to provide the same amount of calories and micronutrients in both groups.

2.2.4. Meal Frequency

Meal frequency is the number of times food is eaten within a particular period of time [3].

The effect of meal frequency has been studied on 12 boxers who have been imposed food restriction by ingesting 1200 $kcal \cdot day^{-1}$ for two weeks [41]. Some of the boxers ate 6 meals a day while others ate only two meals a day. As shown in **Table 6**, the results suggest that when the same diet energy consumption takes place, lower frequency meal intake leads to a greater myoprotein catabolism.

What may support the findings?

Frequency of meals has been recognized as one of the factors that may affect work performance [6].

Here [41], the same energy-restricted diet has been imposed to boxers and has yielded no significantly different change of boxers body weight, whichever the

Table 6. Effects of meal frequency on myoprotein catabolism

Variables	Two $meals \cdot day^{-1}$ compared with 6 $meals \cdot day^{-1}$ group values
Change of body weight	no difference
Decrease in lean body mass	higher
Decrease in urinar 3-methylhistidine/creatinine	lower

a. The lower the meal intake frequency, the higher the decrease in lean body mass. b. References of the data mentioned in the table above are found in the present review text, where commentaries have been carried out.

frequency of meals. However, the decrease in lean body mass has differed according to meal intake frequency: the former has been greater where the latter has been lower. That is witnessed by the lower decrease in the urinary ratio of 3-methylhistidine to creatinine.

In fact, 1) 3-methylhistidine to creatinine ratio may be used as an index of the fractional breakdown rate of myofibrillar protein, provided that creatinine excretion is constant [42], and 2) provided that 3-methylhistidine is derived predominantly from actin and myosin in muscle sites, measurement of 3-methylhistidine in the urine enables to estimate the contribution of increased muscle catabolism to the negative nitrogen balance [42].

Actin and myosin (myofibrillar protein) breakdown resulting in lean body mass decrease may possibly cause a decrease in work performance.

2.3. Recovery

Recovery, 1) during a sporting session, refers to the period of time that separates two moments of activity, two exercises or two situations during the sporting session, while 2) after a sporting session it is aimed at initial potentials restoration [43].

1) *Cardiorespiratory Fitness*

A review on amateur boxer physical and physiological attributes signaled that both to accelerate recovery process between rounds and to help support the overall metabolic demands of a boxing match, athletes of both sexes require a high level of cardiorespiratory fitness [44].

After high-intensity exercise, recovery oxygen, also called oxygen debt or excess post-exercise oxygen consumption (EPOC), is the oxygen uptake above resting values used to restore the body to the pre-exercise condition [45]. For that consumption, respiratory system drives inspired air oxygen into the alveoli. From there, cardiovascular system intervenes as soon as oxygen has diffused from the alveoli into the blood that passes along the pulmonary capillaries towards the pre-exercised skeletal muscle cells.

Cardiovascular system intervenes also to drive lactate produced in the previously exercised skeletal muscle cells into the liver for gluconeogenic purposes as well as to drive gluconeogenesis-derived and glycogenolysis-derived glucose from the liver into the previously exercised skeletal muscle cells. In those muscle cells, glycogen synthesis takes place so as to replenish glycogen stocks in the cells. Recovery, endurance improvement, may then be expected as have occurred enhancement of substrate (glucose, glycogen) availability and enhancement of oxygen availability, being that an example of onset of fatigue delay through the improvement of the power or capacity of the ATP generating processes [18].

Acidosis has long been implicated in the genesis of fatigue [18]. High-intensity exercise causes through anaerobic metabolism an increase in skeletal muscle cells production of carbon dioxide, lactate and proton (H^+), what results in metabolic acidosis through the arrival of those three bio-chemicals in the blood [7]. Carbon dioxide that has diffused from the muscle cells into the blood is transported by the flowing blood to the lungs, where it diffuses into the alveoli and then is transferred to the atmosphere by pulmonary ventilation [9]. Elimination of carbon dioxide by the ventilation, which is increased during heavy exercise, limits the decline in the blood pH [6]: metabolic acidosis caused by high-intensity exercise is partly compensated thanks to respiration [46].

From what mentioned above, it appears that, after exercise, respiratory system as well as cardiovascular system must be good enough for the purpose of restoring the body to the pre-exercise condition.

2) *Massage after a Whole Performance*

Massage is the action of pressing and rubbing a subject with one's hands, to help the subject relax or to reduce the pain in the subject's muscles and joints [3].

Compared with passive rest intervention, massage intervention has been found to significantly increase ($p < 0.01$) perceptions of recovery in 8 amateur boxers who completed performances on a boxing ergometer [47]. It is worth signaling that the boxers lay during both kinds of interventions and that comparing results from those two kinds of interventions, no significant difference has been noticed, as regards blood lactate, blood glucose and heart rate values.

What may explain that?

Relationships have been shown between, on the one hand recovery duration and, on the other hand the evolution of finger capillary blood lactate concentration as well as the evolution of lactate concentration in the *vastus lateralis* muscle, both evolutions resulting from cycling to exhaustion on a bicycle ergometer [7].

The relationships enable one to realize that a) at the end of the exercise (at the beginning of the recovery), muscle lactate concentration is higher than blood lactate concentration; b) immediately after, i) muscle lactate concentration decreases exponentially, while ii) blood lactate concentration first increases for the following 7 to 8 minutes before decreasing exponentially; c) approximately from the 30th minute of recovery, muscle lactate and blood lactate concentrations show roughly the same value at each minute; d) muscle and blood lactate concentrations show once more resting values approximately after one hour recovery; e) Roughly between the 8th and the 30th minutes of recovery, blood lactate concentration is higher than muscle lactate concentration.

However, between the 8th and the 30th (at the 20th) minutes of recovery, identical lactate concentration values have been observed when have been compared passive rest intervention with massage intervention in boxers who had simulated boxing performance [47]. Sixty minutes is the duration of the minimum period that must last between two performances for domestic amateur boxing performance [47]. Moreover, after 20 minutes of massage, blood lactate value recorded is, in light of what mentioned above [7], assumed to be identical to that of muscle lactate value. That suggests a possible effectiveness of massage intervention during recovery period between two amateur boxing performances.

Nonetheless, for the assumed effectiveness of massage intervention to be confirmed, similarity must exist between the conditions of the intermittent high-intensity activity of simulating boxing performance on the one hand, and on the other hand, the conditions of the continuous activity of cycling to exhaustion on a bicycle ergometer.

Assuming also that applying massage has resulted in massaged muscle alternate contractions and relaxations, the physiological basis of increased blood lactate clearance due to massage could possibly be the same as that of increased clearance due to low-intensity to moderate-intensity exercise. At those intensities, exercise-produced lactic acid does not accumulate because the removal rate is greater than or equal to the production rate [48].

Attention must also be drawn on the following: a) intensities of recovery exercise have been found to influence the removal rate of blood lactate, and b) blood lactate removal due to passive rest has shown a rate slower than that shown by a recovery exercise intensity but faster than that shown by another recovery exercise intensity [7].

Above, two assumptions have been made as the basis for a possible effectiveness of massage increasing blood lactate removal: a) similarity of recovery conditions between intermittent high-intensity activity of simulated boxing performance and continuous activity of cycling to exhaustion on a bicycle ergometer, and b) similarity of muscular alternate contractions and relaxations between massage and low-intensity to moderate-intensity exercise. In the case that the two aforementioned assumptions are not confirmed, similarity of blood lactate concentration between massage intervention and passive rest intervention reflects the failure of massage to influence either lactate arrival into blood, lactate clearance from the blood, or both arrival and clearance.

Immediately after the end of high-intensity exercise, a) previously-exercising skeletal muscle uptake of blood glucose, driven out of the liver, decreases rapidly but resting values are reached only one hour after the end of the exercise, while b) splanchnic glucose output to blood decreases gradually but basal values are reached only 40 minutes after the end of the exercise [27]. However, recovery interventions here concerned [47] (massage intervention as well as passive rest intervention) have occurred within 20 minutes from the end of the first of two simulated boxing performances, *i.e.* a) before the attainment of resting values of blood glucose uptake by previously exercising skeletal muscle, and b) before the attainment of basal values of splanchnic glucose output to the blood.

When comparison is held between massage intervention and passive rest intervention, the former seems to have influenced, neither blood glucose uptake by the recovering muscle, nor splanchnic glucose output to the blood: for each of both interventions, blood glucose values no significantly differed from the values registered for the other intervention.

As at different submaximal workloads, heart rate increases linearly with increasing work rate within a wide range [6], it may be assumed a decrease of heart rate a) with decreasing work rate; b) when comparing recovery situation with high-intensity exercise situation, and c) when, during recovery, comparing passive intervention with a possibly effective massage intervention.

But in the study here concerned [47], during recovery, heart rate values have shown no significant difference between massage and passive rest interventions. That suggests no significant contribution of massage in physiological recuperation between the two simulated boxing performances here concerned [47].

However, when compared with the passive rest intervention, massage intervention significantly increased perceptions of recovery; what constitutes some evidence of psychological regeneration following massage, according to the authors of the study [47].

3) *Competition Boxers versus No-Competition Boxers*

Massage and cold-water immersion have been reported as recovery modes utilized in both senior elite and non-elite amateur boxers, but significantly more by elite than by non-elite ($p = 0.001$ as regards massage and $p = 0.016$ with regard to cold-water immersion) [49].

In the study here concerned, senior amateur boxers who have already taken part in competitions are referred to as elite boxers while those who have not are not elite and are referred to as development boxers.

The authors of the study hypothesize that massage as well as cold-water immersion utilization more by competition boxers than by no-competition boxers could be due to a possible increased access to multidisciplinary staff for competition boxers.

Another possible explanation may be that competition boxers have had more than no-competition boxers the opportunity to benefit from advantages due to massage and/or cold-water immersion utilization, having the basis of the advantages a physiological and/or a psychological nature.

2.4. Altitude

Altitude is the height of an object or place above the sea [3].

At moderate altitude (1800 m), non-iron-depleted national German team boxers have been subjected during 18 days both to endurance training and daily intake of either placebo in one group or of 1335 mg of ferrous-glycine-sulfate equivalent to 200 mg of elementary iron in another group [10].

The concerned study gave the following results, shown in **Table 2**: 1) total body hemoglobin no significant change in the placebo group, to the opposite of the iron-treated group in which occurred a significant decrease that could not be explained either by training-induced hemolysis, increased urinary iron excretion or occult hemoglobin loss with the stools; 2) in both groups, venous blood a) erythropoietin significant increase, b) reticulocytes significant increase and c) unchanged parameters of iron metabolism; as well as 3) in both groups, unchanged maximal oxygen uptake determined with an incremental treadmill test [10].

A following similar study at low altitude (400 - 1000 m) revealed in most of the iron-treated boxers an increased erythrocyte turnover but not iron loss [10].

The results of the study here commented have confirmed an expected increase in erythropoietin values: a 30% increase has been reported in boxer basal concentrations of erythropoietin after two hours running [7] [10]. That was to be expected as 1) with increasing altitude, there is increasing hypoxia [46], 2) hypoxia is the usual stimulus for erythropoietin secretion [6], 3) the boxers have endurance-trained at the moderate altitude of 1800 m whereas 4) erythropoietin levels increase in response to aerobic endurance exercise [21].

The results of the study here commented show an increase in reticulocytes values that is not surprising. In fact, erythropoietin stimulates synthesis of hemoglobin and red blood cells [27]. The red blood cells that have recently entered the blood, coming from the bone marrow where they have been formed, are referred to as reticulocytes [50]. An increase in the reticulocytes values is not thus surprising when the increase in erythropoietin values has taken place.

The study here commented signals no increase in total body hemoglobin values and unchanged maximal oxygen consumption values. An increase in the maximal oxygen consumption values was not to be expected when the total body hemoglobin values had not increased. In fact, there exists a relationship between hemoglobin and maximal oxygen consumption, the relation being strong ($r = 0.97$) when total amount of hemoglobin (g) is concerned but not strong ($r = 0.25$) when hemoglobin concentration (g/100mL) is concerned [7].

What follows may explain why the study had shown no increase in total body hemoglobin.

Firstly, endurance training moderately increases both the plasma volume and the total amount of hemoglobin so that the hemoglobin concentration is maintained constant or in some cases reduced [6].

Secondly, the success of the "living high-training low" approach to altitude training depends on two key features: 1) living high enough, for enough hours per day, for a long enough period of time, to initiate and sustain an erythropoietic effect of high altitude; and 2) training low enough to allow maximal quality of high intensity workouts, requiring high rates of sustained oxidative flux [51].

Thus, possibly, both living and endurance-training at the altitude of 1800 m during 18 days is an ineffective combination when increase in total body hemoglobin is intended.

Poortmans signals a case where has taken place success of the "living high-training low" strategy and where increases in hemoglobin level and maximal oxygen consumption value have occurred at almost the same percentages: living at an altitude of approximately 2500 m and endurance-training at an altitude of roughly 1200 m combined their effectiveness such as after 14 days, the combination caused in the training persons increases in erythropoiesis (±27%), hemoglobin level (±10%) and maximal oxygen consumption (±9.6%) [7].

2.5. Reminder

The teachings from the present review article may be summarized as follow.

1) *Dietary Supplementation*

1a) *Vitamins Supplementation*

At the 1996 Atlanta Olympic Game, most vitamin users (91%) were boxers.

1b) *Iron Supplementation*

After 18 days of endurance training at the altitude of 1800 m, i) venous blood erythropoietin values as well as reticulocytes values increased, ii) remained unchanged venous blood parameters of iron metabolism as well as maximal oxygen uptake during incremental treadmill test, and iii) total body hemoglobin decreased only in iron-treated group, in contradistinction to the placebo group where it remained unchanged.

1c) *Zinc Supplementation*

Regularity while boxing training, oral zinc supplementation as well as combination of both things influenced plasma levels of calcium, copper, iron, magnesium, phosphorus and zinc in pubescent amateur boxers.

1d) *Sodium Bicarbonate Supplementation*

Ingestion of sodium bicarbonate permitted i) amateur boxers increase the number of punches performed during 4 three-minute boxing sparring rounds interspersed with one-minute rest, and ii) elite male professional boxer benefit from an increase in time to fatigue while performing a boxing specific punch combination protocol.

2) *Body Weight Control*

2a) *Exercise-Induced Thermal Dehydration*

Where a boxer rapid weight loss took place in one study, it was accompanied with total body water decrease. In that study, both total body water and skeletal muscle mass decreased by ~1% - 2% but that was not paralleled by muscle strength decrease.

However, a 26.8% decrease in boxing performance took place in another study where exercise-induced thermal dehydration caused a rapid body mass loss by a 3.8%.

2b) *Fluid and Food Intake Restriction*

Vitamin Status and Plasma Glutathione Levels

Fluid and food intake restriction-caused rapid weight loss left unchanged in elite male boxers the already existing situation of i) low-caloric and low-carbohydrate diet, ii) intakes of vitamins A, E and folate below recommended values and iii) blood vitamin status as well as plasma glutathione levels.

Performance and Mood Profile at 5.16% *Lower Body Weight*

Fluid and food intake restriction-caused rapid weight loss was accompanied by poor performance and a negative mood profile in experienced amateur boxers whose average body weight reduction reached 5.16%.

Performance at 3% *Lower Body Weight*

Energy and fluid restriction did not lead to a significant performance decrease in amateur boxers whose body weight reduction was 3%.

2c) *Various Protein Diets*

At the end of a 9 days weight reduction period, i) nitrogen balance changed to a negative value in boxers who had a low protein diet while it remained unchanged in boxers who had either an ordinary protein diet or a high protein diet, and ii) for the same submaximal work load, both heart rate and oxygen intake increased only in boxers who had a low protein diet while those two variables remained unchanged in the boxers who had the two other kinds of protein diet.

2d) *Meal Frequency*

In food-restricted boxers, it has been noticed that the lower the meal intake frequency, the higher the decrease in lean body mass.

3) *Recovery*

3a) *Cardiorespiratory Fitness*

A high level of cardiorespiratory fitness is required to accelerate the recovery process between two boxing rounds.

3b) *Massage after a Whole Performance*

Massage intervention significantly increased perceptions of recovery in amateur boxers after they have completed performances on a boxing ergometer.

3c) *Competition Boxers versus No-Competition Boxers*

Massage and cold-water immersion have been utilized more by elite than by non-elite boxers.

4) *Altitude*

In non-iron-depleted boxers, total body hemoglobin decrease resulted from endurance training combined with daily iron intake (200 mg of elementary iron) at the moderate altitude of 1800 m.

2.6. Advices

Here follow the advices that result from the teachings concerned by the studies commented in the present review article.

1) *Low Vitamin Intakes*

Research would better be carried out in the aim of checking possible detrimental effects of vitamin intakes below recommended values throughout a whole boxing season, the results being recorded at the end of the season and not at a given moment of the season, as is the case in one of the studies concerned by the present review article.

2) *Additional Vitamin Intakes*

Additional vitamin intakes by boxers are possibly justified only a) when an increased need of concerned vitamins arises, especially when exercise intensity increases; b) when boxers are deficient in the concerned vitamins; c) when it is necessary to prevent tissue damage due to free radicals boxing-practice-caused, and d) when practicing boxing at a high level.

3) *Iron Supplementation*

Non-iron-depleted boxers must not be orally iron supplemented. The boxers will reap no benefit of that and that could possibly be detrimental to boxing performance through total body hemoglobin decrease.

4) *Zinc Supplementation*

Zinc supplementation may possibly be recommended for preventing zinc deficiency in boxing practice-caused as well as the resulting effects that could, perhaps, affect negatively boxing performance and fatigue delay. However, zinc must be supplemented cautiously so as to avoid risks that could result from supplementation-caused changes in plasma levels of minerals, iron and magnesium, for instance.

5) *Intake of Vitamins in Combination with Minerals*

Research work is worth carrying out in the aim of checking the reliability of supplementing boxers with vitamins in combination with minerals.

6) *Sodium Bicarbonate Supplementation*

Due to the severity of the side effects, athletes should try sodium bicarbonate supplementation during practice before using it as a pre-competition aid.

7) *Body Weight Reduction Caused by Exercise-Induced Thermal Dehydration*

The threshold from which exercise-induced thermal dehydration affect negatively boxing performance must be checked during practice before taking account during the pre-competition period.

8) *Meal Frequency*

It is useful to check the highest meal frequency the increase of which permits to avoid lean body mass decrease, *i.e.* the lowest meal frequency the decrease of which results in lean body mass decrease.

9) *Low Protein Diet*

Having low protein diet should be avoided by boxers in order to prevent negative nitrogen balance and, for the same submaximal workload, increases in both heart rate and oxygen intake, which could possibly affect negatively boxing performance.

10) *Body Weight Reduction Percentage*

It seems sound to let boxer rapid body weight reductions attain 3% but not reach 5.16% lower values in order to avoid a decrease in boxing performance as well as a negative mood profile.

11) *Altitude*, *Erythropoiesis*, *Hemoglobin Level and Maximal Oxygen Consumption*

In the aim of increasing erythropoiesis, hemoglobin level and maximal oxygen consumption in boxers endurance-training, one must check the right combination of a) the suitable altitude of living as well as the suitable altitude of training, b) the suitable duration of living as well as the suitable duration of training, and c) the suitable duration of the combination.

12) *Massage*

It is useful that research work be carried out to deal with massage that takes place during the one-minute recovery that intersperses successive boxing rounds.

3. Faith, Life Expectancy, Gender and Childhood

Faith, life expectancy, gender and childhood are going to be dealt with next.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of the present paper.

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